Studies on Copepods from the EEZ of India-
Bay of Bengal and Andaman Sea

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by

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Dedicated to The Almighty…

Declaration

*I hereby declare that the thesis entitled, **Studies on Copepods from the EEZ of India-Bay of Bengal and Andaman Sea** is an authentic record of research carried out by me under the supervision of Dr. (Mrs.) Saramma U. Panampunnayil, Scientist F (Rtd),, National Institute of Oceanography, Regional Centre, Kochi - 18, in partial fulfillment of the requirement for the Ph D. degree of Cochin University of Science and Technology under the Faculty of Marine Sciences and that no part thereof has previously formed the basis for the award of degree, diploma or associateship in any university.*

Kochi

09.04.2010 *(Rashiba A P)*

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I dedicate this thesis to the Almighty

Rashiba A. P.

Certificate

I hereby certify that the thesis entitled ***Studies on Copepods from the EEZ of India-Bay of Bengal and Andaman Sea,*** *submitted by Rashiba, A.P., Part time Research Scholar (Reg. No. 2699) 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 PhD degree of Cochin University of Science and Technology under the Faculty of Marine Sciences and that no part thereof has previously formed the basis for the award of degree, diploma or associateship in any university.*

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Contents

1.1. Plankton

The term *Plankton* was coined by the German marine biologist; the founder of quantitative plankton and fishery research, Victor Hensen in 1887. It is derived from the Greek word `*planao*` meaning `*to wander*` and it has the same etymological root as `planet . Thus plankton is a collective term for a variety of marine and freshwater organisms those drift or float in the water and whose abilities of locomotion are insufficient to withstand currents. Generally, plankton size ranges from tiny flagellates (0.2 mm large) up to giant jellyfish (2m diameter). Many of these organisms are strong swimmers and are capable of moving through relatively long distances over a period of time, particularly in a vertical direction. Photoautotrophic organisms within this community including both eukaryotes (algae) and prokaryotes (Cyanobacteria) are collectively referred to as phytoplankton.

Zooplankton are the diverse assemblage of animals that may drift or actively move in the waters in the world oceans. They transfer organic energy produced by phytoplankton to higher trophic levels, affect higher trophic levels as the synchrony between predator and prey (match-mismatch) and in the successful recruitment of top predators such as fish and sea birds. Thus, the zooplankton plays a pivotal role in the pelagic food web by controlling primary production and shaping pelagic ecosystem (BCLME, 2007).

Marine zooplankton comprises 60 to 80 different types of organisms. They determine the quantity of fish stock. Occurrence and distribution of zooplankton influences pelagic fishery potential. Fishes mostly breed in areas where the planktonic organisms are plenty so that their young ones get sufficient food for survival and growth. Some fishes like mackerels and scrombrids remain planktivorous throughout their life. The failure and success of fishery in European waters has been related to zooplankton availability in North Sea (Hardy and Gunther, 1935). Failure of fishing resources is attributed to the reduced copepod (zooplankton) population (Stottrup, 2000). Many zooplankton taxa are known to be indicator species. They may serve as sentinel taxa that reflect changes in marine ecosystems by providing early indications of a biological response to climate variability.

The first scientific classification of zooplankton is by Schutt in 1892 and it has been extended since and modified several times. The latest revision which is now widely accepted based on length is by Sieburth *et al.* (1978) is given below. ICES Zooplankton Methodology Manual referred by taxonomists everywhere also cites a modified version of the same. According to his classification, the zooplankton ranges over seven size-classes, from femtoplankton to megaplankton. Femtoplankton and picoplankton constitute the smallest microscopic organisms having the size of 0.02-0.2µm and 0.2-2µm respectively. Heterotrophic nanoflagellates having 2-20 µm constitutes nanoplankton. Other protozoans like ciliates belong to the next size class, the microzooplankton (20-200 µm).Mesozooplankton size varies from 0.2 to 2 mm, comprising of copepods,ostracods, decapods, chaetognaths etc. The next two size categories are macrozooplankton (2-20 cm) and megazooplankton (20-200 cm) which includes large jelly fishes, siphonophores, scyphozoans, pyrosoma etc.

1.	Femtoplankton	-	0.02-0.2 µm
2.	Picoplankton	-	0.2-2 µm
3.	Nanoplankton	-	2-20 µm
4.	Microplankton	-	20-200 µm
5.	Mesoplankton	-	0.2-20mm
6.	Macroplankton	-	2-20 cm
7.	Megaplankton	-	20-200 cm.

Based on their mode of life, zooplankton are classified into holoplankton, meroplankton and tycoplankton (Raymont, 1982; Omori and Ikeda 1992). Species spending their whole life as plankton in the pelagic realm are termed as holoplankton (copepods, ostracods,chaetognaths, siphonophores *etc.).* Animals which spend the early part of their life as plankton are grouped under meroplankton (decapod larvae, fish larvae and other invertebrate larvae). The tycoplankton occur predominantly in shallow waters, especially in estuaries. This includes animals such as mysid and other crustaceans that spend part of the day or night cycle as plankton. Also includes benthic species that are swept into suspension from the bottom by strong currents or storms, such as some harpacticoid copepods, gammarid amphipods, cumaceans, isopods *etc.* (Raymont,1983).

1.2. COPEPODS

Copepods are aquatic crustaceans, the diminutive relatives of the crabs and shrimps. Though small in size, they are the most abundant of all crustaceans, forming the bulk of zooplankton of the sea. The name copepod is derived from the Greek words *kope* meaning *oar* and *podos* meaning foot and literally means oar-footed. This name refers to their broad, paddle like swimming legs. They do not have a general common name in English although a few individual species have such names, such the salmon louse and the gill maggot of anglers. Sir Alister Hardy (1956) stated that copepods are the most numerous metazoan animals in the world, even outnumbering the insects which have more species but fewer individuals and the nematodes, both of which had some claim to this position of pre-eminence. Hardy's estimate is based primarily on the planktonic copepods that inhabit the oceans of the world. The entire oceanic realm, which covers about 71% of the world's surface to an average depth of about 3700m, provides an immense volume of water(~1347 million cubic kms) all of which is home to free-swimming copepods. The density of copepods ranges from 70,000 per cubic meter in shallow waters of the North Sea to 100 per cubic meter at 4,000m depth and upto 1.5 million per cubic meter in mating swarms in coral reef environment (Hamner and Carleton, 1979).

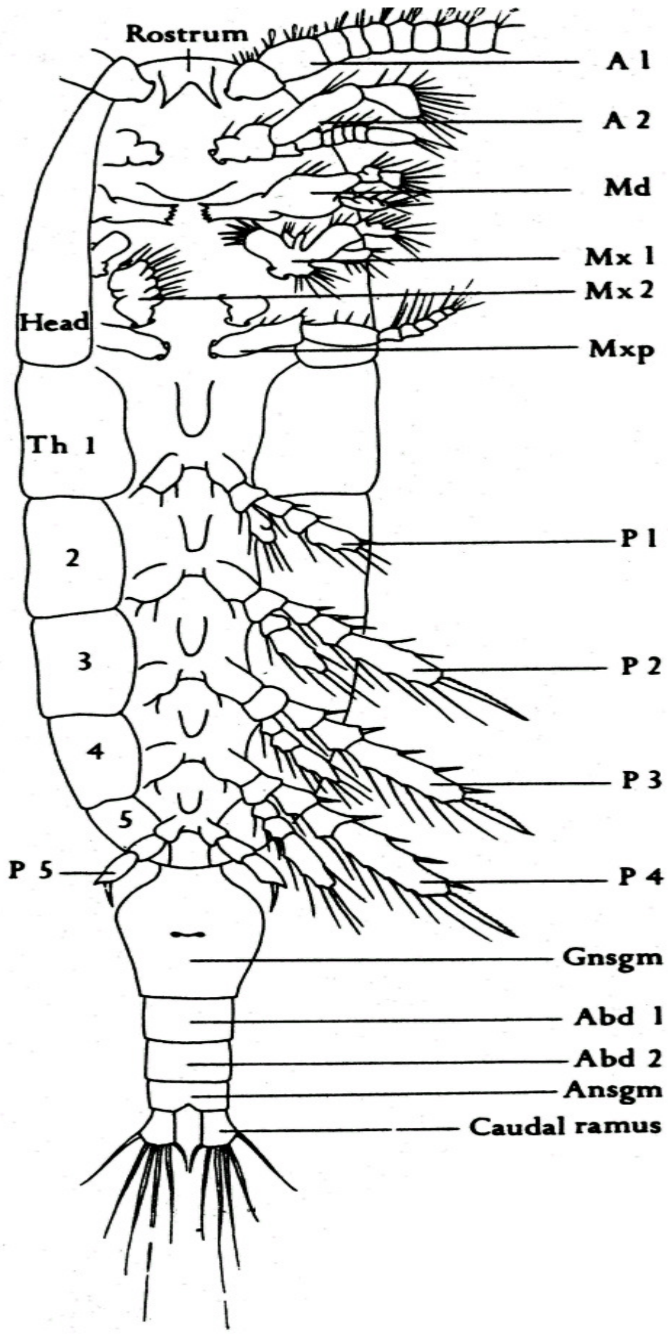
Copepods which are known as *Hoppekrebs,* in Norwegian, *Ruderfusskrebs* in German, *Roeipootkreeft* in Dutch are typically small organisms. In the marine planktonic forms, its total body length is usually between 0.5 and 5.0mm. Although the real giants amongst the copepods are the parasites, some of these are also small, including gill parasites such as *Ergasilus nordmann* and inhabitants of the lateral line canals such as *Colobomatus*, but many attain considerable size. The largest parasites are members of the siphonostomatoid family Pennellidae. Species of *Pennella oken* can reach about 250mm in length and it carries linear egg sacs which may exceed 350mm in length.

Characteristic features of copepods

Copepods are so diverse that there are 11500 species belonging to 200 families and 1650 genera known at the end of 1993. But since the true diversity of the benthic harpacticoids, poiecilostomatoid and siphonostomatoid association of marine invertebrates has yet to be revealed and hence this number could be easily doubled. Copepods have successfully colonized all salinity regimes from fresh water to marine and hyper saline in land waters and all temperature regimes from sub zero polar waters to hot springs. They also have an immense vertical range occurring from depths of 9995-10002m in the Philippine trench (Wolff, 1960), to an altitude of 5540m up in the Himalayan mountains. This vertical range represents about three quarters of the maximum possible range in the earths surface, from the deepest point in the Marians trench to the peak of Mount Everest (about 20,372 m). Copepods have a hard exoskeleton and its body comprises a cephalosome of 6 somites and a post cephalic trunk of 9 somites and a somite which represents the telson. The cephalosome consists of 5 cephalic somites and the first thoracic somite bears the maxillipeds. Almost all copepods have the I^{st} thoracic somite fully incorporated into the cephalosome. The post cephalic trunk comprises the 2 to 5^{th} thoracic somite each of which bears a pair of biramous swimming legs, the genital (7^{th} thoracic) somite that bears the genital opening or openings in both sexes and 4 post genital abdominal somites. The abdominal somites are all limbless although the anal somite bears a pair of setiferous caudal rami. In many species the trunk somite are fixed to each other or to the cephalosome.

Although they lack compound eyes, these athropods have a single simple eye in the middle of the head. Sometimes it is only present in the larval stage. This simple eye can make a differentiation between light and dark only. Antennules are uniramous and comprise up to 27 segments. The antennae are typically biramous with a two segmented protopod, bearing the exopod, which has up to 9 segments and the endopod which has up to 4 segments. In many copepods the antenna is uniramous with the exopod having been lost.

The mouth opening is covered by a postero-ventrally directed labrum; the mandible is typically biramous with a 2 segmented protopod bearing a large gnathobase on the coxa. The exopod is 5 segmented and the endopod is 2 segmented. In parasitic forms, the pulp is often reduced and in some, it is missing.



DIAGRAMATIC REPRESENTATION OF CALANOID COPEPOD

(Ventral view) After Bradford, 1972.

A1- First antennae (antennule); A2 – Second antennae (antenna); Md – Mandible;
Mx 1 – First Maxillae (maxillule); Mx 2 – Second maxillae (maxilla);
Mx p - Maxillepeds; P1 to P5 – Pereopods (swimming legs);
Gnsgm – Genital segment; Abd – Abdominal segment; Ansgm – Anal segment

Fig. 1.1. General morphological features of Calanoid copepods

Paired paragnaths are present on each side, between the bases of the mandibles and maxillules. The paragnaths are sometime fused medically to form the labium. The mouth opening is covered by a postero-ventrally directed labrum; the mandible is typically biramous with a 2 segmented protopod bearing a large gnathobase on the coxa.

The exopod is 5 segmented and the endopod is 2 segmented. In parasitic forms, the pulp is often reduced and in some, it is missing. Paired paragnaths are present on each side, between the bases of the mandibles and maxillules. The paragnaths are sometime fused medically to form the labium. Biramous maxillule consists of three segmented protopod bearing a well developed pre coxal arthrite, 1 coxal and 2 basal endites, a coxal and/or basal exite, a one segmented exopod and three segmented endopod. The maxillules are often reduced to a bilobed process and are missing in some forms. Uniramous maxilla is 7 segmented and its protopod comprises pre coxa, coxa and basis. The precoxa and coxa each typically have 2 endites and the basis has one endite. The endopod consists of 4 small segments and is sometimes lost. The maxilliped is uniramous and comprises precoxa, coxa basis and a 6 segmented endopod. The precoxa has 1 endite, the coxa has 3 endites and the basis is armed with a maximum of 3 setae. The maxilliped is often reduced and sometimes missing.

The 1st to5th pairs of swimming legs are typically biramous with 3 segmented protopod and 3 segmented rami. These legs are often reduced and sometimes missing, especially in parasitic forms. The 5th leg is often modified by reduction on loss of the endopod or by fusion of the endopod to the basis.

Members of the 1st to 5th leg pairs are joined medially by a rigid inter coxal sclerite which ensures that both legs of a pair beat simultaneously. The pre coxa of the swimming leg is reduced to a lateral plate at the base of the leg. The sixth legs are reduced, forming the apparatus that closes off the genital openings in both sexes.

Importance of copepods

Copepods play an important role in the overall economy of the sea as well as in human life. They are ranked as the world` most abundant metazoan and they form the first vital link in the food chain that leads from the minute algal cells up to the large fishes and mammals. They form the bulk of zooplankton even up to 85% and are in a dominant position in all the seasons and in all parts of the world ocean, except during the bloom of phytoplankton in marine waters of temperate and high latitudes.

Copepods are the primary consumers of phytoplankton and form the major secondary producers. Role of calanoids in the sea is comparable to that of herbivorous land animals. In contrast to phytoplankton copepods are more important as they occupy the entire water mass and thus participate in the transport of food from upper layers to the deepest parts of the sea. Even more, large masses of bathypelagic calanoids migrate from the upper layers to considerable depths, carrying with them large amount of organic matter in a vertical direction. This horizontal and vertical migration of large masses of calanoids affect the salt and gas balance of the water traversed (Bogorov, 1939). Thus, there occurs a link between upper, intermediate and abyssal layers by means of continuous vertical chain of several calanoid groups living at different depths.

They are preyed upon by the juveniles of nearly all fishes, as well as by the adults of pelagic fishes such as Herring, Sardine, Scomber, Anchovy, Sprats and others (Russel, 1976). Herring feed directly on copepods during their larval development and continue to feed on them as adults. From European waters, the relation between larval teleosts and copepod has been well established. *Pseudocalanus, Temora, Acartia, Calanus* and *Oithona* form the food of teleost larvae. *Centropages, Paracalanus, Calanus* and *Tortanus* were observed as food of many larval fishes (Raymont, 1982). Harpacticoids are abundant in the bottom layers of marine environment and may have an essential role to play in future development of fish farming (Gee, 1989).

Harpacticoid copepods are the predominant, meiofaunal element in the diets of flat fishes and salmonids. Pacific salmons feed on large calanoids during their stay in the sea (Hardy, 1956). Whales of the group Mystacocoeti (Sei whale, Blue whale, *etc*.) also feed on calanoids. For the detritus feeders, copepods are an important energy source that they produce faecal pellets 200/individual/day and these flux of faecal pellets to the ocean floor may have a significant impact on nutrient cycling and sedimentation rates too (Huys and Boxshall, 1991). They have high nutritional value. The various stages of their life cycle are intermediate in size between rotifers and brine shrimp nauplii, and thus they can bridge the gap in the size spectrum of available food. Thus, it is undeniable that copepods play an important role in ecosystems, by virtue of their place in food webs as well as by their potential to be used by man in different ways. At the end of the last century, shipwrecked persons, who needed to feed themselves in situ (Dussart and Defaye, 2001), already used them as a source of food. Planktonic copepods constitute the bulk of the biomass in most pelagic zooplanktonic communities and are important food source for higher trophic organisms including krill and fishes(Nybakken,2005).

Copepods, especially *Eucalanus hyalinus* and *Centropages hamata* are known to ingest large quantities of oil droplets. However, ingested oil globules will remain unaltered and a small portion will enter the food chain with some degree of concentration. Owing to the increase in the defecated oil particles, the oil is likely to sink to the sea floor and it has been reported that approximately 20% of the oil in the environment is biologically modified through defecation.

Not only the commercially exploited fishes of temperate waters feed directly on copepods but also other organisms such as ctenophores, chaetognaths, siphonophores and other carnivores also gather in large herds and devastate the copepod population of entire region. In the tropical Indian Ocean, especially in the south west coast where the influence of monsoon is well-pronounced, large population of copepods develop following the phytoplankton abundance. This is followed by shoal of anchovies and later by carnivorous fishes like *Trichiurus* sp. Some species of copepods especially estuarine species like *Nitochre* sp., *Oithona* sp. are being mass cultured and are used as live feed for early developmental stages of fishes and shrimps.

Copepod as parasites

The Salmon louse *Lepeophtheirus salmonis* Kroyer, can cause devastating economic losses to salmon farmers. Kabata (1958) found that heavy infestation by the gill parasite *Lernaceocera* caused a weight loss of upto 28.9% in *Melanogrammus aeglefinus*. Parasites of commercially important shellfishes, such as Mytilicola *intestinalis and M. orientalis* parasitizes mussels and found out to cause considerable loss of weight in infested hosts (Mann, 1951) and thereby reduce their market value.

The harpacticoid copepods *Amenophia orientalis* and *Parathalestris infestus* are pests of Wakame, the brown seaweed that is cultivated widely in Korea and Japan as a food crop. These copepods make galls and pinholes in the fronds of the seaweed and reduce its commercial value (Ho and Hong, 1988).

Copepods as biological indicators

The superiority of live organisms over hydrologic index is particularly evident in complex cases, such as regions affected by mixed waters, currents of brief duration, *etc*. Virketis (1957) revealed the pattern of currents in the neck of White Sea after a study of the composition and distribution of zooplankton with special reference to calanoids.

Calanoids together with other biological indicators have revealed the origin, dynamics and distribution of water masses in the Gulf of Maine, Northern Atlantic English Channel, Sea of Japan, *etc*. The abyssal waters of the Northwestern Pacific have been characterized on the basis of the composition and distribution of the calanoid fauna (Brodski, 1948). They provided bulk of information necessary for establishing the pattern of water masses in the Kara Sea.

An over generalized geographic range of a species can be broken down into clearly defined areas occupied by different varieties of the species. However, they must be accurately determined quantitatively before they may be used as indicators. An examination of numerous specimens of *Pleuromamma* spp. has revealed that the depth and various currents exert a direct influence on the morphologic differentiation.

Copepods and fisheries

Copepods reveal the presence of schools of commercial fishes and whales. Data on the distribution of calanoids such as *Calanus finmarchicus*, *C. cristatus* and *Rhincalanus gigas* provide valuable information for whale fishing, as whales tend to gather in waters with a dense population of the above mentioned calanoids as well as some euphausids.

Fattening of many fishes coincides with mass appearance of 2nd phase of the fifth copepodid stages of copepods as there is large amount of fat deposited in the body of copepod at that stage. *eg*: fattening of Herring and *Calanus tonus*. Sardine depend upon calanoids and they determine the fattening of this fish. Sardine prey mostly on small pelagic species such as *Paracalanus parvus*, *Pseudocalanus elongates*, *Calanus pacificus* and others.

The practical value of calanoids as guide forms will undoubtedly increase as more information becomes available on the fauna of the different seas, more specifically on the taxonomy and ecology of the various species. Live organisms, inseparable from their environment, accurately reflect its nature and the changes occurring therein. The species of copepods most often used in biological control are *Macrocyclops albidus* and *Mesocyclops longisetus*. Also, in Honduras was used *M. thermocyclopoides*. Each copepod could kill an average of 7.3 first-instars larvae of Aedes per day (Hernández-Chavarría and Schaper, 2000).

Classification

Copepods belong to the Phylum Arthropoda and Class Crustacea. Neocopepoda and Progymnoplea are the two Infra Classes under the Subclass Copepoda. Platycopioida is the single Order coming under the Infra Class Progymnoplea.

The Infra Class Neocopepoda has two Super Orders-Super Order Gymnoplea and Super Order Podoplea. Order Calanoida comes under Super order Gymnoplea and remaining 8 orders are under super order Podoplea. These orders are viz., Order Misophrioida, Gelyelloida, Harpactioida, Mormonilloida, Cyclopoida, Siphonostomatoida, Poecilostomatoida, Monstrilloida. In marine environments, mainly the orders Calanoida, Poecilostomatoida, Cyclopoida and Harpactioida are encountered. Usually the calanoids dominate the zooplankton community and at times cyclopoids & poecilostomatoids are found in swarms. Harpacticoids are abundant in bottom layers.

Life Cycle

It includes upto 6 naupliar and meta - naupliar stages and 5 copepodial stages prior to the adult. Development is sometimes abbreviated, especially in parasitic forms. Sperm is transferred by means of spermatophores that are placed on the female by the male. The spermatophores discharge the sperm *via* a paired copulatory pores into paired seminal receptacles with the genital somite of the female where they are stored.

Reproduction

The female copepod produces clusters of eggs that are typically carried in paired egg seeds and are attached to her abdomen. In some groups there is a single egg sac or a loose egg mass, in others the eggs are released directly and are not carried by the female.

Development

Mating: There is no special copulatory organ for an internal fertilization, the term copulation is used for the attachment of a spermatophore to the genital field of the female. A spermatophore is a container filled with sperm and various secretions. It is produced internally by the male and expelled during copulation. The reproductive behavior of copepods is very diverse. In some species adult males clasp juvenile females who able to copulate straight after the final moult of the female. This behavior may be interpreted as a consequence of competition between many males for few females. In other species the males guard their females at least for the time necessary for the spermatophore to discharge its contents in to the female. This guarding has the effect of searing paternity (Postcopula).

In some other cases, a complex mating behavior precedes copulation. Females in such cases may be endowed with effective mechanisms to keep off males from copulatory attempts.

Eggs: A few hours or days after copulation, egg sacs are formed by the female. Most species produce paired egg sacs. These sacs are carried outside the body under the abdomen and consist of eggs embedded into a mass of secretions. Depending on size and lifestyle, a few to several dozens of eggs develop inside their protective cover. Some parasites produce several thousand eggs. The eggs are probably still nourished by the females. Larvae hatch out in few days and egg sac is cast off.

Larvae: The first larva of copepod is called *nauplii.* They are very small (20/µm) and like the adults, are found in very different habitats. Usually they pass through six naupliar stages, which are separated by a moult. The first stages have only 8 pairs of appendages that are responsible for locomotion and feeding. The older nauplii already show buds of further mouth appendages and swimming legs. The 6^{th} naupliar stage moults into the 1^{st} copepodid. This moult is accompanied by important morphological changes.

1.3. General Oceanographic features of the study area

The oceanographic features of the study area viz., the Bay of Bengal and the Andaman Sea were reviewed separately in the coming sections.

1.3.1.The Bay of Bengal

The Bay of Bengal (BoB) is a unique semi-enclosed basin that extends between latitudes 0° to 23°N and longitudes 80° and 100° E occupying an area of 4.087×10^{6} km^{2}. It is surrounded on three sides by landmasses and connected to the Pacific Ocean through the Australian sea wages. The BoB covers 0.6% of the world ocean and is a region of positive water balance. The average annual excess of precipitation over evaporation is the order of 70cms (Venkateshwaran, 1956). Though the basis is located in the monsoon belt, it comes under the influence of the semi annual seasonality of the Asian monsoon (Ramage, 1971). Rainfall over the BoB shows wide variability and strong seasonality. Thus, the southeast coast of India has a winter rainfall maximum, while the rest of the regions have a summer monsoon maximum (Ramage, 1984).

The BoB is bounded in the West by the East Coast of Sri Lanka and India, on the north by the deltaic region of the Ganges – Brahmaputra – Meghana river systems, on the East by Myanmar peninsular extending up to the Andaman and Nicobar ridges. The southern boundary of the BoB is approximately along the line drawn from the Dondra Lead in the South of Sri Lanka to the North Tip of Sumatra. The bay occupies an area of about 2.2 million sq km and the average depth is 2600m with a maximum depth of 5,258 m.

The BoB hosts a unique system of inter-related oceanographic and sedimentary processes induced by the seasonally reversing monsoon winds and the enormous supply of freshwater and silt ($16x10^8$ t/y) through several peninsular Indian rivers. Subramanian (1993) estimated that rivers of Indian subcontinents alone contribute about $13.86x10^6$ tones of terrigenous materials annually to the bay. Subramanian (1993) concludes that the positive water balance of the BoB is due to this excessive river rain off and rainfall, which is in support of the statement of Ramnathan and Pisharady (1972). Run off from the Indian rivers to the BoB plays a critical role in the process of monsoon intensification by creating and sustaining low salinity layer on the top of the bay. This discharge (Rajamani, 2006) from bordering rivers exceeds $1.5 \text{ X } 10^{12}m^3$ (UNESCO, 1988) and the annual rainfall over the bay is in excess of 2m (Gill, 1982).

The BoB, a northern extended arm of Indian Ocean when compared to the Arabian Sea, experiences quite different hydrographical condition, mostly caused by the enormous continental discharge. This basin has the very fluvial inputs via some of the largest rivers of the world. Ganges, Brahmaputra, Cauvery, Damodar, Godhavari, Irrawady, Krishna, Mahanadi, Mahaveli, Pennar and Salween fall into the BoB (Milliman and Meade, 1983). Thus by considering the area north of 12°N, it is possible to think the BoB as worlds' largest estuary. This enormous continental discharge during summer substantially lowers the salinity values in the BoB that causes strong, vertical stratification and inhibition of vertical mixing.

The BoB experiences differential heating and cooling of the land and sea. During winter monsoon (Nov-Feb), the winds are weak (~5m/s) and blows from the northeast. This wind brings cool and dry continental air into the BoB. In Contrast during Summer Monsoon (June – Sept) winds are strong (~10m/s) and they blows south west, brings humid maritime air into the BoB. The surface circulation within the basin, reverse semiannually which is not strictly in accordance with the wind reversal. The reversal of surface circulation brings about marked changes in the hydrography of the upper waters. During the winter monsoon when the winds are still northeasterly, the current along the western boundary reverse and flows northward. This is called East Indian Coastal Current (EICC) that peaks during March – April (Spring inter monsoon) when the winds are week and posses anticyclonic curl (Shetye *et al.,* 1993).

The BoB is a unique ocean with inter related oceanographic, biological, sedimentary process. However, the BoB is conventionally believed to be less productive than the Arabian Sea (Madhupratap *et al.,* 2003). Although many major river systems bring in large quantities of nutrients, the narrow shelf, heavy cloud over and less light penetration have been attributed to this. Though during spring inter monsoon period the BoB is reported to be oligotrophic, with the Western BoB Current (WBC) enhancing productivity in the coastal region and pockets of very high production resulting from the eddies or recirculation zones (Gomes *et al.,* 2000). But in summer monsoon, the reduction in cloud cover and enhanced irradiance (Warren *et al.,* 1988) as well as nutrient inputs from river runoff trigger productivity in the Northern Bay (Gomes *et al.*, 2000).

1.3.2. Andaman Sea

The Andaman Sea is a part of the north eastern Indian Ocean, bordered by Myanmar, Thailand and Malaysia in the north and east, Andaman and Nicobar Islands in the west and Sumatra in the south. Its narrowest part has a width of 35km and depth of 30m. It occupies an area of 6.02×10^5 km^2 and has a volume of 6.6×10^3 km^3 and an average depth of 1096m. The Andaman Sea contains a relatively extensive basin with a maximum depth of 4360m and uneven bottom topography. A north-south arc of volcanic islands and seamounts, including the Barren and Narcondam islands in the Andaman Sea, delimits this basin from 2 smaller basins on the north and south.

The Andaman islands which are part of an anticlinal belt passing from Arakan Yoma in Burma through Andaman and Nicobar Islands and Mentawai Islands west of Sumatra, separate the Andaman Sea from the BoB except from numerous channels, *viz.,* (a) The Preparis Channel, divided into north and south portions by the Islands of the same name, (b) The Ten Degree Channel, between the Andaman and Nicobar groups of Islands and (c) The Great Channel, between Great Nicobar Island and Sumatra. The Ten Degree Channel is about 1800m deep while Preparis and great Degree Channel have 200m and 800m depth respectively. Exchange of water between the BoB and the Andaman Sea occur through these Channels. Towards south between Malaysia and Sumatra, the Andaman Sea is connected to the Pacific Ocean water flowing through the South China Sea and the Bay of Bengal through the Malacca strait. The major rivers draining into the Andaman Sea are the Irrawaddy and the Salween with the former having an average discharge of 13560 m^3/sec. The quantity of sediment carried by Irrawaddy is estimated to be approximately 363 million tones annually (Groves and Hunt, 1980).

The Andaman Sea is one of the least exposed regions of the Indian Ocean. Oceanographic researches in the Andaman Sea date back to 1869 when Francis Day, a well known army officer and fishery biologist, visited these islands. He recorded the occurrence of 136 species of fishes in the Andaman waters (Day, 1878). Thereafter a number of investigations were carried out in this region. The most comprehensive and outstanding study of the Andaman sea was carried out from 1913 to 1925 by Surgeon Major R. B. Seymour Sewell and published in the memoirs of the Asiatic Society of Bengal (Sewell, 1932).

The Andaman Sea is influenced by large quantities of freshwater runoff from the perennial rivers of Burma, Thailand and Malaysia. This runoff largely influences the topmost layers by reducing the salinity of the surface water. Below the surface layer oceanic conditions prevail. The hydrography and topography of the eastern and the western Andaman Sea are different. Since it is a confined physiographic basin, flow to open ocean areas of the BoB occurs through the channels around and between Andaman-Nicobar Islands (Bhattathiri and Devassy, 1981). Water flow from the Bay of Bengal to the Andaman Sea occurs through the Preparis Channel. The Great Channel lying between Great Nicobar Island and Sumatra is the conduit for the Pacific Waters to the Andaman Sea - Bay of Bengal Complex. The Andaman Islands have steeper continental slope on the eastern side compared to the western one, which is very irregular (Murthy *et al.*, 1981). So may be one side of the island holding more zooplankton biomass and generic diversity is more stable to suit the living conditions of zooplankton compared to the more dynamic environmental changes on the other side.

1.4. Review of Literature

The antiquity on zooplankton investigation started on 1857 when the ship *Novara* engaged in sampling from 52 stations along 40°S eastward up to 80°E and along 85°N northward up to Madras and eastward up to Sumatra. Then IIOE Atlas (1962-65), IOBC Atlas (1968-73), ICES (2007), Zietschell (1973) and Rao (1979) done considerable works on zooplankton. Panikkar and Rao (1973) cited most of the work done on IIOE. Recent works on zooplankton are mainly focused on the effect of climate upon them (Purcell N.S and Decker, 2005;Smith and Madhupratap, 2005; Montoya-Maya and Strydom,2009). The relationship of zooplankton and phytoplankton was studied by Semenova and Aleksandrove (2009) and Havens *et.al*.(2009). Studies on the spatial and temporal distribution of zooplankton were done by Sameoto (1986), Herman (1992), Schneider *et al.* (1994) etc. Zooplankton distribution, community structure and its measurement have all been well documented in different parts of the major oceans and water bodies.

Copepods were one of the better studied micro crustacean holoplankton. They successfully colonized all salinity regimes (from fresh water, marine and hyper saline inland waters) all temperature regimes (such as polar waters to hot springs) and all vertical regimes (Philippine trench of depth 9995-10002 m to an altitude of 5540 m up in Himalayan Mountains). They were described by hundreds of Copepodologists of which Gunnerus,1770 stands first who described *Monoculus finmarchichus* the first portrayed and best studied copepod till today.

Earlier studies on Copepods were mostly based on their taxonomy of which Zenker (1854), Thorell (1859), Claus (1857-95), Canu (1892) and Giesbrect (1892) were outstanding. The first natural and most detailed classification was done by Sars (1905) up on which a series of revisions in the phylogency were attempted by a number of taxonomists. Claus (1857 – 1895) classified copepods based on their mode of life *ie.,* fractioning (Grathostomatic) and parasitic (Siphonostomata) where as Canu (1892) classified them based on nature of female genital opening. *ie;* Monoporodelphia and Diporodelphia. The most recent and widely accepted classification of copepods was done by Huys and Boxshall (1991) and Humes (1994). According to Huys and Boxshell (1991) there were 10 orders, of which 8 were coming under Super Order Podoplea and the Order Calanoida comes under Super Order Gymnoplea. Both these Super Orders were coming under Infra Class Neocopepoda. The remaining order Platycopioida came under Infra Class Progymnoplea.

Norwegian copepods were the best studied ones by the world famous copepodologists. Giesbrecht (1892) and Sars (1903-1918) provided excellent monographs. Copepods of the British Waters, Maldives and Laccadive Archipelagoes were thoroughly studied by Wolfenden (1904, 1906 and 1911). Copepods of Indian Ocean as well as British Channel were studied by Farran (1911, 1913, 1926 and 1936). Sewell published excellent monographs on copepods of Indian waters alone (1912, 1914, 1929, 1932 , 1947 and 1948). At the same time copepods of Mediterranean Sea were studied by Rose (1933) and Japanese waters were studied by Mori (1937) and Tanaka (1956 and 1964).

Subpolar water copepods were described by Brodsky (1950). Owre and Foyo (1967) detailed copepods from the Florida Segment. Studies on copepods of North Atlantic region were carried out by Fleminger (1957) and that of the Pacific Ocean by Bradford (1971 and 1972, 1988 and 1994) and Bradford and Jillet (1974 and 1980). The spatial distribution of copepod population on the eastern continental shelf off Rio de Janiero state of Brazil was analyzed in relation to the hydrographic regime in summer and winter season, by Rubens et al. (1992). Osore et al. (2003) studied the composition, abundance and diversity of Copepods from the Makupa creek. Data on the distribution of zooplankton in the Atlantic Ocean were given by Deevey and Brooks (1977), Madin *et al*. (2001), Gaudy *et al.* (2003) and Alcaraz *et al.* (2007) and that of the Pacific Ocean were given by Roman *et al.* (1995), White *et al.* (1995), Saltzman and Wishner (1997) and Kang *et al.* (2004). The role of feeding behavior in sustaining copepod population in the tropical ocean was studied by Wiggert *et al* (2005). Reid (1998) stands high in studying copepods from all parts of USA.

Extensive works on different aspects of the Bay of Bengal was done by Qasim (1977), NIO (1977), Nair *et al*. (1977), Peter and Nair, (1978), Bhattathiri *et al.,* (1980), Bhattathiri and Devassy (1981), Devassy (1983), Unger et al.(2003), Madhupratap *et al.* (1983, 2003). Comparatively more studies were conducted in the Arabian Sea (Achuthankutty, 1980, Nair *et al.*, 1981, Rakesh *et al.,* 2006) than Bay of Bengal. The physical characteristics of the east coast of India were studied by La Fond (1957), Suryanarayana et al.(1991), Murthy *et al.* (1981, 1992), Shetye *et al.* (1991, 1993, 1996), Gopalakrishna *et al.* (2002), Sarma *et al.* (1999), Gauns *et al*. (2005) and Maheswaran (2004). General hydrography and circulation of BoB was well studied by Varkey *et al.* (1996). Upwelling at BoB takes place during March-May leading to annual phytoplankton production and subsequently leading to increased secondary and tertiary productivity (Ganapathy, 1954; Gomes *et al*., 2000; La Fond, 1958; Murthy and Varadachary, 1968; Rao *et al.*, 1986; Prasannakumar *et al*, 2002; Madhupratap *et al.*, 1986; Schott and McCreary, 2001). Studies on secondary productivity, abundance and composition of mesozooplankton in BoB were carried out by Krishnakumari and Goswamy (1993), Panikkar and Rao (1973), Nair *et al.* (1981), Achuthankutty *et al.* (1980), Madhupratap *et al.* (2003) and Rakesh *et al.* (2006). The abundance and distribution of fish population mainly depend on the availability of zooplankton.

Knowledge on the taxonomy and distribution of copepods from the Indian Ocean was mainly based on some of the earlier expeditions in this area. It was initiated by Bengal. Cleve (1901), Scott (1902), Thomson and Scott (1903), Wolfenden (1906), Brady (1910) were the prominent figures during earlier works on copepods of Indian Ocean. Yet the most detailed studies on the Copepod fauna of Indian Waters were done by Sewell (1912, 1914, 1929, 1932 and 1948) who surveyed coastal regions of the Bay of Bengal, the Arabian Sea, Chilka Lake, S. Burma and the Andaman and Nicobar Islands. Later he described copepods of West Coast of India and Malay Archipelago (1929-‘32) and copepods of John Murray Expedition (1947 – 1948). Realizing the need for an ocean wide systematic survey of the Indian Ocean, the SCOR (*Scientific Committee on Oceanic Research*) of the ICSU in collaboration with UNESCO and other international and national organizations developed a large-scale scientific program called International Indian Ocean Expedition (IIOE, 1960-65). Nine nations participated in this Biological Programme. The zooplankton samples collected during the expedition formed the basis for a series of papers dealing mainly with zoogeography, ecology and systematics. The basic information on copepods of the IIOE was given in the *Plankton Atlas on Copepoda* (IOBC, 1970). Kasturirangan *et al.* (1973) summed up the distribution and abundance of copepods collected during the International Indian Ocean Expedition. Geographical aspects of Centropagidae, Clansocalanidae and Temoridae were described by Fleminger and Hulsemann (1973).

Oceanographic research in the Andaman Sea dates back to 1869 when Francis Day visited these islands. But the first and most outstanding study of the Andaman Sea was carried out from 1913 to 1925 by Sewell during the IIOE. Even during this period, the Andaman Sea received very little attention compared to the other regions of the Indian Ocean. Comprehensive investigations on many aspects of oceanography were carried out during 1979-1980 by *RV Gaveshini* of National Institute of Oceanography. It was during the 51st, 52nd, 67th and 68th cruises of *RV Gaveshini*, a comprehensive study on zooplankton covering the entire Andaman Sea was conducted. Other Oceanographic Research Vessels such as *ORV Sagar Kanya* and *FORV Sagar Sampada* played significant roles in data collection from the Andaman Sea under several prorammes such as MR-LR Programme.

The Andaman Sea was influenced by large quantities of freshwater from the perennial rivers of Burma, Thailand and Malaysia. This runoff largely influenced the top most layers by reducing the salinity of surface waters. There were some reports available on the physical and hydrographical features of the Andaman Sea (Wyrtki, 1971; Maslennikov, 1973; Rao, 1981; Murthy *et al.,* 1981; Ramaraju *et al.*, 1981; Bbhattathiri *et al.,* 1984.

Primary productivity in the Andaman Sea has been studied from the time of IIOE by Kabanova (1964), Prasad (1966), Qasim (1977), Bhattathiri and Devassy

(1981), Devassy and Bhattathiri (1983), Bhattathiri (1984), Sarojini and Sarma (2001) and Madhu (2004). By comparing the results on primary productivity done by these scientists, it was concluded that the Andaman Sea was less productive than BoB. The extra cellular production and its role in the Andaman Sea available by Pant (1981) agreed with the above results that the extra cellular production by phytoplankton was low in the Andaman sea compared to the Laccadive Sea and its values varied from 1.79 to 0.18$mgCm^{-3}h^{-1}$.

Before the IIOE, virtually nothing was known about the zooplankton standing crop of the Andaman Sea. Even during the IIOE, this area gained little attention as far as zooplankton studies were concerned. Later Madhupratap *et al.* (1981) and Nair *et al.* (1981) have done a comprehensive study from this area. Zooplankton abundance and secondary production from this area was done by Antony *et al.* (1997).

Indian Copepodologists

Seasonal distribution of planktonic copepods of Madras coast were studied by Menon (1931); and Menon (1945) studied that of Thiruvanathapuram coast. Jacob and Menon (1947), Bal and Pradhan (1945), George (1953) and Ganapathy and Rao (1954) gave outstanding contributions for the development of Copepodology in India. Krishnaswamy (1953a, 1953b and 1957) gave detailed study of copepods of Madras Coast. From the Indian Ocean, such studies were carried out mostly in the Arabian Sea (Madhupratap and Haridas, 1990; Smith SL 1995; Hitchcock *et al*., 2002; Smith and Madhupratap, 2005, Saraladevi, 1976, 1977, Saraladevi and Rao, 1980, Saraladevi *et al.,* 1979, Saraswathi, 1973a, 1973b, 1986, Saraswathy and Iyer, 1986, Stephen, 1977, 1984, 1988, 1992,1998, Stephen and Saraladevi, 1973, Stephen and Iyer, 1979, Stephen and Rao, 1980, 1985, Stephen *et al.,* 1992). Unlike in the Bay of Bengal, the high zooplankton biomass in the central and eastern Arabian Sea during summer monsoon was sustained by high primary productivity induced mainly by open ocean- and coastal up welling (Smith and Madhupratap, 2005).

Compared to the west coast, copepods of the east coast have been less intensively studied. Copepods of the Hoogly-Maltah estuarine system were studied by

Sarkar *et al.,* (1986). Studies on the Copepods of the Bahuda estuary were taken up by Mishra and Panigraphy (1996). A season dependant abundance of plankton including copepods was presented by Kumar and Sarma (1988) from Vishakhapatnam harbour area. The Vellar estuarine system had been extensively studied by Kannan and Krishnamurthy (1985). The species composition and abundance of copepods in Pichavaram mangroves was studied by Godandaraman (1994). Multivariate methods were used to detect the differences in the biotic structure of copepods between samples in space and time or changes over time from a polluted harbour of the BoB and a bar built estuary of east coast was done by White *et al.* (2006).

1.5. Scope and Objectives of the Study

The main objectives of the study are:

- ❖ To study the seasonal distribution of copepods with special reference to their qualitative and quantitative distribution, with notes on biodiversity in the Andaman Sea and the Bay of Bengal.
- ❖ To study the spatial and temporal distribution of copepods in the Andaman Sea and the Bay of Bengal.
- ❖ To understand the hydrography and the environmental characteristics of the Andaman Sea and the Bay of Bengal and their role in the distribution and biomass of copepods.
- ❖ To study the vertical migration/diurnal migration of the copepods.
- ❖ To study the difference between the coastal and oceanic composition of copepods in the study area and the factors responsible for it.

Globally there is a drive to create database for zooplankton for forecasting fishery like the Costal and Oceanic Plankton Ecology, Production and Observation Database (COPEPOD- O'Brien, 2005). The survey made during Marine Research on Living Resources(MR-LR) was important because it alone provide time-series zooplankton collections which were lacking in Indian Ocean especially in the Bay of Bengal.

The previous studies mostly outline the general geographic distribution of species, many do not consider the spatio-temporal variations, which could be significant in ecosystem analysis. Information on the distribution usually relates to a particular genus or family or is confined to a small area. In view of these facts, the present study gives a detailed status on the vertical and horizontal species composition, distribution, biomass and abundances in relation to the prevailing hydrographic conditions of the Bay of Bengal and the Andaman Sea.

Chapter 2

Materials and Methods

The study is based on the samples collected during 5 cruises carried out in the Bay of Bengal and one from the Andaman Sea by the research vessel ***FORV SAGAR SAMPADA*** (Plate. 2.1). Samples were collected from the Exclusive Economic Zone (EEZ) as a part of multi-disciplinary project entitled *Marine Research – Living Resources (MR-LR) Assessment Programme*of the Regional Centre, NIO – KOCHI, funded by the Ministry of Earth Sciences – (MoES), Govt. of India through the Centre for Marine Living Resources and Ecology (CMLRE). This programme, initiated during 1997, envisages comprehensive assessment of Marine Living Resources of the Indian EEZ and studies on the influence of the Marine Environment on these resources.

2.1. Study Area

Samples for the present study were collected from the Exclusive Economic Zone (EEZ) along the east coast of India from its 2 of 4 major regions- the Bay of Bengal (0.525 X|10^6 km^2)and the Andaman Sea (0.698 X 10^6 km^2).There were 22 stations selected from the Bay of Bengal out of which 12 were studied up to a depth of 1000 m and remaining 10 stations were explored up to the mixed layer depth only(Fig.2.1a.). There were 8 stations selected from the Andaman Sea(Fig.2.1b.) for the studies on copepods. They were sampled along 5 transects at 11°N 13°N, 15°N, 17°N and 19°N in BoB and along 4 transects at 7°N, 10°N, 15°N and 17°N in the Andaman Sea for physico-chemical parameters, namely temperature, dissolved oxygen and macronutrients (nitrate, phosphate and silicate). Along each transect, samples for the estimation of biological parameters, such as primary production, secondary production including the efc were collected, preserved and brought to the lab for further qualitative and quantitative study. To study the effect of cyclone on formation of any copepods 50 samples from 16 stations were selected. So as to unravel the phenomenon of diel vertical migration 101 samples collected both during day and night from different depth and strata were studied.

2.2. Sampling Seasons

The sampling seasons selected for these studies were Summer Monsoon (SM), Winter Monsoon (WM), Spring Inter Monsoon (SIM) and Inter Monsoon Fall. The details of the study periods are given in Table 2.1.

Table 2.1. Classification of seasons (JGOF protocol) and cruises under taken in the study area

Seasons	Cruises undertaken	Area
Summer monsoon or Southwest Monsoon (Jun-Sept)	Cruise 175 (25th July– 8th Aug 1999) Cruise 205 (18th July– 4th Aug 2002)	The Bay of Bengal
Inter Monsoon Fall (October)	Cruise 207 (16th Sept – 3rd Oct 2002)	The Andaman Sea
Winter monsoonor Northeast Monsoon (Nov-Feb)	Cruise 178 (11th Nov – 24th Nov 1999) Cruise 209 (10th Nov –30th Nov 2002)	The Bay of Bengal
Spring Inter Monsoon (Mar-May)	Cruise 193 (4th Apr – 28th Apr 2001)	The Bay of Bengal

2.3. Sampling procedure and Methodology

2.3.1. Physical parameters

2.3.1.1. Temperature and Salinity

The sea surface temperature (SST) was measured using bucket thermometer. A Sea Bird CTD (Sea Bird Electronics Sea *Model: SBE-911 Plus USA*) (Plate. 2.2) was used to measure temperature – salinity profiles at 1m intervals and water samples were collected from the standard depths. Salinity values from CTD were corrected against the values obtained from Autosal (*Model 8400A*) onboard. The processed 1-m bin averaged temperature and salinity values were used to construct T and S profiles at each station and examined for spikes and spurious data. The data corresponding to spikes were deleted and only quality data on temperature and salinity were used in the present study. Mixed layer depth (MLD) was computed as the depth at which density rises by 0.2 units from the surface. This density difference is equivalent to a 1.0°C change in temperature, if salinity is constant.

2.3.2. Chemical parameters

Collection of water samples were made from standard depths using 1.8 litresNiskin bottles attached to the CTD with remotely operated closing mechanism. The samples were sub-sampled immediately and analyzed for dissolved oxygen, nitrate, phosphate and silicate. Standard methods followed for each estimation are given below in detail.

2.3.2.1. Dissolved Oxygen

Dissolved oxygen (DO) was determined by Winkler's method as described in Grasshoff (1976). Water samples were carefully collected in glass bottles (125ml) without trapping air bubbles. Samples were immediately fixed by adding 0.5ml of Winkler A (manganous chloride) and 0.5ml of Winkler B (alkaline potassium iodide) solution and mixed well for precipitation. The dissolved oxygen was later analyzed after acidification by titration against standard sodium thiosulphate using starch as indicator. The concentration of oxygen in the sample was calculated as,

$$\text{Dissolved oxygen (ml/litre)} = 5.6 * N * (S-B_m) * V/(V-1) * 1000/A$$

Where, N = Normality of the thiosulphate

S = Titre value for sample

B_m = Mean titre value for blank

V = Volume of the sample bottle (125ml)

A = Volume of sample titrated (50ml)

2.3.2.2. Nutrients

The major nutrients analysed were Nitrate - Nitrogen (NO_3-N), Phosphate - Phosphorous (PO_4-P) and Silicate - Silicon (SiO_4-Si). Samples for nutrients were collected in clean glass bottles and analyses were carried out by autoanalyser SKALAR (*Model – SA 1050*) onboard.

Nitrate in the sample was first reduced to nitrite using a reductor column filled with amalgamated cadmium granules and the nitrite (NO_2) was reacted with sulphanilamide in an acid solution. The resulting diazonium compound was coupled with N - (1- Naphthyl) -ethylenediaminedihydrocloride to form a colouredazo dye and the absorbance was measured spectrophotometrically at 543nm.

Dissolved inorganic reactive phosphate was estimated by the formation of a reduced phosphomolybdenum blue complex in an acid solution containing molybdic acid, ascorbic acid and trivalent antimony, adopted by the method of Grasshoff*et al.,* (1983). The absorbance of the colour complex was made at 882nm.

The determination of dissolved silicate in seawater was based on the formation of molybdenum blue complex when the acid sample is treated with a molybdic solution the absorbance of which was made at 810nm (Grasshoff*et.al*; 1983).

The chemical environmental data derived were used for interpreting the biological component especially copepods.

2.3.3. Biological parameters

2.3.3.1. Primary productivity

Primary production is expressed as $mgCm^{-3}d^{-1}$. A known concentration of radiocarbon ($Na_2H^{14}CO_3$) was added to the sea water sample and the ratio of the uptake of radiocarbon to the added radiocarbon by the phytoplankton was converted to total carbon uptake by multiplying with the total inorganic carbon in the sample. Vertical profiles of production measurements were integrated to yield a production rate per unit area in units of $mgC\ m^{-2}d^{-1}$.

Primary productivity measurements were made according to Indian JGOFS protocol (UNESCO, 1994) using ^{14}C - technique introduced by Steeman Nielsen (1952). Polycarbonate (Nalgene, USA) bottles used for primary productivity incubations were soaked for 72 hours in a 5% solution of detergent, rinsed thoroughly with deionised water and subsequently soaked for 72 hours in 0.5N HCl solution. Bottles were then rinsed with distilled water and kept filled with Milli-Q water for 48 hours.

For measuring *in-situ* primary productivity, water samples were taken from seven predetermined depths (0, 10, 20, 50, 75, 100 and 120m) from the euphotic zone one hour before the sunrise(Plate 2.3).. Before addition of radio active carbonate, none of the samples were exposed to light. Samples were immediately sieved through a 200µm mesh to remove large zooplankton and transferred to five clean Nalgene PC bottles of 300ml capacity for each depth. Before addition of radioactive carbonate, none of the samples was exposed to light (as either light can enhance productivity or degrade/reduce the photosynthetic efficiency due to light shock in samples from deeper depths). To each PC bottle containing seawater sample, 1ml solution of 5µCi (185 kbq) radioactive carbon (*BRIT, DAE, Mumbai*) was added. From one bottle, 100ml sample was filtered on to 47mm GF/F (nominal pore size 0.7µm) filter paper for determining the initial adsorption of the ^{14}C by the particles in the bottle. From the remaining bottles at each depth, one was covered with aluminium foil and transferred to a black bag to determine the production in the dark. Thus, one dark and three light bottles were used at each depth for *in-situ* incubation for 12 hours from sunrise to sunset.

The bottles were deployed *in-situ* to suspend them at the appropriate depths using polypropylene line attached to a buoy. The 'mooring' system was thus deployed approximately one hour before sunrise, and allowed to drift freely for 12 hours during fair weather seasons during monsoon however, due to inclement weather, primary productivity mooring buoy was tied to the ship and let to drift freely in such a way that the rope was not taut. The ship was occasionally maneuvered to keep the mooring ~ 150 - 200m away from it. The system was then retrieved ~30 minutes after sunset.

Immediately after retrieval, samples in each light and dark bottles were filtered on to GF/F filter and the filters were transferred to scintillation vials. A drop of 0.5N HCl was added to each vial and capped it overnight. All vials were held at room temperature until the radioactivity was counted. Before counting, all vials were uncapped and left open overnight. Five ml of liquid scintillation cocktail (SISCO-Bombay) was added and the radioactivity was counted in a liquid scintillation system (*Wallac 1409, DSA- Perkin Elmer- USA*) .

The count (disintegration per minute - DPM) rates were converted to daily production rates (mgC $m^{-3}d^{-1}$), which were obtained from the triplicates that generally agreed within ±10% of covariance and were averaged to obtain mean values for a given depth. Production rate in the dark bottle was subtracted from the mean value of light bottle to correct for non-photoautotrophic carbon fixation or adsorption. Similarly, to determine the initial activity added (Time zero T_0) in the bottles, 0.2 ml of sample was transferred to a scintillation vial and 0.2 ml of ethanolamine was added to it (ethanolamine prevents the radiolabelled inorganic CO_2 from escaping to the atmosphere). The daily production rate of various depths was used to calculate integrated production of the water column (mgC m^{-2} d^{-1}).

Calculation:

Primary production (mg C m^{-3} day^{-1}) = 1.05 X S_{DPM} X W / S_A X T

Sample Activity (SA) = V* T_{DPM} / A_{vol}

Where,

DPM = Disintegration Per Minute

S_{DPM}= DPM s in filtered sample

T_{DPM} = Total ^{14}C DPMs (in 0.25ml)

A_{vol}=Volume taken to measure sample activity

V = Volume of filtered sample (litres)

T = Time (days)

1.05 = correction for the lower uptake of ^{14}C compared to ^{12}C

W = Dissolved Inorganic Carbon (DIC) concentration in sample (~25000 mgC m^{-3})

The depth wise production was integrated to obtain the production for the entire euphotic zone (Dyson *et al*., 1965).

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

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

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

2.3.3.2. Mesozooplankton Biomass

The mesozooplankton samples were collected using Multiple Plankton Net (*HYDRO-BIOS*) with a mouth area of 0.25 m^2 and a mesh size of 200 µM (Plate 2.4). This sampler was based on the principle of opening and closing of a series of individual plankton nets in succession at desired depth ranges by pressure triggering. The system consisted of a main powered Deck Command Unit and square shaped stainless steel frame (0.25m^2) with canvas part to which five net bags were attached (mesh size – 200 µm). The net bags were opened and closed by means of an arrangement of levers, which were triggered by a battery powered Motor Unit. The Multiple Plankton Net was operated with an electrical connection(singular or multi conductor cable) between Deck Command Unit and Underwater Unit. The net was hauled vertically with a speed of 1m/s.

The depths of hauls were fixed based on the thermocline besides two standard depths(1000-500m, 500-300m). The thermocline depths were 300m to Base of thermocline(BT), Base of thermocline to Top of Thermocline layer(BT-TT, Thermocline layer) and Top of Thermocline to the surface(TT-0 or mixed layer). The depth of occurance of the thermocline was taken as the depth where the temperature falls by 1̊C from the surface and 15̊C isotherm was considered as the bottom of the thermocline (Kesavadas, 1992). The number of strata sampled varied according to station depth and hydrographic conditions.

The term biomass denoted the amount of living matter present in the zooplankton, and was used to evaluate the standing stock. The fixation and preservation of the sample was followed by the standard protocols (Steedman, 1976; Postel*et al*. 2000). Prior to estimation of biomass, larger zooplankters such as medusae, ctenophores, salps, siphonophores and fish eggs larvae were separated from the sample and their biomass was taken separately and added to the biomass of the rest of the zooplankton. Biomass was estimated by displacement volume method. For this, the zooplankton sample was filtered through a piece of clean, dried netting material (200 μm mesh size). The interstitial water was removed with the blotting paper. The filtered zooplankton was then transferred with a spatula to a measuring cylinder with a known volume of 4% formalin – seawater solution. The displacement volume was obtained by recording the volume of fixative in the measuring jar displaced by the zooplankton. 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 ($0.25m^3$)

Zooplankton biomass was estimated by displacement volume method, and samples were preserved in 4% buffered seawater formalin. Later in the laboratory, the 100% of the samples sorted out to the possible lowest taxonomic level using standard references (UNESCO 1968; ICES 2000). The values were converted to milliliter per unit volume for biomass (ml m−3) and No per unit volume (No m−3) for density.

2.3.3.3 Copepods

Copepods were sorted out from the samples for their quantitative and qualitative analysis. The species level identification of copepods was done using dissecting microscope (Nikon Smz 645 and Nikon Eclipse E 400). Identification was made up to the species level following the works of Gieshbrecht (1892), Sewell (1947-48), Kasthurirangan (1963), Wallershaus (1969) Bradford (1994) and Tanaka (1965, 1973), Gopalakrishnan. T.C(1982), Grice.G.D& K. Hulseman(1966), Brodsky,K.A(1950),. About 12% of the total copepods from the whole sample (51,506 copepods individuals from all the seasons and depth or

25,31,147 copepods from 1000m^3 of water column.) were immature , hence their identification was not done.

2.3.3.4. Fish landings

Data of fish landing from the east coast of India, during the years 1999-2002 were obtained from CMFRI special publication No.89 (Srinath, *et al.* 2004).

2.3.4. Statistical Analysis

The following statistical methods were applied for drawing inferences from the quantitative data obtained.

The software programmes*viz.,**SPSS*** (*Statistical Programme for Social Sciences version 11.0*) and ***PRIMER v 5*** *(Plymouth Routines in Multivariate Ecological Research, version 5*), were used for univariate and multivariate analyses of data.

Statistical analysis for **2 Way ANOVA**, standard deviation and correlation was done based on ***SPSS11***software packages *for Windows* for testing the presence of significant differences among the parameters between stations and between seasons. Correlation results were used to correlate the environmental parameters with the biological parameter.

Community structure: ***PRIMER v5 for windows***was used for the analysis of community structure.

MDS (Non - metric Multi DimensionalScaling)

This method was proposed by Shepard (1962) and Kruskal (1964) and this was used to find out the similarities (or dissimilarities) between each pair of entities to produce a 'map', which would ideally show the interrelation ships of all.

(a) Diversity Indices:

i) Shannon - Weaver index (H')

In the present study, the data was analyzed for diversity index (H') using the following Shannon - Weaver's formula (1949):

$$H' = \sum S \, Pi \log 2 \, Pi \ldots..$$
$$i = 1$$

which can be rewritten as,

$$H' = \frac{3.3219\ (N \log N - \sum ni - \log ni}{N}$$

where, H'= species diversity in bits of information per individual

n^i = proportion of the samples belonging to the ith species (number of individuals of the *i*th species)

N = total number of individuals in the collection and

$\sum$ = sum.

ii) <u>Margalef richness index (d)</u>

$$d = (S-1) / \log N$$

iii) <u>Pielou's evenness index (J')</u>

The equitability (J') was computed using the following formula of Pielou (1966):

$$J' = \frac{H'}{\log_2 S} \text{ or } \frac{H'}{\text{In}S}$$

where, J' = evenness,

H' = species diversity in bits of information per individual and S = total number of species

iv) <u>Simpson index (D)</u>

$$D = 1 - \lambda,$$

where, $\lambda = \sum Pi2$

$$Pi = \frac{ni}{N}$$

ni = number of individuals of i, i2 etc. and N = total number of individuals.

(b) Similarity Indices:

i) <u>Cluster analysis</u>

Cluster analysis was done to find out the similarities between groups. The most commonly used clustering technique was the hierarchical agglomerative method. The results of this were represented by a tree diagram or dendrogram with the x- axis representing the full set of samples and the y-axis defining the similarity level at which the samples or groups are fused. Bray - Curtis coefficient (Bray and Curtis 1957) was used to produce the dendrogram. The coefficient was calculated by the following formula:

$$S_{jk} = 100\left\{1 - \frac{\sum_{i=1}^{p} \left| y_{ij} - y_{ik} \right|}{\sum_{i=1}^{p} (y_{ij} + y_{ik})}\right\}$$

$$= 100 \frac{\sum_{i=1}^{p} 2\min(y_{ij}, y_{ik})}{\sum_{i=1}^{p} (y_{ij} + y_{ik})}$$

where, y_{ij} represents the entry in the ith row and j th column of the data matrix i.e. the abundance or biomass for the ith species in the j th sample;

y_{ik} is the count for the ith species in the k th sample;

| | represents the absolute value of the difference;

'min' stands for, the minimum of the two counts and

∑ represents the overall rows in the matrix.

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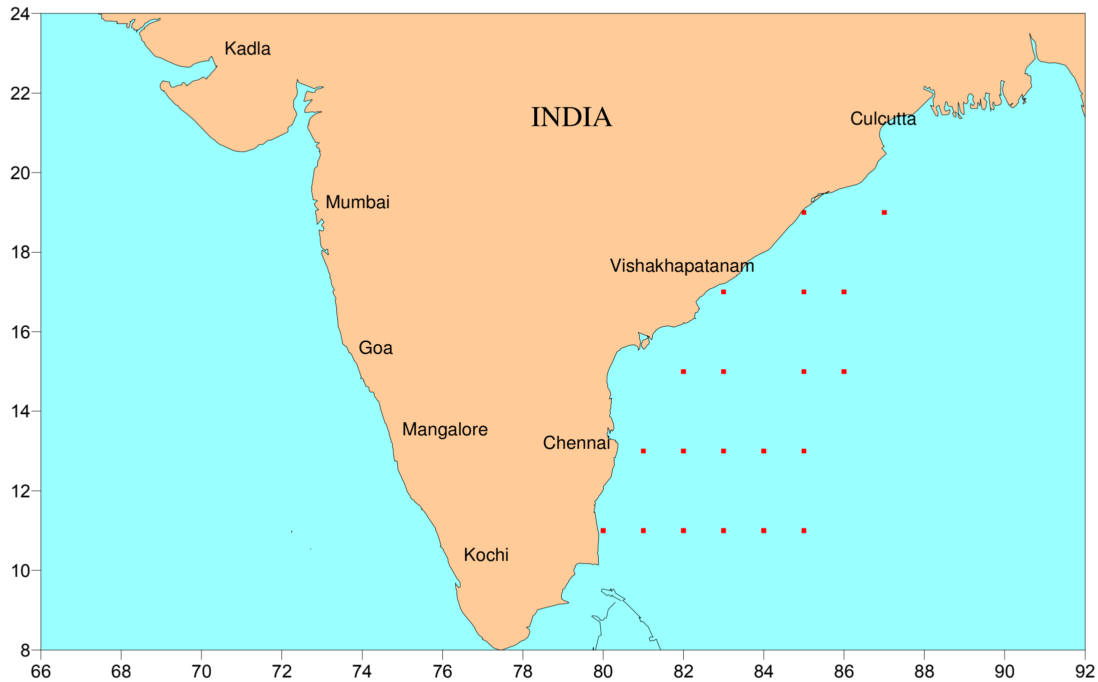


Fig. 2.1a. Study area showing station positions at theBoB

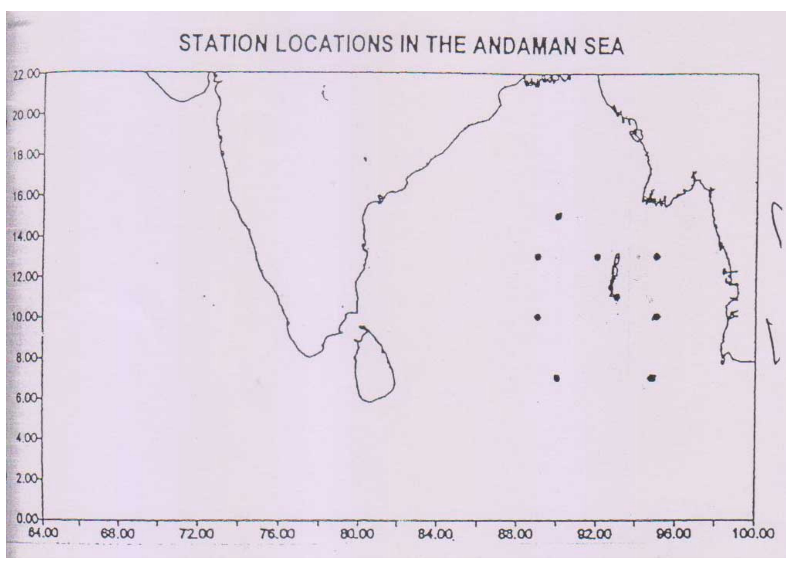


Fig. 2.1b. Study area showing station positions at the Andaman Sea

Plate 2.1.CMLRE Research vessel *FORV Sagar Sampada*

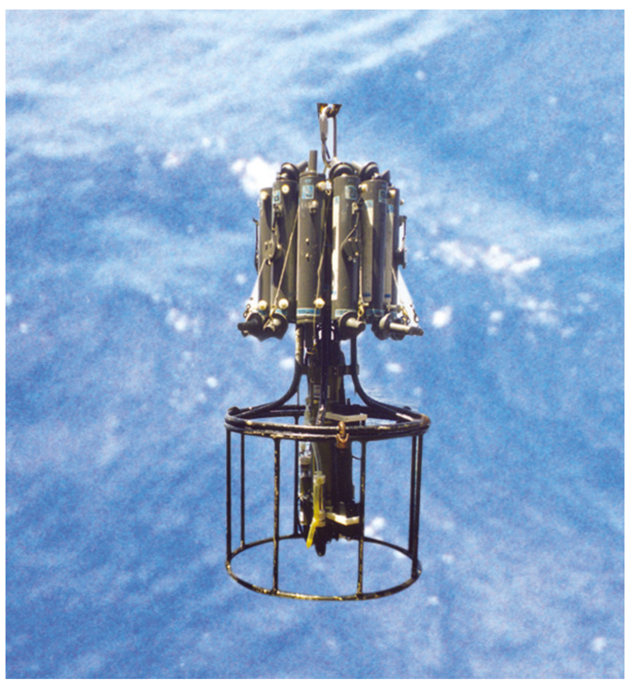
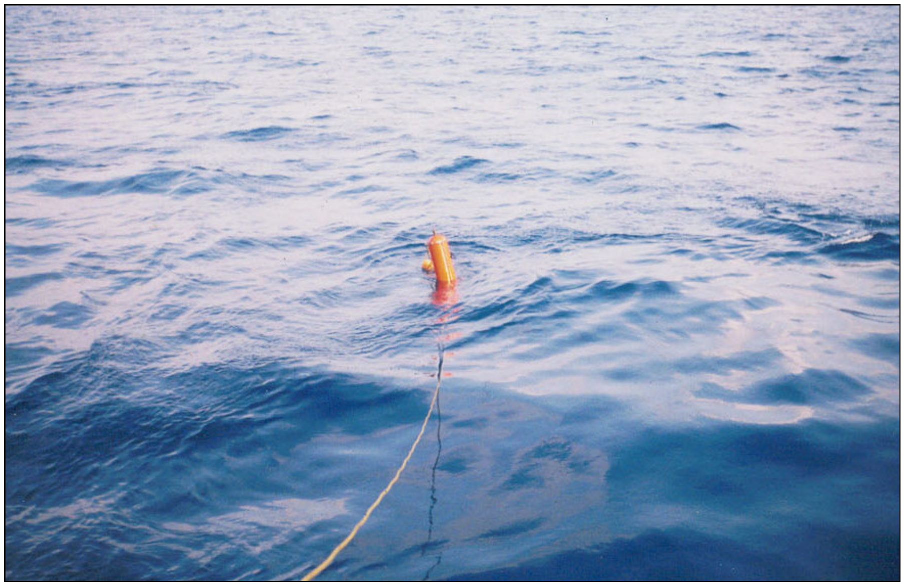


Plate 2.2. CTD rosette with Niskin bottles



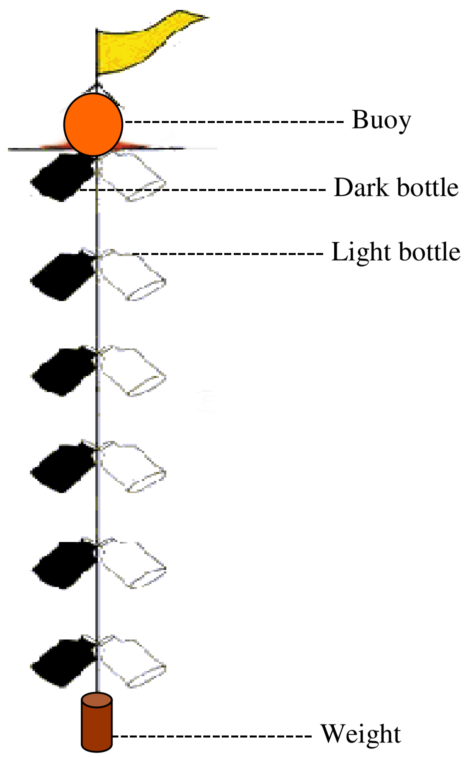


Plate 2.3.Deployment of mooring buoy for *in-situ* incubation for primary productivity studies

Plate 2.4. Multiple Plankton Net (MPN)

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Chapter III

Hydrography

3.1. Introduction

In a marine ecosystem, hydrographic conditions of the sea determine the existence of communities and the size of population, distribution. The regulatory influence of the hydrographic conditions over the living environment is the result of independent and interrelated actions of non-living elements, which are variable in space and time and are very useful to understand the dynamics of the marine ecosystem.

The BoB, compared to Indian Ocean is an ocean of 'positive water balance.' It receives $1.382 x 10^9$ ton.year^{-1} of river run-off (Subramanian, 1993) or $1.5 x 10^{12}$ m^3 of freshwater and $16 x 10^8$ ton/year silt from several peninsular Indian rivers (Shetye *et al*. 1996), but experiences more precipitation than evaporation for most of the year leading to an upper layer of less saline waters. Conventionally the BoB is believed to be relatively less productive compared with the neighbouring Arabian Sea (Qasim, 1977; Radhakrishna *et al*., 1978; Prasannakumar *et al*., 2002, Madhu, 2004).

In this chapter, temporal and spatial variability of physical parameters such as Sea Surface Temperature (SST), Sea surface Salinity (SSS), Sigma-*t*, Mixed Layer Depth (MLD) and the chemical parameters such as dissolved oxygen and nutrients (phosphate, nitrate and silicate) are discussed.

3.2. Results

Physicochemical Environment of the BoB

3.2.1. Summer Monsoon

3.2.1.1. Physical characteristics

The summer monsoon is characterised by weak (av.5ms^{-1}) and predominantly southwesterly and occasional north westerly winds (Fig. 3.1). The SST varied between 28.9 to 29.5 °C (av. 29.3°C). Higher SST was observed along the oceanic stations, and it was ***minimum*** in the coastal waters off 15°N (Fig. 3.2a). The SSS was in the range of 33.2 – 35.1 psu (Fig. 3.2b). In general, relatively high SSS (>32 psu) observed were during the study period. Maximum salinity (33.4 psu) observed were at 11°N 84°E where as the minimum value was observed at 17 °N 86°E . The MLD was relatively shallow in the northern region and deep in the south (Fig.3.2c). At the coastal station of 15°N, it even decreased to 30m and the maximum MLD was observed at the offshore station of 13°N. A northward decrease in SSS was found in the inshore as well as in the offshore waters.

3.2.1.2. Chemical characteristics

The distribution of DO showed an increasing trend towards the north. The values ranged between 140 to 180 µM (av.161µ M) in the coastal stations (Fig.3.3a). The nitracline observed was between 30-40m along the oceanic waters while it was deeper along the coastal waters. Nitrate concentration was less than 2 µm in the upper 50 m water column (Fig.3.3b). Silicate concentration also was similar to the distribution along the surface waters as that of nitrate (Fig.3.3c). Upper 40m of water column showed less than 0.6 µm concentrations of phosphates (Fig.3.3d). Offshore regions were characterized by deep nitracline (Fig.3.4b) and traces of inorganic silicate and phosphate could also be noticed in the upper 50m of the offshore waters. (Fig.3.4 c and d).

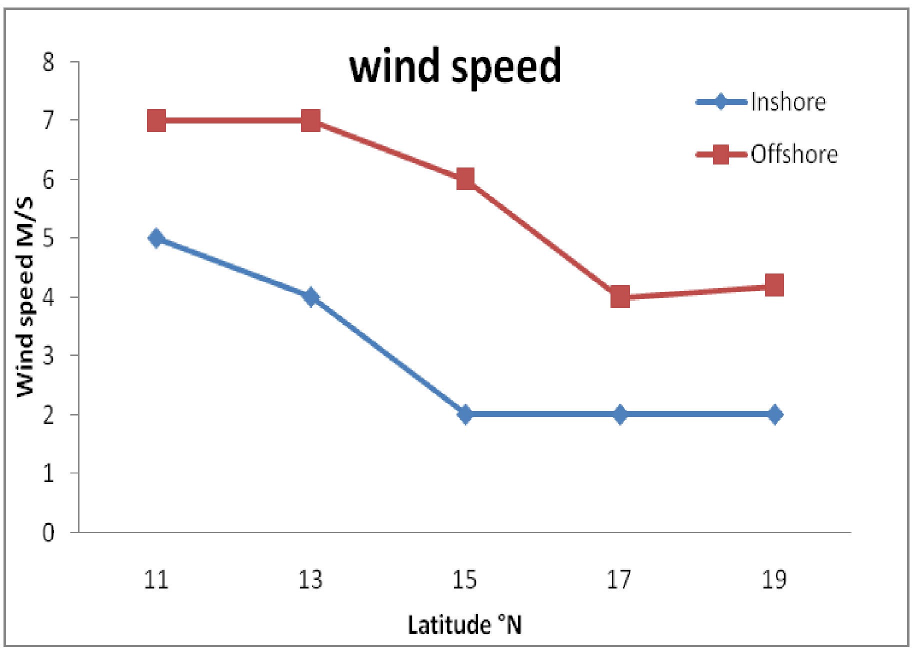
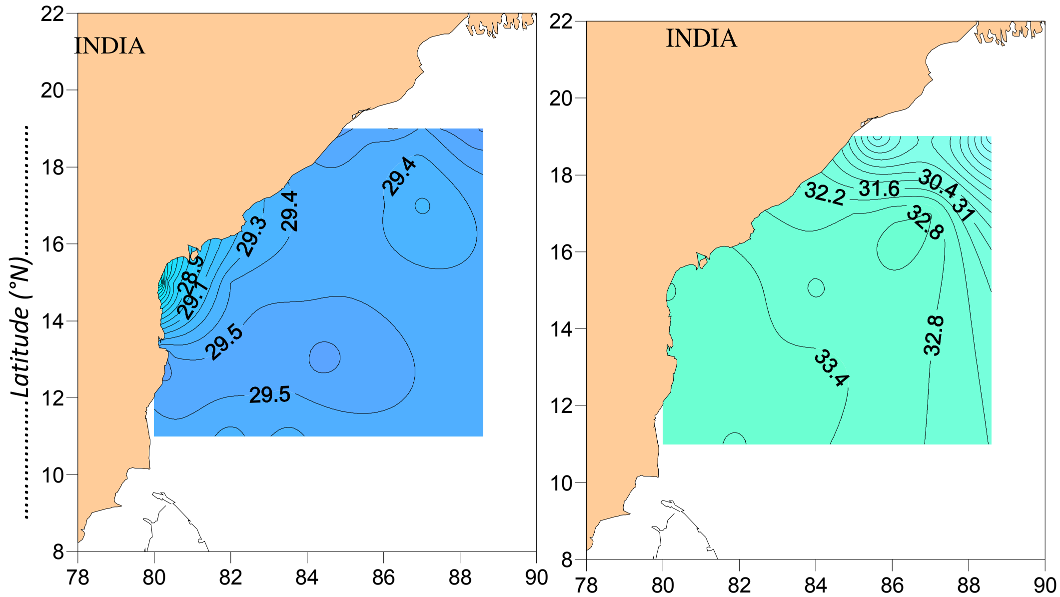


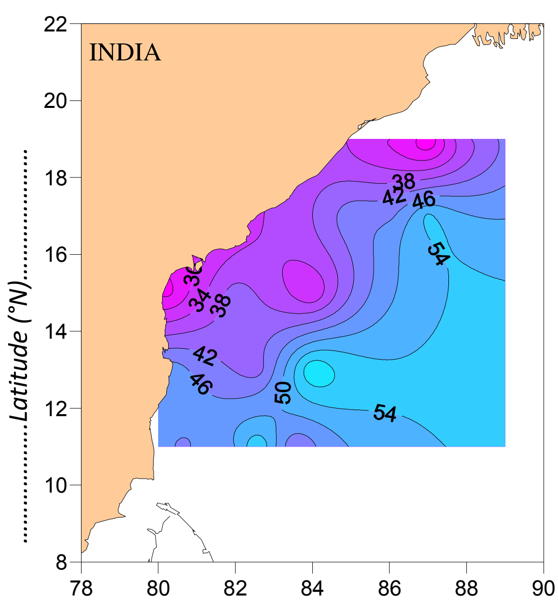
Fig. 3.1. Distribution of wind speed during summer monsoon in Bay of Bengal

(a) **(b)**



……………*Longitude (°E)*…………………

(c)



……………*Longitude (°E)*…………………

Fig. 3.2. Distribution of (a) SST (b) SSS and (c) MLD during summer monsoon in the Bay of Bengal

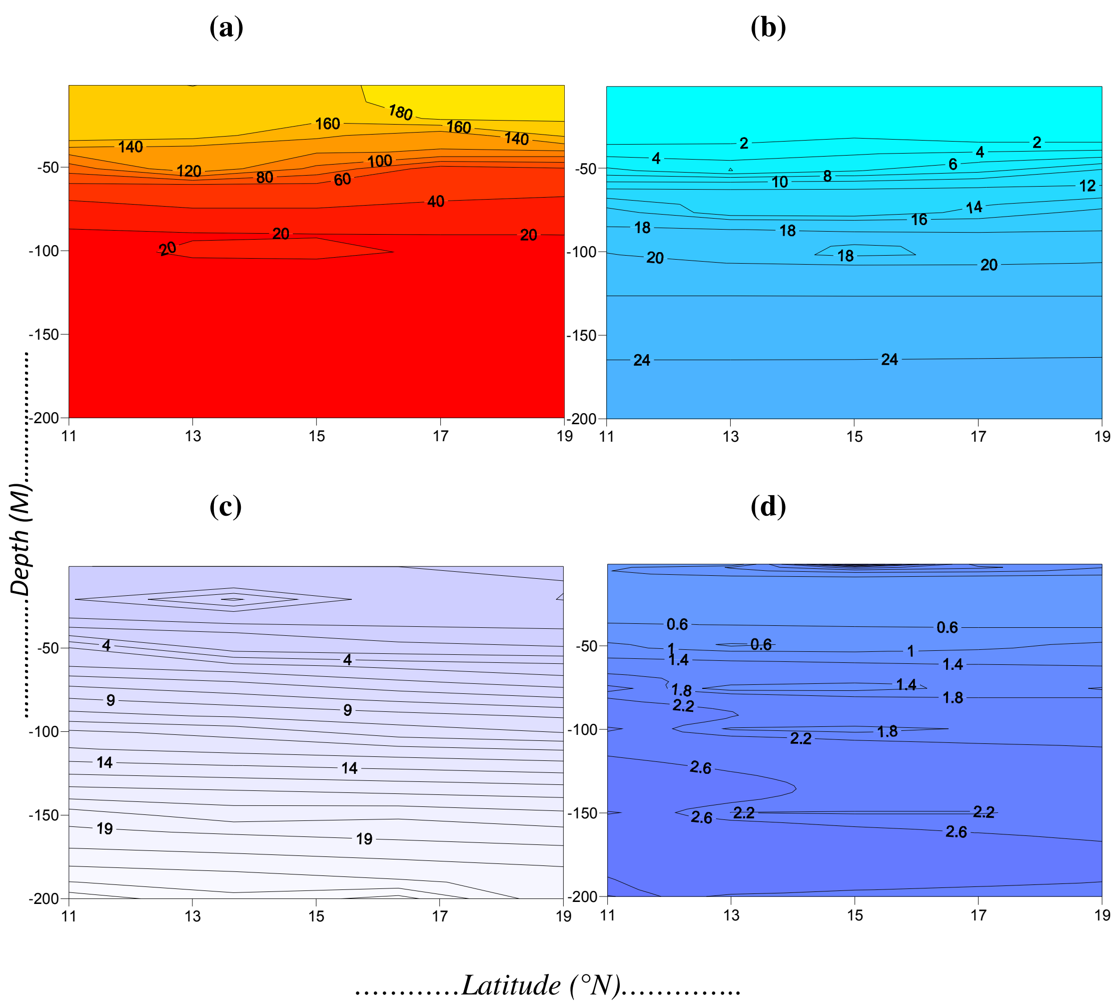


Fig. 3.3. Vertical distribution of (a) dissolved oxygen (μM L^{-1}) (b) nitrate (μM L^{-1}) (c) silicate (μM L^{-1}) and (d) phosphate (μM L^{-1}) along the coastal stations of Bay of Bengal during summer monsoon

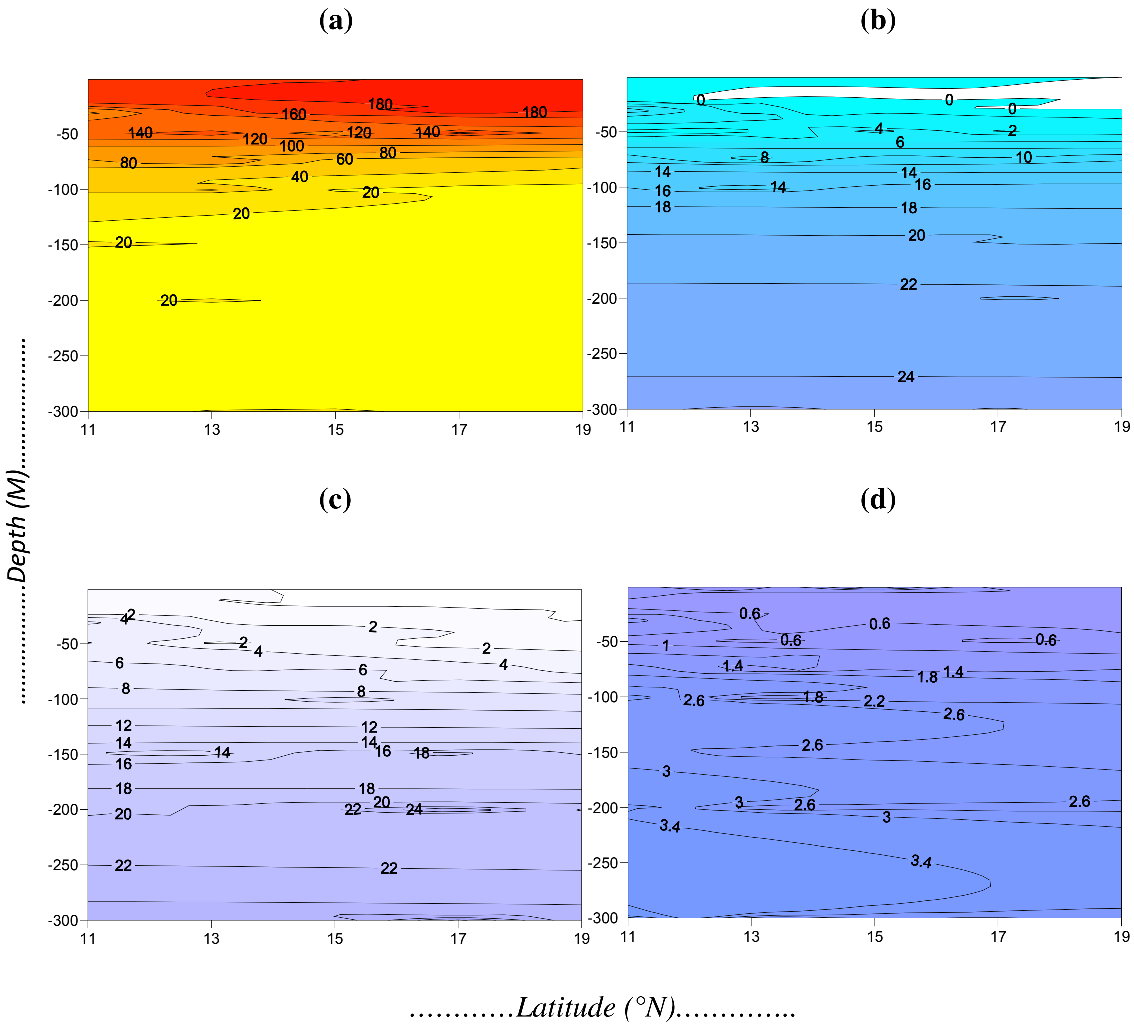


Fig. 3.4. Vertical distribution of (a) dissolved oxygen (µM L^{-1}) (b) nitrate (µM L^{-1}) (c) silicate (µM L^{-1}) and (d) phosphate (µM L^{-1}) along the oceanic stations of Bay Bengal during summer monsoon

3.2.2. Winter Monsoon

3.2.2.1 Physical characteristics

During the winter season, generally weak winds (Fig.3.5) were prevalent in the study area (av. 5.1m/s). SST during winter varied between 26.3 to 28.9 °C (av. 27.7) and it was higher in the central BoB and it decreased towards the coast (Fig.3.6a). The SSS showed maximum (34.4) in the central BoB and it decreased towards the coastal and northern regions (Fig.3.6b), which could be attributed to the inflow of Mahanadi-Ganges-Brahmaputra river systems. Generally MLD was deep in the coastal regions (>50m) and it was shallow (<40m) in the offshore area (Fig. 3.6c).

3.2.2.2. Chemical characteristics

DO was saturated in the surface layers of both inshore (>200 µM) and offshore waters (Figs. 3.7a and 3.8a). Traces of inorganic nutrients (nitrate, phosphate and silicate) were observed above 50m inshore waters (Figs.3.7 b, c and d) as compared to offshore (Figs. 3.8 b, c & d). The northernmost latitudes showed higher amount of dissolved oxygen concentrations in the surface water.

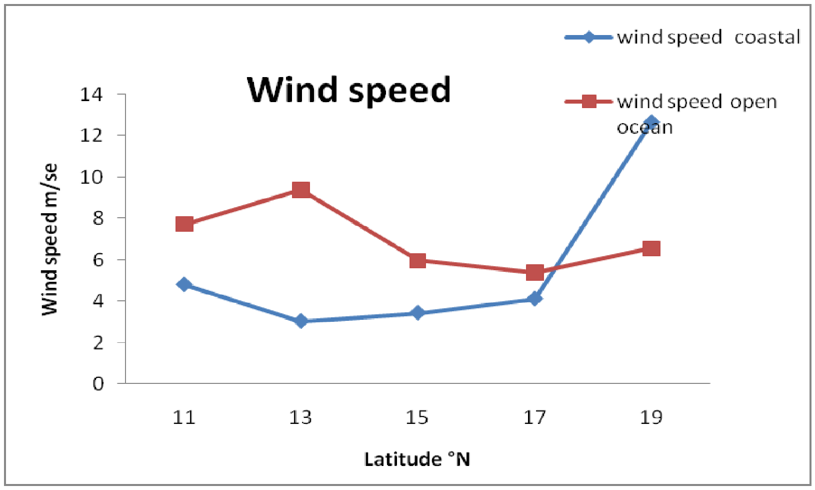
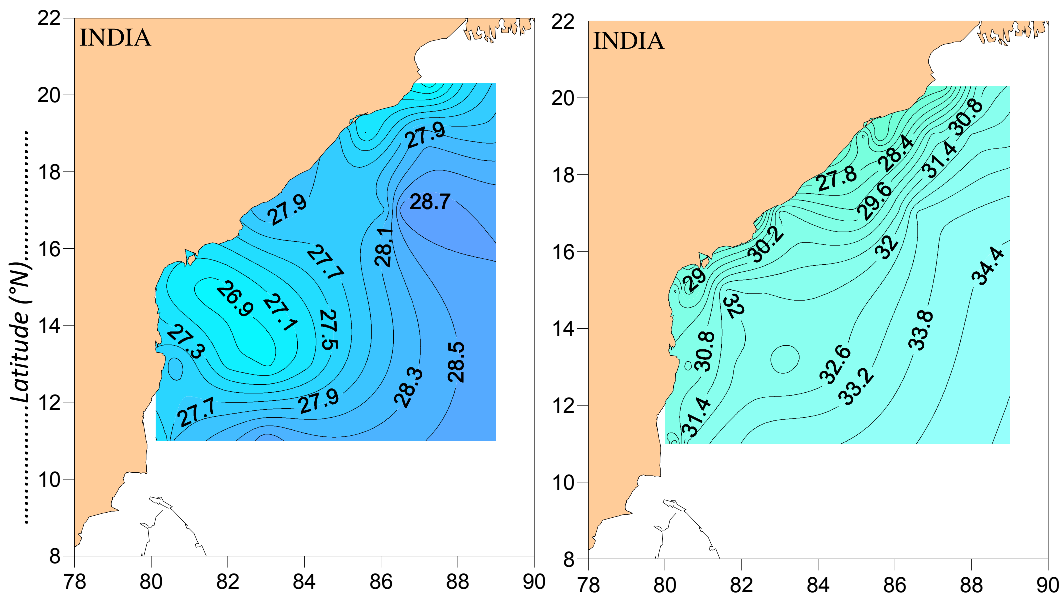


Fig. 3.5. wind speed during winter monsoon in Bay of Bengal

(a) **(b)**



................*Longitude (°E)*......................

(c)

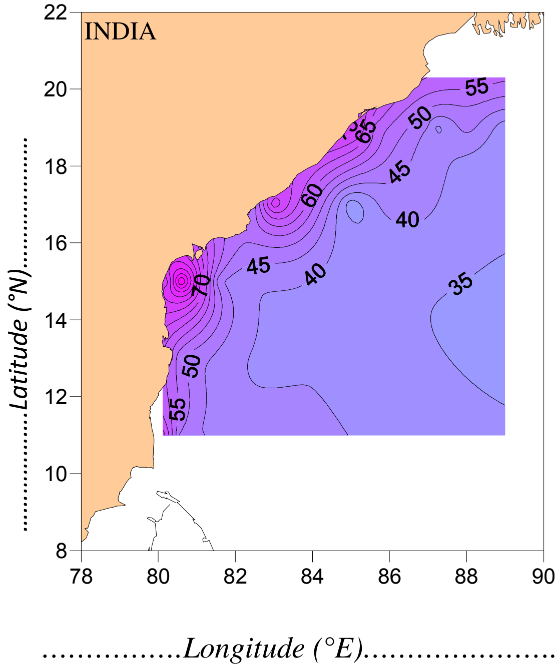
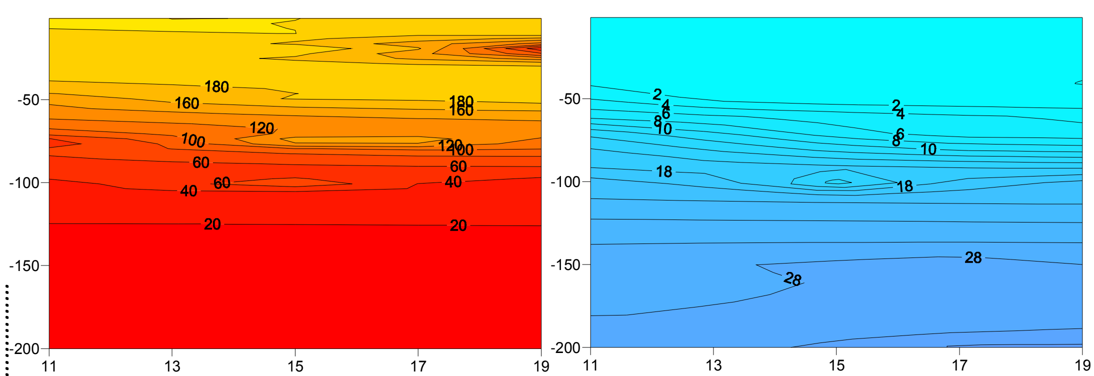
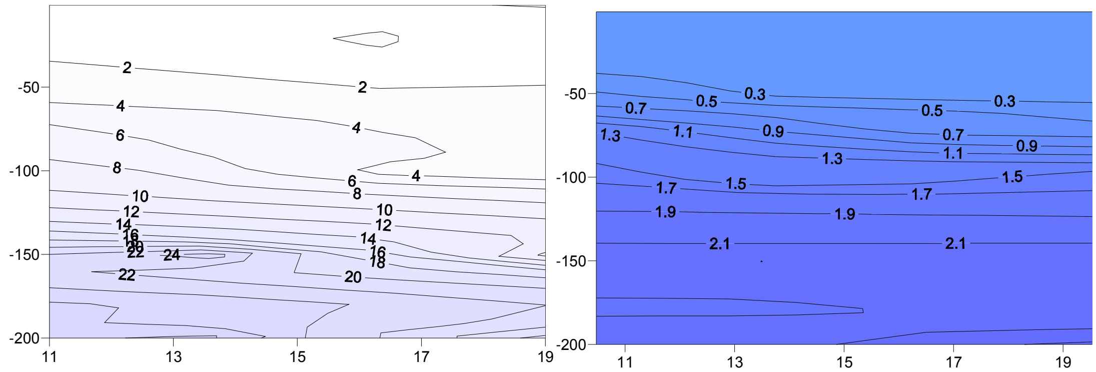


Fig. 3.6. Distribution of (a) SST, (b) SSS and (c) MLD during winter monsoon in the Bay of Bengal

(a) **(b)**



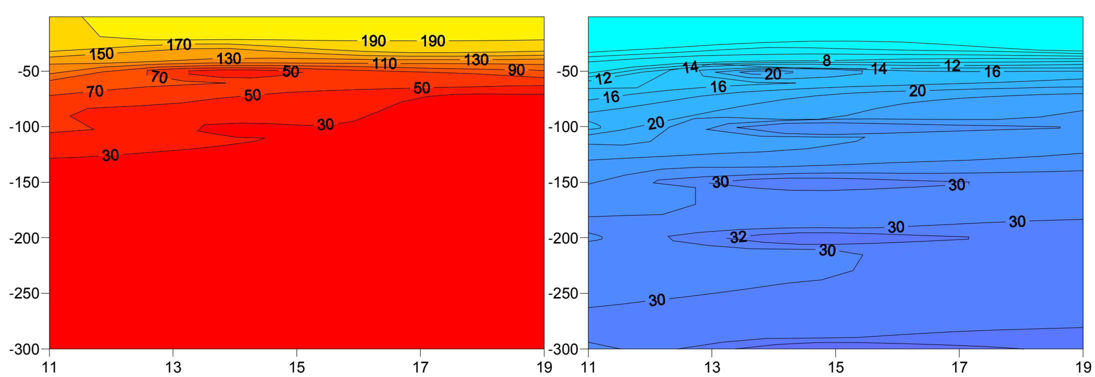
(c) **(d)**



…………*Latitude (°N)*…………..

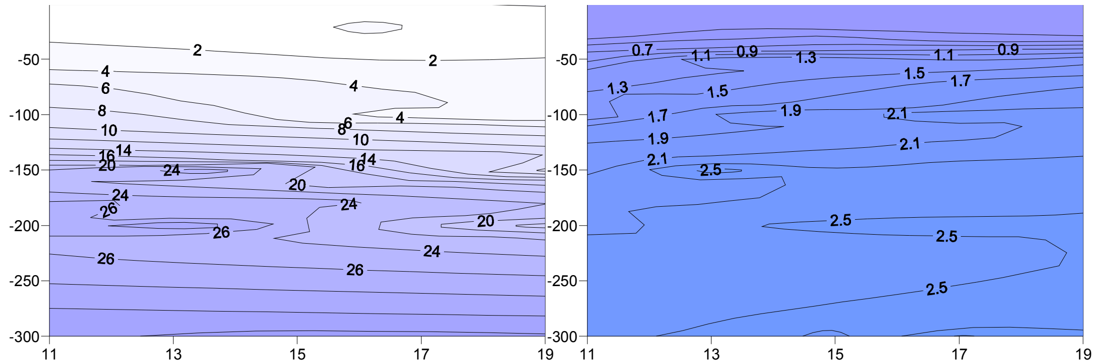
Fig. 3.7. Vertical distribution of (a) dissolved oxygen (µM L^{-1}) (b) nitrate (µM L^{-1}) (c) silicate (µM L^{-1}) and (d) phosphate (µM L^{-1}) along the coastal stations during winter monsoon

(a) **(b)**



(c) **(d)**

……………*Depth (M)*……………



…………Latitude (°N)…………..

Fig. 3.8. Vertical distribution of (a) dissolved oxygen (µM L^{-1}) (b) nitrate (µM L^{-1}) (c) silicate (µM L^{-1}) and (d) phosphate (µM L^{-1}) along the oceanic stations during winter monsoon

3.2.3. Spring Inter monsoon

3.2.3.1. Physical characteristics

During spring inter monsoon, weak northeasterly winds were present all over the BoB. Surface winds blowed steadily from the southwest and the magnitude increased towards north. Strong winds (12 m/s) were observed in the northern inshore (especially 19°N) region of the BoB (Fig. 3.9). SST showed relatively high values in the entire area (>29 °C) and the inshore offshore variability in SST was minimum (Fig.3.10a) SSS and surface sigma-t were also found to be high (>32 and >20) during this season (Figs. 3.10b). Shallow MLD (<30 m) was observed all over the area during this season (Fig.3.10c).

Thermocline layer depth ranged between 129 to 214m (av. 150m) and the minimum thermocline depth was recorded at the region of coastal station along15°N whereas the maximum was observed at the oceanic station along 17°N.

High concentration of dissolved oxygen formed a tongue like intrusion in 20-50m of coastal waters and 20-40m of oceanic waters from 11°N to 19°N. The range of Dissolved Oxygen was 133 to 216 at the surface layer. The minimum value of dissolved oxygen was recorded from the oceanic station of 17°N at 200m depth.

3.2.3.1. Chemical characteristics

High concentration of DO (>200 µM) was evident in the upper layers of both inshore and offshore waters (Figs. 3.11a and 3.12a). A relatively deeper nitracline (>50 m) was also a characteristic feature in the upper layers during this season. The vertical distribution of nitrate showed a deep nitracline along the BoB below 50m depth. The northern inshore waters were characterized by the up sloping of nitrate in the depth of 20m. The up sloping of isolines of inorganic phosphate from south to north were also recorded during this period. In the oceanic waters the concentration of phosphate was not detectable above 50m depths from south to north. Southern coastal waters were rich in inorganic silicate above 50m and showed a down sloping of isolines of 1µm toward south in the oceanic. But inorganic silicate was completely absent above 50m along the coastal stations except the northern transects (Fig .3.11 a,b,c and d).

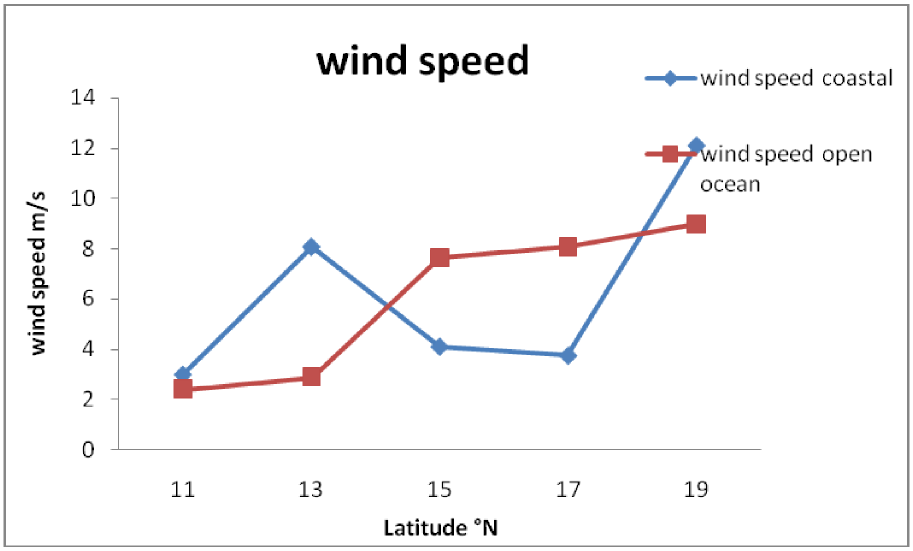
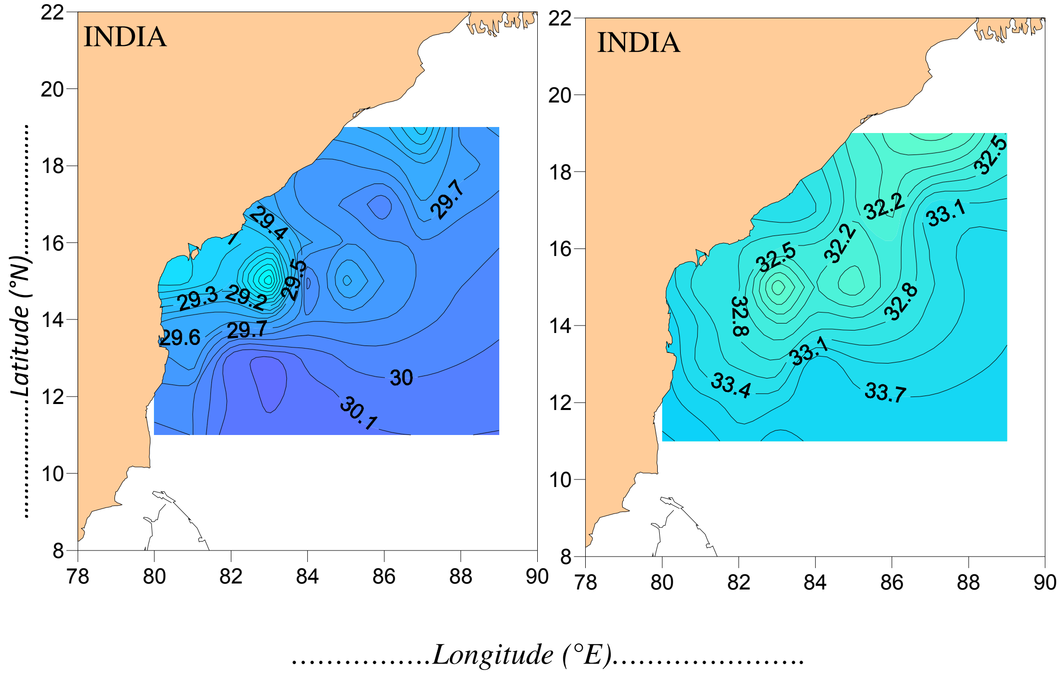


Fig. 3.9. Wind speed during spring inter monsoon in Bay of Bengal

(a) **(b)**



(c)

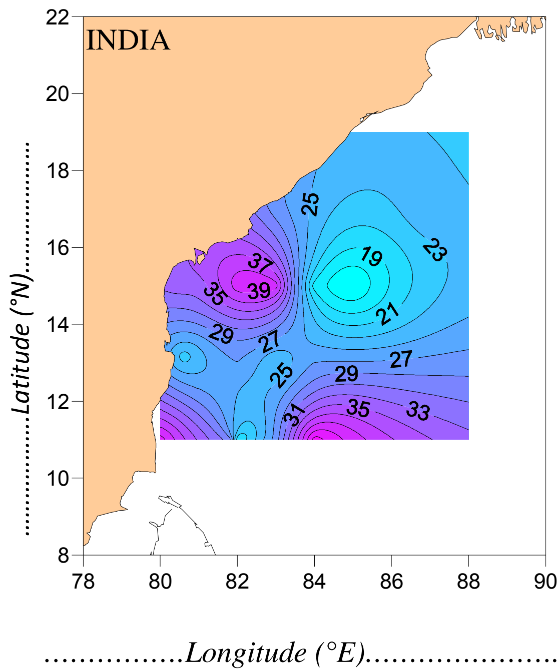


Fig. 3.10. Distribution of (a) SST (b) SSS and (c) MLD during spring inter monsoon in the Bay of Bengal

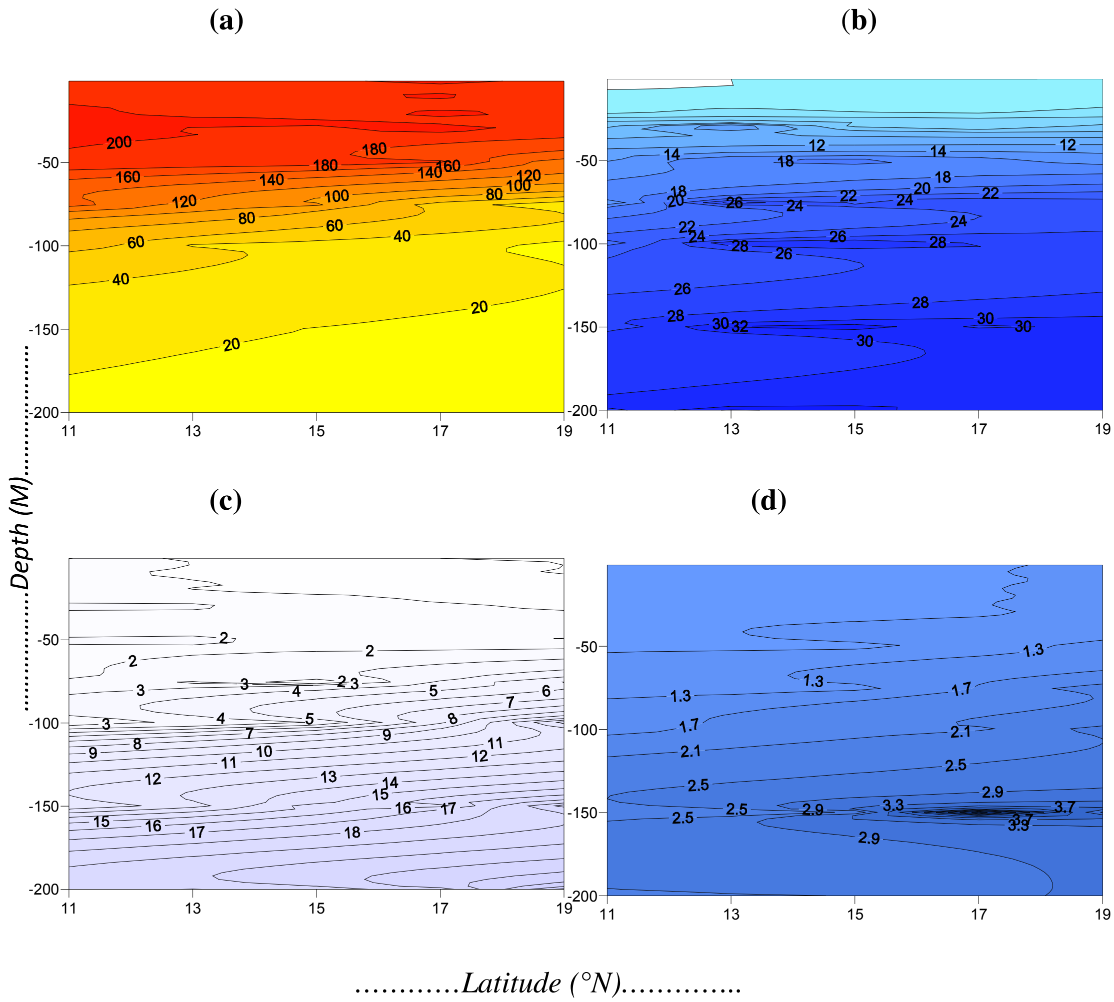


Fig. 3.11. Vertical distribution of (a) dissolved oxygen (μM L^{-1}) (b) nitrate (μM L^{-1}) (c) silicate (μM L^{-1}) and (d) phosphate (μM L^{-1}) along the coastal stations during spring inter monsoon

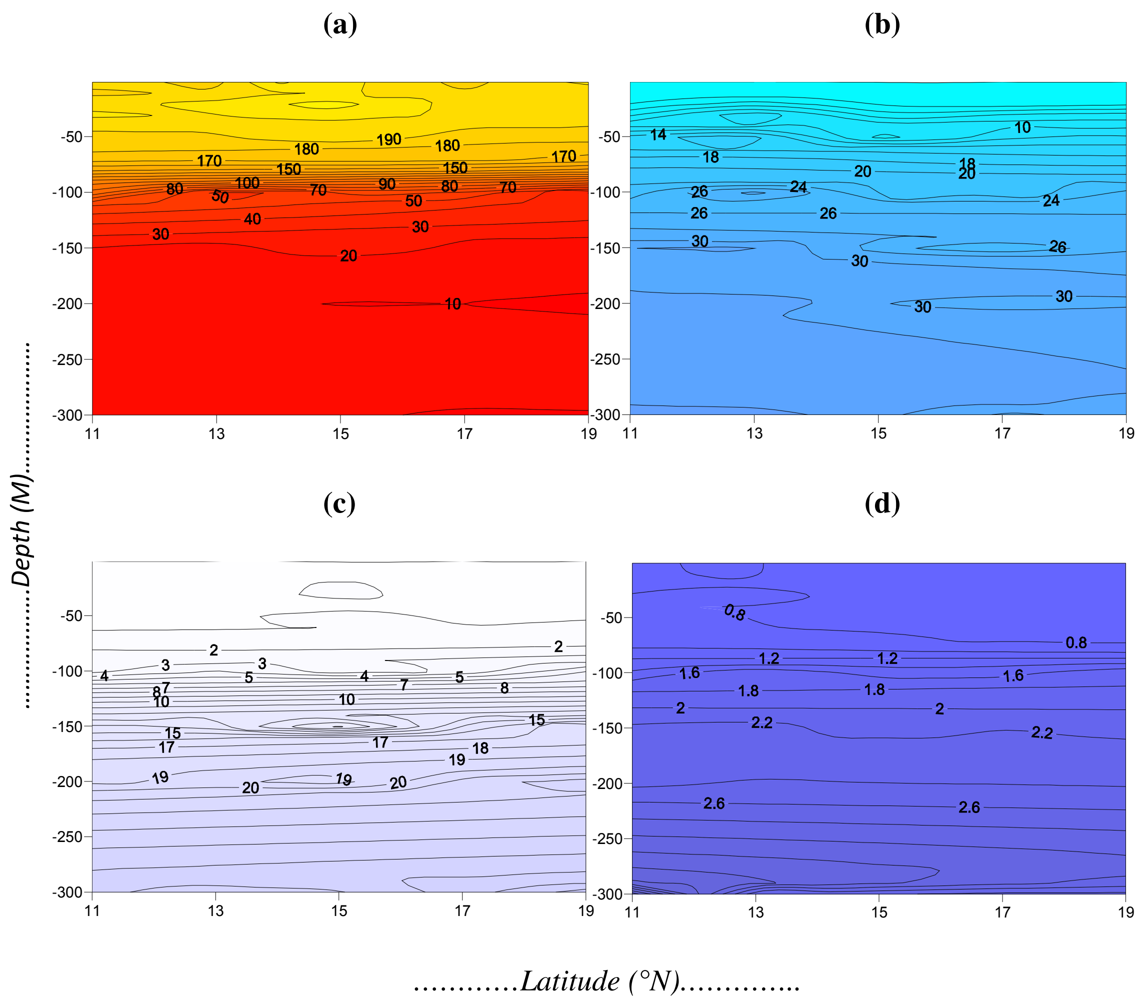


Fig. 3.12. Vertical distribution of (a) dissolved oxygen (µM L^{-1}) (b) nitrate (µM L^{-1}) (c) silicate (µM L^{-1}) and (d) phosphate (µM L^{-1}) along the oceanic stations during spring inter monsoon

3.2.4. Physico-chemical characteristics of the Andaman Sea during fall inter monsoon

During fall inter monsoon, along the 13°N, 10°N and 7°N stations in the western Andaman Sea, the surface temperature was 29.3°, 28.3 and 28.7°C (Fig. 3.13). The surface salinity was 31.9, 33.2 and 31.9, respectively. The mixed layer thickness was 40, 25 and 23 m at three stations. At the northern station (13 °N), a temperature inversion of 0.4°C was observed at a depth of 60 m. While in the eastern Andaman Sea, surface temperature was 28.2°C, 28.1°C and 20.6°C respectively. The corresponding surface salinity of these stations was 29.5, 32.9 and 32.8 respectively. The isopycnal of these stations showed the thickness of mixed layer of 18 m. The distribution of hydrochemical properties followed more or less similar trend along the western and eastern sides of the Andaman Sea (Fig.3.14). Both regions exhibited saturated mixed layer which was devoid of nutrients. There appeared a removal of nitrate from the water column below the thermocline depth in the western Andaman Sea, which was however, absent in the eastern side (Fig. 3.16).

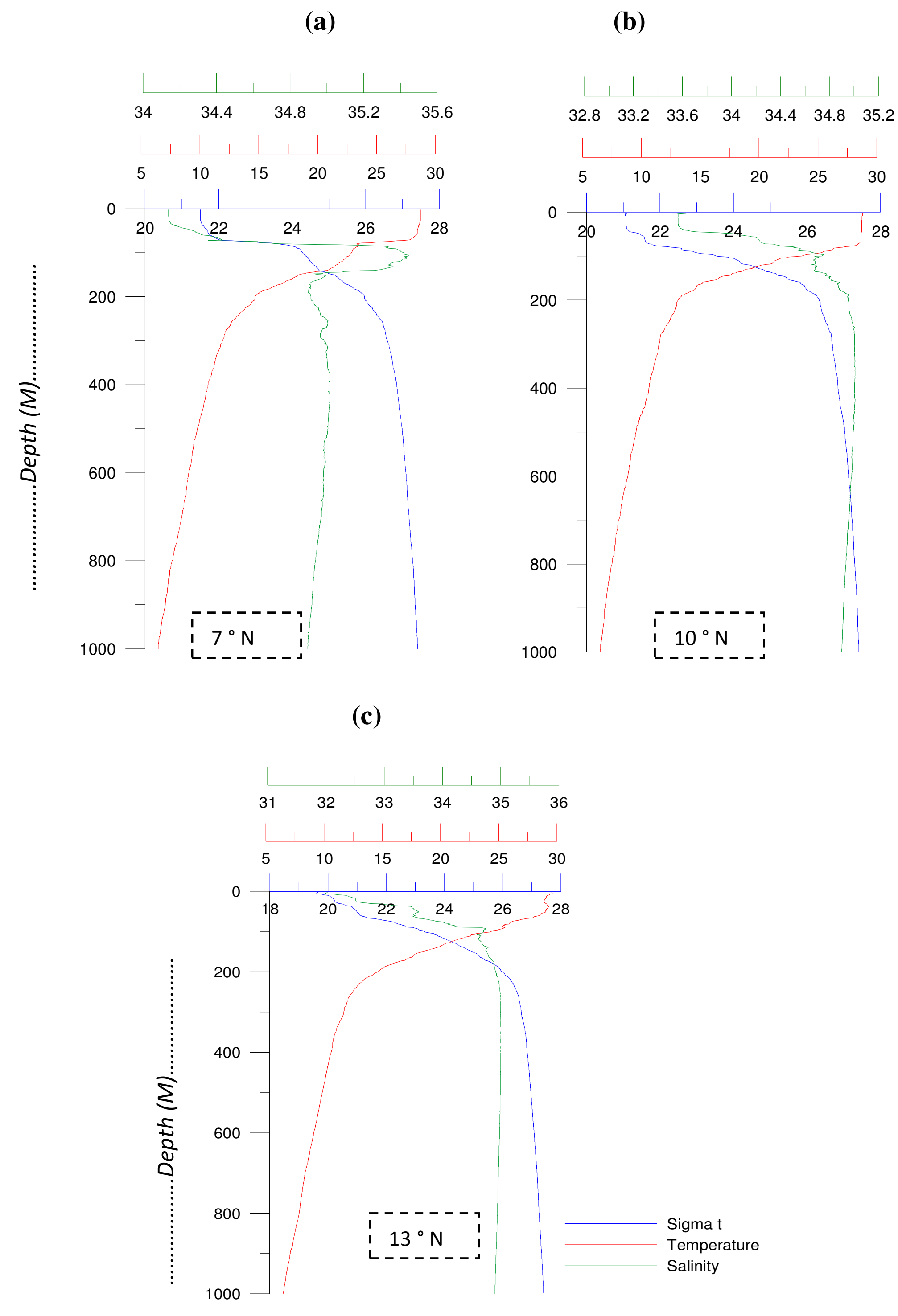


Fig. 3.13. Temperature, Salinity and Density profile in the (a) 7 ° (b)10°N and (c) 13°N of western Andaman Sea

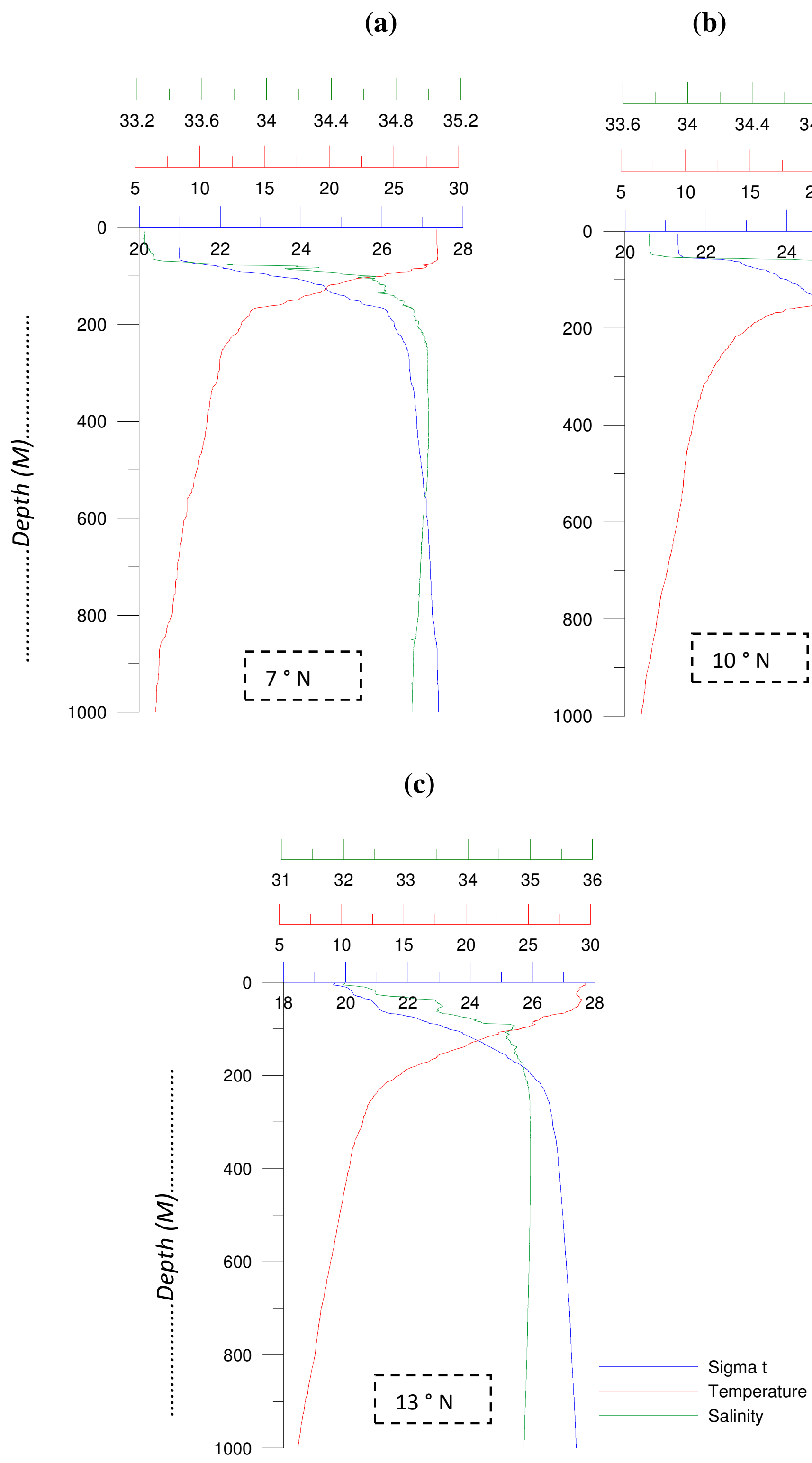


Fig. 3.14. Temperature, Salinity and Density profile in the (a) 7° (b)10°N and (c) 13°N of eastern Andaman Sea

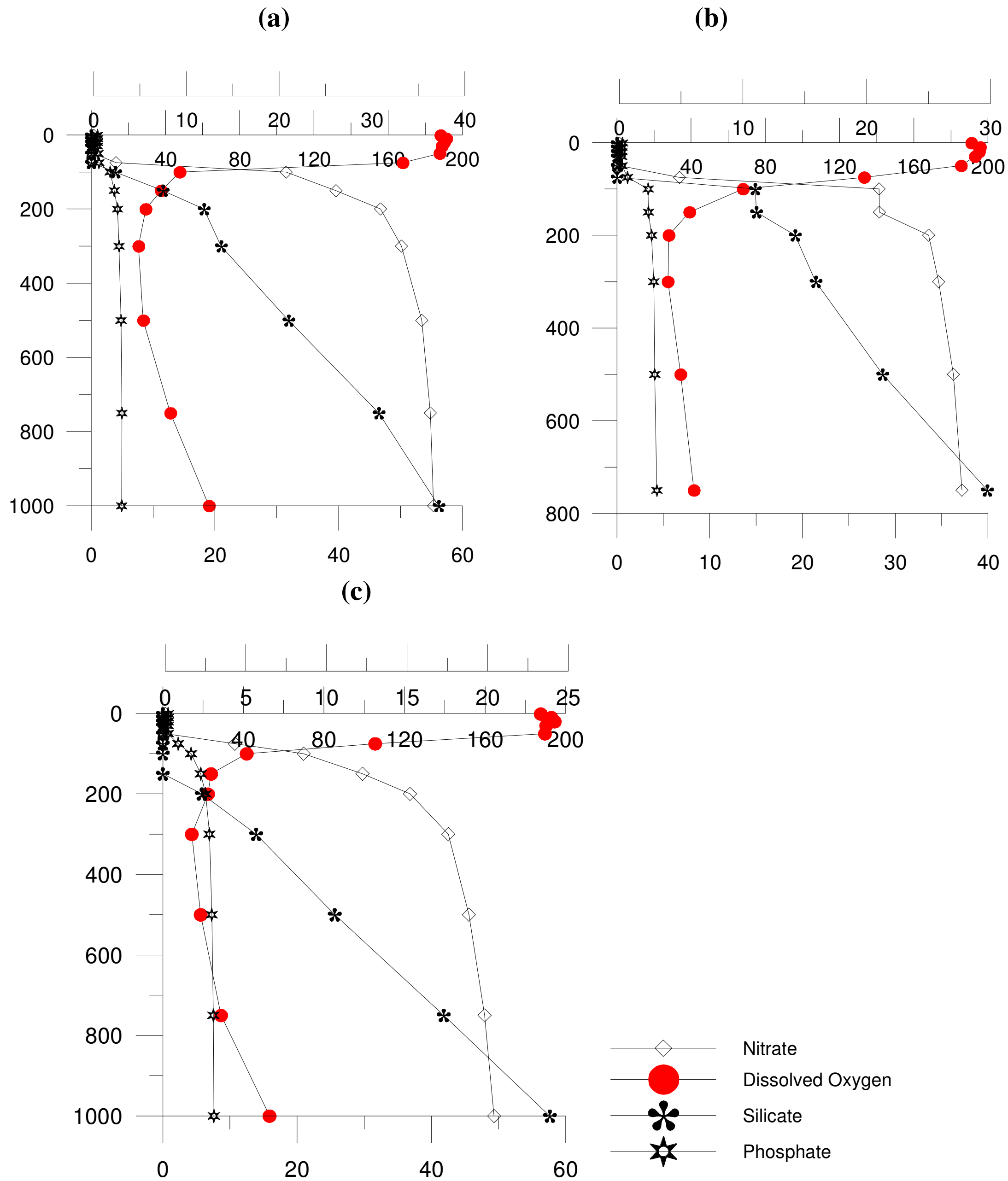


Fig. 3.15. Vertical distribution of nitrate, dissolved oxygen, phosphate and silicate at (a) 7 ° (b)10°N and (c) 13°N of western Andaman Sea

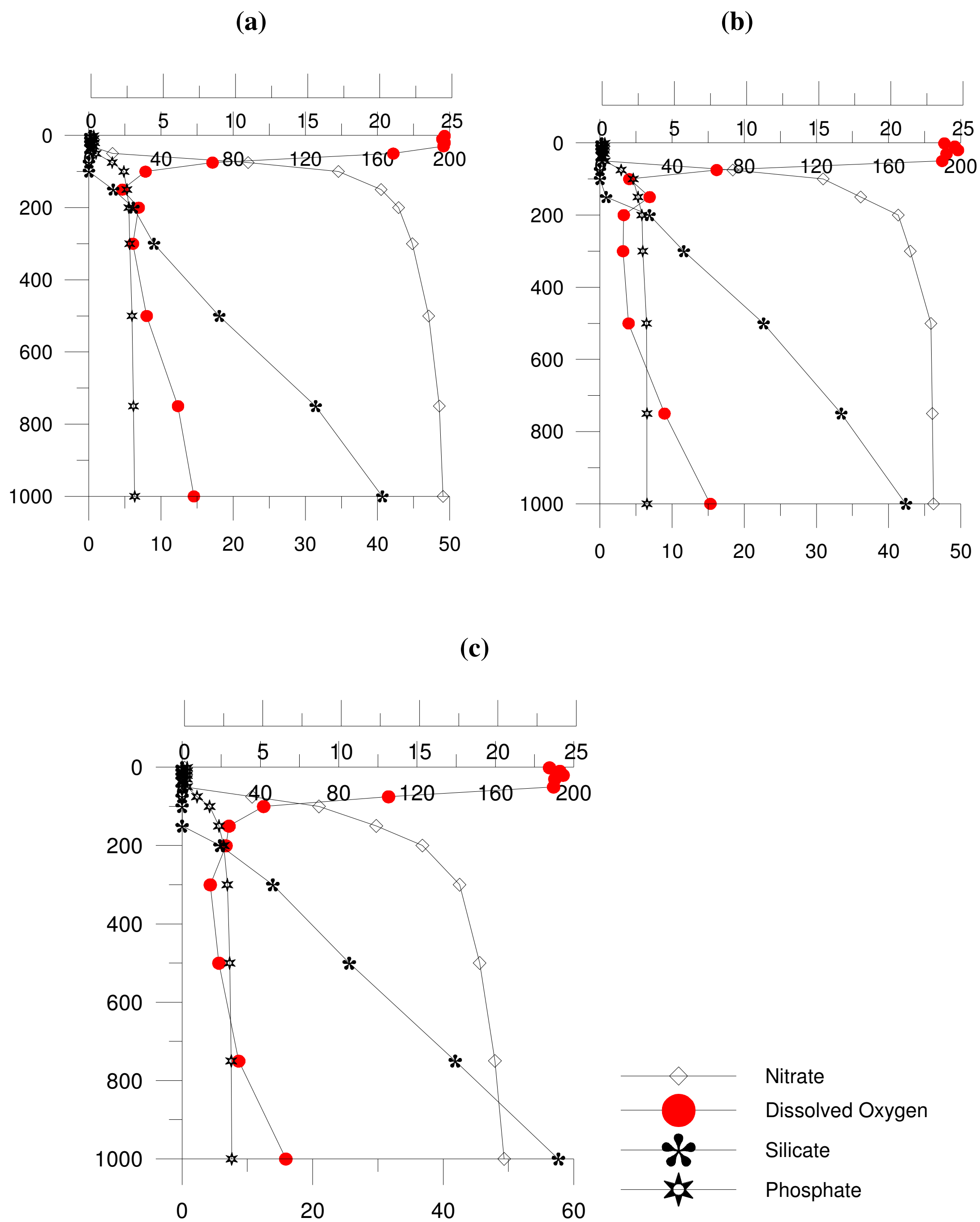


Fig. 3.16 Vertical distribution of nitrate, dissolved oxygen, phosphate and silicate at (a) 7 °, (b)10°N and (c) 13°N of eastern Andaman Sea

Hydrographical studies are important as the seasonal timing of phytoplankton and zooplankton production altered in response to recent climate changes. The Bay of Bengal hydrography was characterized by immense fresh water input, which was modified by the eddies and cyclonic gyres. In the Bay of Bengal when upwelling was very weak, cyclonic storms were found to enhance chlorophyll biomass and primary production (Madhu et al., 2002). Even during this period, the water column was sufficiently stabilized and the DCM waning towards the coast was a permanent feature, which probably influenced the pelagic ecology of this coastline.

The Average SST, density and Salinity of the BoB & the Andaman were found to be slightly different- (28.2 C, 22.41 C, 33, 20.74 and 33.02 psu for the Andaman sea) during the study period.

The temporal changes in avg SST,density and salinity showed that during SM values reached its maximum and got its lowest value during WM and get increased during Spring. The spatial changes showed that these values were high in oceanic than the coastal stations and more at northern side than the southern side of the BoB.

The BoB was believed to be biologically low productive region having a comparatively thinner and less intense Oxygen minimum zone with no evidence of denitrification. (Rao et.al.,1994; Sardessai et.al; 2007). The seasonal variability and distribution of dissolved Oxygen in the surface layer in the BoB appeared to be significantly influenced by physical processes like eddies and water circulation in the intermediate and deeper layers. Although large influx of fresh water adds biogenic matter to the Bay along with the mineral particles, the biological demand for Oxygen does not lead to anoxic or Oxygen depleted conditions prevailing in the Arabian Sea (Naqvi et.al., 2000).

Chapter IV

General Biological Environment

4.1. Introduction

Most of the available information on plankton dynamics and physical-biological linkages originates from studies in temperate waters while fewer studies have been carried out in tropical waters where hydrographical conditions are quite different (Prasannakumar *et al.*, 2000). Phytoplankton, which contribute 25% of the total vegetation of the planet are responsible for 95% of total marine primary production and 45% of total global primary production. They play a vital role in initiating the flow of energy in a usable form through oceanic ecosystems and are even reported to induce climatic changes (Madhu, 2004).

The incorporation of new organic matter in to the living tissue, from single celled autotrophic producer to multi-cellular key stone species of the food web is denoted as biological production. In a marine eco system, the process of biological production is controlled either by bottom-up or by top-down phenomena (Naqvi and Jayakumar, 2000; Madhupratap *et al.,* 2003). In bottom–up control mechanism, the supply of nutrients in the medium determines the production rate. It can be found in the food chains prevailed in eutrophic waters. At the same time the microbial community controls top-down control of biological production. It persists in oligotrophic water where microbial loops are connected strongly to the food chain.

Zooplankton, which include representatives of almost every taxon of the animal kingdom play an important role in studying the faunal biodiversity of aquatic ecosystems. They occur in the pelagic environment either as holoplankton or meroplankton. They are the indicators of energy transfer at secondary trophic level as they feed on phytoplankton and facilitate the conversion of plant material into animal tissue and in turn constitute the basic food for higher animals. Thus the occurrence and distribution of zooplankton directly influence pelagic fishery potentials. Fishes are found to breed mostly in areas where the planktonic organisms are plenty so that their young ones could get sufficient food for survival and growth (Bhargava, 1996). Zooplankton also act as indicators of pollution and, it is hopeful to note that certain planktonic organisms are reported to be capable of concentrating radio isotopes and can act as indicator of certain pollutants.

The qualitative and quantitative estimation of secondary production gains attention as it throws light upon the magnitude of primary production and at the same time provides information on tertiary production. They are the important grazers of phytoplankton and are also capable of diel-vertical migration and horizontal movement with the help of water currents. They inhabit all layers of oceans down to the greatest depth (Banse, 1964). They are capable of vertical transfer of carbon from surface waters to the deeper waters and even to the sediments on the bottom. The secondary producers are key components in the ocean bio-geo-chemical fluxes (Banse, 1995).

4.2. Results: Biological Environment of the BoB

4.2.1. Summer Monsoon

4.2.1.1. Primary Productivity

During summer monsoon, the BoB was found to be oligotrophic except the oceanic waters off 15° N. Surface primary productivity were in the range of 0.8 to 45.8 mgC $m^{-3}d^{-1}$. (Avg. 16.1 mgC $m^{-3}d^{-1}$). The surface and column primary productivity of coastal stations showed an increasing trend towards north except at coastal waters off 15°N (Table 4.1). In addition to the cold waters near the coast, shallow mixed layer and nitracline and the up sloping of isotherms, isohalines and isopycnals towards the coast showed the signature of upwelling near the coastal waters off 15°N. The enhanced surface and column primary productivity (surface - 1.4mg m^{-3} and column 42.8 mg m^{-2}) supports a biological evidence to this physical process. Maximum primary production was found at surface almost in all the stations.

4.2.1.2. Secondary production

Understanding secondary production or zooplankton distribution is essential because they play a pivotal role in the trophic link between primary production and predators. Studies on the zooplankton distribution in the BoB during and after IIOE are scarse and those available are mostly from the coastal area.(Achuthankutty et.al., 1980; Nair et.al., 1981; Rakesh et.al.,2006)

a) Mixed Layer Depth

Average mesozooplankton biomass obtained were 262 ml/1000m^3 [33 – (1500 ml/1000m^3). Maximum biomass obtained was at station off Paradweep ie., at position of 19°N Lat. Average biomass calculated for coastal station was 320.69/1000m^3. The same for oceanic station was higher namely 362ml/1000m^3 [Fig.4.1].

b) Thermocline Strata

The average biomass of coastal region was 63 ml/1000m^3 and did not show any murky difference from the average biomass of oceanic region namely 64.25 ml /1000m^3)

c) BT-300m Depth Strata

Biomass varied between 16-133 ml/1000m^3 with an average of 40ml/1000m^3. Maximum was obtained along 15°N latitude. Coastal (46ml/1000m^3) stations had a larger biomass than oceanic stations (30 ml/1000m^3).

d. 300-500m Depth Strata

A progressive decrease in biomass was observed with the increase in depth. Average biomass obtained were 18ml/1000m^3 and 10 – 30ml/1000m^3). The southern region (11°N) recorded maximum mesozooplankton biomass at this depth. Inshore – offshore variation is negligible (18.4 and 19 ml/1000m^3 respectively).

e. 1000-500m Depth

Least biomass was recorded at this depth. (average 7.1 ml/1000m^3). The mesozooplankton biomass varied from (4 to 16ml/1000m^3). Here too the southern bay recorded maximum biomass (at 13°N). The coastal average (8.33ml/1000m^3) exceeded the oceanic average (5ml/1000m^3).

4.2.1.2. Winter Monsoon

a) Primary Production

During winter, the surface waters of the BoB was found to be more productive than other seasons especially at Latitude 11°N and 15°N. Surface primary productivity were in the range of 0.7 to 28.9 mgC m^{-3}d^{-1} (Average 8.6 -10.6 mgCm^{3}d^1). The maximum value for the surface primary productivity (28.9 mgCm^{-3}d^1) were recorded along the oceanic waters off 11°N. Primary productivity maxima were found to be between 0 and 20m depth at all the stations. The maximum surface phytoplankton abundance was noticed from the oceanic station off 11°N and 15°N.

b) Secondary Production

a. Mixed Layer Depth

Average meso-zooplankton biomass obtained was 177.52 ml/1000m^3. Maximum Biomass obtained were at the oceanic station of 15°N(309ml/1000m^3). Biomass increases with increasing longitude except at the head of Bay, where at the mixed layer depth the coastal station recorded maximum biomass for zooplankton. The average biomass for coastal stations was 121.17 ml/1000m^3 whereas that for oceanic stations showed a two fold increase in the average biomass value (222.6 ml/1000m^3).

b. Thermocline Strata

Average biomass obtained was 99.65ml/1000m^3 only (48% of mixed layer density). The biomass varied from 28-258 ml/1000m$^{3.}$ From South to north the average biomass of zooplankton increasesd both at coastal and oceanic regions except at 15°N, where a tremendous zooplankton concentration was observed in the coastal region and at 17°N in the oceanic region . Coastal (average 82.84 ml/1000m^3) and oceanic (average 113.1 ml/1000m^3) difference is considerable at this thermocline layer.

c. BT-300m Depth Strata

Mesozooplankton biomass varied from 17.5 to 117.6 ml/1000m^3 with an average of 36.98ml/1000m^3. Maximum was obtained at the oceanic station of 17°N latitude. Coastal (23ml/1000m^3) stations had a lesser biomass than oceanic stations (40.27 ml/1000m^3).

d. 300-500m Depth Strata

Average biomass obtained was 16ml/1000m^3 (10 to 30ml/1000m^3). The northern region (19°N) recorded maximum mesozooplankton biomass at this depth. Inshore – offshore variation confirms the fact that during winter monsoon, the productivity observed was higher at oceanic stations than the coastal station at all depth strata (10 and 17.5/1000m^3 respectively).

e. 1000-500m Depth

Average mosozooplankton biomass continuously decreased with each depth strata . An increase in average biomass was observed in this strata (average 32.6ml/1000m^3). The mesozooplankton biomass varied from 4 to 123 ml/1000m^3.

Maximum biomass obtained were at the oceanic station of the head of the bay. The coastal average (16 ml/1000m^3) recorded were more than half of that of the oceanic (36.75ml/1000m^3).

4.2.1.3. Spring Inter Monsoon

4.2.1.3.1. Primary Productivity

During spring inter monsoon, the average primary production was comparatively higher than winter monsoon. The surface primary production of oceanic stations were in the range of 0.9 to 15.1mgC m^{-3} d^{-1} (4.6±5.4 mgC m^{-3}d^{-1}). The maximum surface and column primary productivity of 15.1 mgC m^{-2}d^{-1} and 424 mgC m^{-3}d^{-1} were recorded off 13°N at depth above 20m.

4.2.1.3.2. Secondary Production

During inter monsoon spring, the bay appeared less productive than summer monsoon.

a. Mixed Layer Depth

The biomass recorded was only 50% of that appeared during Summer Monsoon, ie, only 123 ml/1000m^3(34 to 444ml/1000m^3), (Highest biomass was recorded) . The coastal station sustained high biomass (148ml/1000m^3) compared to oceanic (61ml/1000m^3) .

b. Thermocline Layer depth

Thermocline layer exhibited an average of 42 ml/1000m^3 mesozooplankton biomass (13 to 150 ml/1000m^3) of which the highest value was noticed off Chennai region. The coastal and oceanic average of mesozooplankton biomass were 57 and 25 ml/1000m^3 respectively.

c. BT-300m Depth Strata

The average mesozooplankton biomass recorded was 23 ml/1000m^3 (4 to 65 ml/1000m^3). The highest mesozooplankton biomass was recorded off Vishakapattanam along 17°N . The average mesozooplankton biomass recorded at coastal and oceanic stations 24 and 15 ml/1000m^3 respectively.

d. 300-500m Depth Strata

Average mesozooplankton biomass observed was 17.37 ml/1000m^3) (with the range of 6 to 40 ml/1000m^3). Coastal (17.2 ml / 1000m^3) – Oceanic(22 ml/1000m^3) average mesozooplankton biomass reflects considerable variation.

e. 500-1000m Depth Strata

In this season the average mesozooplankton biomass recorded was higher than Summer Monsoon. *ie* ; 9.2 ml/1000m^3 (3 to 48 ml/1000m^3). The average biomass in the coastal stations was 7.92 ml /1000m^3 and that of the oceanic stations was 16.14 ml/1000m^3.

4.3. Tertiary Production

Nearly 5 decades ago Panikkar and Jayaraman, (1956 and 1966) pointed out the differences in biological productivity and fish landings in waters of east and west coast of Indian peninsula, and attributed the differences to distinct hydrological processes. The assemblage wise landings from the BoB during the years 2000 and 2001 coincides with the secondary productivity data. The source of data of marine fish landings in India by Central Marine Fisheries Research Institute (Srinath , et al; 2006). The total fish landings and pelagic fish landings along east coast of India are presented in the table 4.2 . The head of Bay is more productive than Orissa Coast (Table 4.2). The southern pocket of the BoB at 13°N Lat. ie., the Chennai region accounts for highest productivity and ultimately for highest fish landings from that region. The annual production from the BoB during these successive years denotes an average growth rate of 18%. Only the Orissa coast faced a decrease of 5% fish landings. Other coasts gained 7 to 38% of extra fish landings.

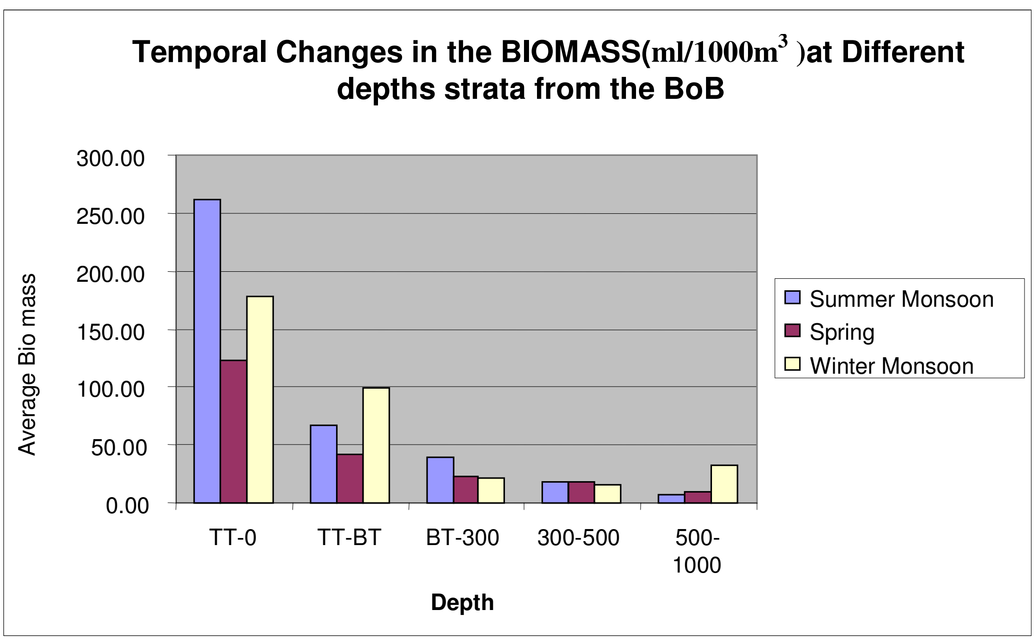


Fig. 4.1 – Temporal changes in the Biomass of zooplankton(ml/1000m$^{3)}$ at different depths strata at the BoB

Table 4.1. Seasonal and spatial variations in primary productivity of the BoB

Surface primary productivity of the BoB during different Seasons						
	SM		**WM**		**Spring**	
	SPP (mgCm^{3}d^1)	**Column** (mgCm^{2}d^1)	**SPP** (mgCm^{3}d^1)	**Column** (mgCm^{2}d^1)	**SPP** (mgCm^{3}d^1)	**Column** (mgCm^{2}d^1)
11^0 –Coastal	0.8	109	28.9	566	0.9	149
11^0 –Oceanic	7.3	293	7.9	326	8.8	358
13^0 –Coastal	1.1	126	0.7	26	15.1	424
13^0 –Oceanic	1	186	5.8	285	4.6	158
15^0 –Coastal	45.8	470	10.5	433	3.6	348
15^0 –Oceanic	9.4	116	3.2	423	12.3	275
17^0 –Coastal	-	-	3.1	144	1.2	371
17^0 –Oceanic	2.8	60	4.3	236	5.4	241
19^0 - Oceanic	14.2	427	2.2	253	4.7	385

Table 4.2 – Assemblage wise fish landings in the BoB during the years 2000 and 2001

	2001					2002				
	Pelagic fishes	**Demersal fishes**	**Crustaceans**	**Molluscs**	**Total**	**Pelagic fishes**	**Demersal fishes**	**Crustaceans**	**Molluscs**	**Total**
19°N	49148	25162	22391	809	97510	84416	44698	28719	701	158534
17°N	35449	29333	6809	276	71867	36143	24418	7699	169	68429
15°N	88386	41891	21289	1191	152757	99371	38165	25072	2303	164911
13°N	196650	113077	32808	8174	3507 09	220207	123341	40038	15080	398666
11°N	7919	1846	485	1763	12013	11468	4769	1000	2222	19459
Landing in tonnes										

Source: Marine Fish Landings in India,1985-2004. Estimates and Trends. *CMFRI Spl.Publ.*, No.89:161 pp

Chapter V

Copepods in the Bay of Bengal

5.1. Introduction

Copepods, though small in size, are the most abundant of all crustaceans, forming the bulk of the zooplankton of the sea (Gopalakrishnan, 1984). They are among the most important secondary producers in coastal and marine ecosystems, representing an important link between phytoplankton, zooplankton and higher trophic levels such as fish. However, when evaluating data on copepod abundance & distribution, it becomes apparent that information on oceanic species is scarce. Moreover, in many studies the data on abundance did not seem to reflect adequately the whole community of copepods as the mesh size employed was not appropriate for the wide size range of copepods to be collected (Halliday *et al.,* 2001). Moreover studies on the copepods of the east coast of India are few too (Steele, 1977), Madhupratap (1983), Saraswathy (1973a, b, 1986), Stephen (1984, 1972, 1992). Fernandes et.al,(2009). In this situation, this research would contribute to our knowledge of the copepod bio-composition, their vertical, horizontal and temporal distribution, their reaction towards cyclone, and responses towards various environmental factors of EEZ of East coast of India.

The copepods collected during the John Murray expedition and the records of Indian museum (Sewell, 1912) gives early accounts of the BoB. A number of papers with many new species were described from the Madras coast

(Krishnaswamy, 1953). Copepods above thermocline and below thermocline from the northern BoB were given by Stephen (1984). A comparison of coastal copepods from the Arabian Sea and the BoB was also dealt in Stephen 1992. The copepods collected during the IIOE throws light on the copepod fauna of the epipelagic waters. Saraswathy (1973) had shown that Pluromamma indica dominates in the BoB. Stephen et.al (1992) gave an overall picture of copepod taxa subsorted from the IIOE. The distribution of family Calanidae in Arabian Sea and the BoB is shown by Stephen (1992). Like MR-LR, there is another programme named BOBPS (Bay of Bengal Process Studies), aimed at understanding the biogeochemical processes with a view to investigate the carbon flux potential in this oligotrophic and uniquely located basin. An important role of this investigation was to understand the zooplankton dynamics. Especially copepods in the open ocean and the near coastal waters of this sparsely studied area (Madhupratap et.al., 2003., Ganus et.al., 2005., Fernandes et.al; 2009)

5.2. RESULTS

5.2.1. Bio-composition of Copepod at the Bay of Bengal

The classification of copepods at all taxonomic levels has been more hypothetical and pragmatic than natural and subject to modifications.

The copepod species analyzed from the water samples of the BoB during 3 seasons and from 5 stratified depths consists of 5 orders only, viz., Calnoida, Harpacticoida, Cyclopida, Mormonilloida and Poecilostomatoida. Order Mormonilloida have only 2 identified species, both obtained from the mesopelagic waters of the BoB.

Family Oithonidae was the only identified family that belonged to the Order Cyclopoida from the BoB during present study, which comprised a single genus Oithina under which 3 species were able to identify, viz., *Oithona plumifera, O. similes and O. spinirostris*. Family Oncaeidae, Corycaeidae and Sapphrinidae were the 3 families which came under the Order Poecilostomatoida. In family Oncaeidae only *Oncaea venusta* was identified, family Corycacidae was represented by 5 species and family Sapphrinidae by 6 species.

Out of 318 species recorded, 23 species were new to the study area. The species recorded as first report from the study area were *Eucalanus bungii, Eucalanus inermis, Drepanopsis orbus, Xanthocalanus amabilis, Bradyidius angustus, Gaidius minutus, Gaidius brevispinus, Euchirella areata, Chirudinella Cara, Uneucheata bispinosa, Pareucheata simplex, Scottocalanus australis, S.terranovae, Scaphocalanus impar, Scolecithricella modia, S. arcuata, S. lophophora, S. lamellifer, Xanthocalanus cornifer, Metridia pacifica, Heterorhabdus pacificus, H. setuligear* and *Euaugaptilus squamatus.*

Rare species of copepods obtained during the study include, *Onchocalanus affinis, Cephalophanes frigidus, Euchirella venusta, E.maxima, Pareucheata scotti, Scottocalanus investigatoris, Scolecithricella propinqua, Metridia pacifica, Lucicutia macrocera, L. lucida, Heterorhabdus pacificus, Mesorhabdus angustus, M. brevicauda, Dissetta palumbii, D.scopularis, Euaugaptilus facilis, Nullosetigera helgae* and *Aritellus giesbrechti.*

The endemic species obtained during the course of study include, *Centropages tenuiremis, Acartia minor, A. sewelli, Scottocalanus daughlishi, Pontellopsis scotti* and *Pontella investigatoris.* A systematic list of copepod obtained during study period from the BoB including the AndamanSea is given in Table 5.1. Images of frequently occurring copepods such as Nannocalanus Minor, Eucalanus etc. coming under the order Calanoida are given in plates 1 to 9.

5.2.2. Density of Copepod

The total copepod analysed from the mixed layer depth of the BoB include 1,35,76,836 per 1000m^3. This includes a volume of 27,81,140 copepods from the SM`09 and 9,95,060 copepods from the WM`09. Inter monsoon Fall of 2001(SIM`01) recorded a value of 27,34,303 copepods /1000m$^3$. During 2002, SM recorded a value of 29,58,875 copepods and WM contributed 41,07,458 copepods per1000m$^3$. The copepods identified from the thermocline layer include a total of 44,02,788 per 1000 m$^3$ from the SIM`01, SM`02 and WM`02. The copepods analysed from the BT-300m depth strata includes a volume of 3,99,607 copepods where as from 300-500m depth strata includes a volume of

2,02,040 copepods. Copepods analysed from the lowermost strata includes 1,04,360 copepods per 1000m^3 of water column of the BoB. The density of copepods at different depth strata of the BoB and the AndamanSea is given in Table 5.2. It shows that the density gradually decreases towards depth.

5.2.2.1. Percentage composition of copepods

A total of number of 2,55,566 copepods were identified from the waters of the BoB of which a total of 277 species were identified, which comprises 35 families and 89 genera (Stephen.R & Rashiba.A.P., 2010). Of which, 262 species had their percentage composition less than 1%.

Only 12 species constitute nearly 75% of the copepods of the BoB. *Acrocalanus* and *Oncea venusta* dominated out of 98,647 copepods analyzed from the mixed layer (Table 5.3). The thermocline layer was dominated by *Corycaeus* sps., *Oncea venusta* and species belonging to *Acrocalanus spp*., *Corycaeus* spp. and *Paracalanus* spp. dominated the BT-300 layer where as the 300-500m layer was dominated by *Corycaeus* sp. and *Pleuromamma indica*. The percentage composition of *Pleuromamma abdominalis* was maximum at BT-300m layer. At 300-500m layer, the *Pleuromamma indica* together with *P. abdominalis* formed the bulk of copepod population. Presence of *Subeucalanus pileatus* was merely 4% at this layer. The influence of all other species upon the copepod population percentage increased towards the depth. But at the thermocline layer it reduced to 17%. At 500-1000m depth, they formed 52% of copepod population. About 10% of copepod collected from the Bay of Bengal was immature forms or their body parts were broken so that their identification was not possible. Vertical distribution of the abundance of most important species of copepods (based on their percentage of occurrance at the BoB) was done in Fig.5.1. The figures reveal the importance of thermocline layer of the BoB to the Copepod abundance and diversity. The copepods, whose presene in hundreds per ml or more are selected to plot the figures to compare their abundance in vertical section of the water column.

5.2.3. Geographical distribution of Copepods

Copepods are not randomly distributed in the sea, but their distribution is affected by the structure of the water masses on large and small scales (Cassie, 1963; Steele 1977). Spatial heterogeneity with in a copepod population evolves from 2 sources - first is the physical and chemical properties of the sea or the environment in which the copepods live and second is the physiological and behavioural properties of the copepods themselves. Anyway spatial distribution encompasses the reaction of the copepods to their biological environment including responses to patches of potential food organisms and predators.

5.2.3.1. Spatial distribution of Copepods

A total of 136 copepod species were recorded from the mixed layer (Table 5.4) depth of the BoB during all the seasons selected. In which 28 species were found to be ubiquitous, 58 species were common but were not observed from all stations. Maximum species diversity and the highest number of species were obtained from 13ºN Latitude. A total of 16 species out of 136 copepods obtained from mixed layer were confined to 13ºN Latitude. The important species enlisted from that area include *Pseudoamallothrix indica*, *Augaptilus glacialis*, *Chirundinella magna*, *Chirundina streetsi*, *Eucalanus hyalinus*, *Lucicutia challengeri*, etc. 15ºN Lat. stands at second position on the diversity of copepods considered `rare` species. A total of 14 species obtained from that area were not captured from any other area of the BoB. They include *Monacilla typica*, *Pontellopsis spiniceps* & *Isias tropica.*

The diversity of species found to decrease towards northern region. From the species obtained from 17ºN Lat., only two were distinguished as confined to that area. They were *Pontellopsis scotti* and *Euchirella rostrada*.

Out of 154 species obtained from the thermocline layer (Table 5.5) 39 were identified as ubiquitous, where as 61 obtained from more than one station failed to confirm their presence at all the stations of thermocline layer. Here also a northward decrease obtained for the number of species which were treated as restricted to that area. From the head of Bay only 2 species were obtained and not reported from any other part of Bay. *Candacia bipinnata* and *Candacia truncata* were those 2 species reported from thermocline layer of head of Bay. *Eucalanaus sewelli* and *Chirundina indica* and *Gadius minutes* were identified only from the samples of 17ºN Lat. Important species obtained from the thermolcine layer of Southern the BoB included *Aetideus armatus*, *Euchirella curticauda*, *Hemirhabdus grimaldi, Mesorhabdus brevicaudatus*, *Sappharina auronitens, Scottoclanaus australis,* etc.

From the BT-300m depth strata, (Table 5.6) a total of 103 species were procured from Bay of which 15 species were present in every station of the BoB at this depth strata, considering all the 3 seasons. The central Bay (at 15ºN Lat.) had the maximum number of restricted copepod species (15 species) and the 13ºN and 17ºN Lat. had the least (only 3 species each). *Aegisthus mucronatus*, *Paracandacia simplex* and *Clytemnestra scutellata* were captured from head of Bay, where as *Eucalanus inermis* and *Heterorhabdus spiniforns* from the 17ºN Lat. *Metridia okotenis* and *M. princeps* were obtained from 15ºN Lat. where as *Paraeuchaeta simplex* from the southern BoB.

At the 300-500m depth strata (Table 5.7) 140 species of copepods were identified of which 50% reported from more than one station. 15 species were widely distributed in nature where as 12 species were identified from the southern BoB only. The common copepod species of these depth strata included *Subcucalanus crassus, S. subcrassus, S. pileatus, S. mucronatus, Pleuromamma indica* and *P. abdominalis, Lucicutia challengeri* and *L. flavicornis* .

The southern BoB was particular with copepod like *Centraugaptilus rattrayi, Chirundina streetsi* and *Parcucheata scotti* whereas the central Bay had *Eucalanus longiceps, Lophothrix humilifrons* and *Metridia princeps*. From the northern Bay, *Chiridius gracilis, Drepanopsis orbus* and various species of *Luciutia* were identified as confined to that area.

Out of 156 copepod species encountered from the 500-1000m depth strata, 87 were identified from more than one station at different latitudes of the BoB (Table 5.8). But species like *Xanthocalanus irritans, Chiridius gracilis, Nullosetigera impar, Spinocalanus spinosus, Gaidius tenuispinus, etc* were recorded from 13ºN Lat. *Eugaptilus bullifer*, *Euchirella bella* & *Nullosetigera bidentatus* were found to be restricted to 500-1000m depth, 15ºN Lat. strata and

Eucalanus sewelli to 17ºN Lat. The head of the bay had following particular species such as *Euaugaptilus nudus, E. squamatus*, *Scaphocalanus elongatus*, *Scolecithricella tropica* and *Scottocalanaus australis*.

5.2.3.2. Vertical distribution of copepods at the BoB

Out of 266 species of copepod encountered from all the depth and stations of the BoB, only 46 species were ubiquitous. 148 species were found to be occurring in more than one station and more than one depth strata. About 15 species were found to be confined to mixed layer depth. They include *Acartia danae*, *Calanopia auirvilli* and *C. minor, Pontellopsis regalis*, P. *securifer, P. scotti, Pseudodiaptomus aurivilli etc*. *Chirundina streetsi* and *Xanthocalanus cornifer* were recorded only from the surface layer of the BoB (Table 5.9).

From the copepod species noticed from the thermocline layer, 13 were found to be confined to this layer. They included 4 species of *Eucheata* such as E. f*lava, E. indica, E. media* and *E. minuta*.

From the Harpaticoids only *Clytemnestra scutellata* was found to be confined to BT-300m layer. The 300-500m layer had 13 species and 500-1000m layer had 30 species of copepods having confined distribution. Euaugaptilidae and Scolicithricidae were the dominant members of these two deeper layers.

5.2.3.3. Temporal variation of copepods at the BoB

Seasonal wise changes in the distribution of copepods were analysed. Distribution of different orders of copepods at different depth strata revealed the dominance of Order Calanoida at every depth (Fig. 5.2) of the BoB. SM accounts for the maximum Calanoid percentage composition at every depth strata except 500-1000m at which the winter monsoon observed for maximum calanoid percentage. Temporal variation of numerical abundance of different species of copepods at the mixed layer depth strata is given in Table 5.10 and that of thermocline layer is Table 5.11. A total of 55223 copepods were obtained during SIM, where as 27392 copepods were identified to different species and immature during SM and 41546 copepods were analysed during WM. Temporal variation of numerical abundance of copepods at BT-300m depth strata of the BoB is given in Table 5.12 and that for 300-500 depth strata is given in Tab.5.13 and that for 500-1000 in Tab.5.14.

5.2.3.4. Diel Vertical Migration among copepods at the BoB

To study the Diel vertical migration of Copepod, two set of tables were prepared. First set (Tab.5.15a-15e) indicated the migration shown by the different orders of sub class copepoda where as the second set (Tab.5.16.) indicated the migration shown by different families of order calanoida at the BoB. The 24 hour time duration was split in to 8 set of time intervals or time zones. The abundance of each order of family at each depth strata was noted to detect whether they follow any specificity of depth at a particular time period. The distribution of copepod during night and day at five depth strata were given in figures 5.3 and 5.4 respectively.

During night at 19-22 time intervals, numerical abundance of Order Calanoida was recorded in its maximum at the mixed layer. In all other time zones, they concentrated more at thermocline layer.

Order Cyclopoida dominated the surface layer during night. During day time, they preferred the thermocline layer.

Order Harpacticoida was found maximum at the surface layer during 02-06 hrs and 06-09 hrs only. All other time, they aggregated at thermocline layer. Numerical abundance of the Order Mormonilloida was more at thermocline layer during 02-06 hrs. They were almost equally distributed at all depth during different time zones.

Order Poecilistomatoida was mostly recorded at two upper layers. During dusk, they found abundant at deeper layer. Family Acartiidae was found maximum at the surface layer during night at 02-06 hrs and during day time at 14-17 hrs. During dawn and dusk they concentrated on the surface layer. After dusk and midnight, they were observed only at thermocline layer. None of the members of this family was obtained from the deeper depth strata of the BoB.

Family Aetididae were reported from every depth strata. It was interesting to observe their accumulation at thermocline layer. They were found in excess at the surface layer during night after dusk. At midnight they concentrated in the thermocline layer.

Family Aritellidae were reported only 4 time zones at 2 depth strata only. So their vertical migration could not be assessed from this data. They were obtained mostly from the deeper layer during all the time zones. Family Augaptilidae also concentrated at the thermocline layer. During midnight, they concentrated at surface layer. During day time they were observed at the deeper strata of water column.

Family Candacidae was absent in the deeper layers at every time interval except the presence of 2 members at 300-500m depth during dawn. Their concentration at the thermocline layer was remarkable. Family Centropagidae was found mostly concentrated in the first two depth strata, mostly on surface layer. Maximum number of centropagidae were obtained from the surface layer during night and recorded little during day time. Family Clausocalanidae was collected from the BoB at 3 time intervals, viz., during midnight, dawn and during dusk. They preferred the thermocline layer.

The diel vertical migration of the family Eucalanidae from the BoB was interesting. During dusk, they concentrated on the thermocline layer. After dusk their concentration reached maximum at surface layer. At midnight they 'sinked' to thermocline layer. At the time of dawn, they were obtained from all the depths of strata but maximum concentration was at thermocline layer. During noon and after noon hours, the numerical abundance of Eucalanidae at the deeper layer reached its maximum.

Concentration of the family Euchaetidae in the thermocline layer was remarkable. Their numerical abundance at the deeper layer reached its maximum only during day time. Thermocline layer supported maximum members of the family Calanidae during most of the time zone. After dawn, they had their appearance at deeper strata.

Numerical abundance of the family Heterorhabdidae was maximum at the thermocline layer. During dusk, they were captured maximum from the thermocline layer and after dusk, maximum from surface layer. During dusk, the family Mecynoceridae obtained from the surface layer only. After dusk, numerical abundance of Mecynoceridae was more at deeper strata. During dawn, they were reported mostly from the surface layer.

The family Metridiidae was concentrated mostly at the thermocline layer. During day time, they were absent in the surface layer. Their concentration at the surface layer reached its highest vale at 19-22 hrs time intervals. The family Paracalanidae was not recorded from the deeper layer. Most of the time during day, they were concentrated on thermocline layer.

Maximum numerical abundance of the family Phaennidae recorded from the thermocline layer at noon. Mixed surface layer of the BoB recorded the maximum numerical abundance of the family Pontellidae. Only during noon the abundance at thermocline layer out numbered the abundance at surface layer.

The diel vertical migration of the family Pseudocalanidae could not be assessed from the present study. They were mostly reported from the deeper strata. Numerical abundance of the family Scolecithricidae was more at thermocline layer. During day time they avoided the surface layer. The mixed surface layer accounted for the maximum abundance of Temoridae. They were never recorded from the deeper layers. Diel vertical migration of the family Tortanidae could not be studied from the present data. They were reported from the deeper layers of the BoB during dawn.

5.2.3.5. Comparison of mixed layer of two summer seasons

A total of 118 species were recorded from the surface layer of the BoB during summer season. 54 species of copepods were found common. 40 species of copepods obtained from the sample were unique to the summer monsoon of 1999 where as only 24 species were particular to the summer monsoon seasons of 2002 (Table 5.17). It was evident from the result that fine filter feeders and heribivorous copepods such as *Paracalanus, Acrocalanus, Clausocalanus and Undinulavulgaris and U. darwini* were getting depleted in the water column of the Bay.

5.2.3.6 Comparison of mixed layer of 2 winter seasons

Out of 135 species encountered from the surface layer of the BoB during winter seasons of 99 and 2002, only 52 were common. 56 species of copepods, obtained from winter season of 1999 were unique to that period where as only 27 species obtained from winter season of 2002 were not obtained from the 99 data (Table 5.18).

5.2.3.7. Temporal variations of copepods at east coast of EEZ of India

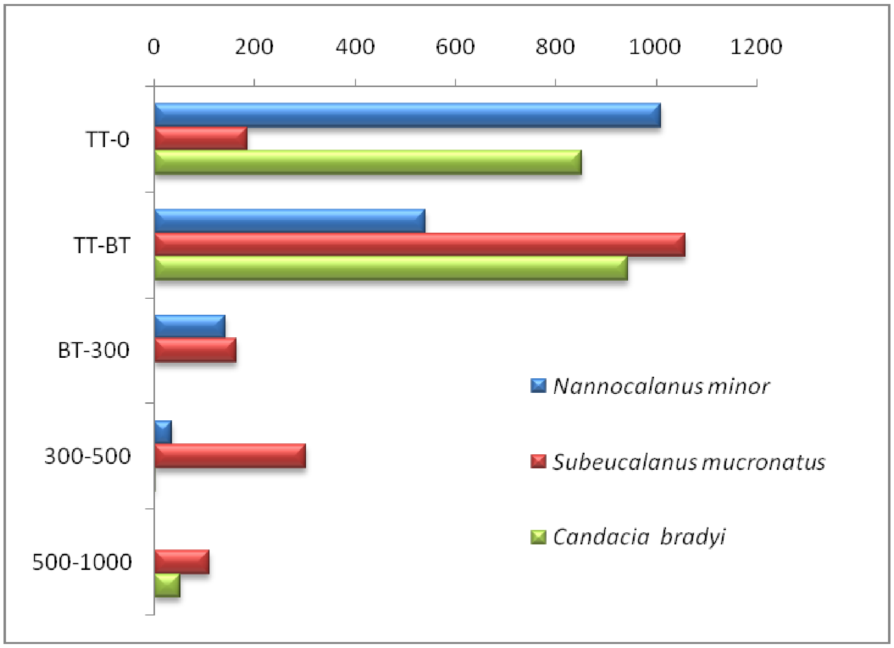
To check the presence of different species at EEZ of east coast of India a table was prepared. Species obtained during the three different seasons at the BoB and one season from the Andaman Sea was used to prepare the Table 5.19. Almost all the species which are new to the study area obtained from the Andamn Sea during the Intermonsoon fall. While reviewing the earlier studies the significant difference noticed was increase in cyclopoids namely *Oithona* spp. in the upper strata. In the mixed layer *Paracalanus indicus and Acrocalanus longicornis,* the small sized herbivores were very abundant compared to large size species namely *Eucalanus* and Calanids. The density of carnivores both large and small size forms were increased. *Lucicutia grandis* an indicator of lower OMZ were rare where as other species of the family such as *L.flavicornis, L.clauzi & L. bicornuta* were occurred frequently. The intrusion of Indo - pacific species into the BoB might be contributing to the higher diversity. Veronica and Ramaiah (2009) observed that during summer monsoon the mesozooplankton biomass in the BoB was at par with the same in the productive Arabian Sea. They had identified 132 species and in the present study 314 copepod species were identified. The review of copepod studies during the IIOE and afterwards also indicated higher species diversity in the Bay. The recurring cyclones and the cold core eddies not only favours phytoplankton production but inducted many bathypelagic species in the upper mixed layer. Prasannakumar et al (2010) attributed reduction in sunlight penetration, due to varied reasons, responsible for less biological production but suggested possible shifting of deep waters to the MLD. From IIOE onwards the earlier studies indicated high diversity in the BoB, although density was low compared to the AS. Stephen (1984) observed 54 species from the BoB against 32 from AS. At 100-0m, Haridas and Madhupratap (1986) recorded only 72 species from the BoB.

5.2.3.8. Comparison of the Copepod species from the mixed layer of the BoB before and after Cyclone

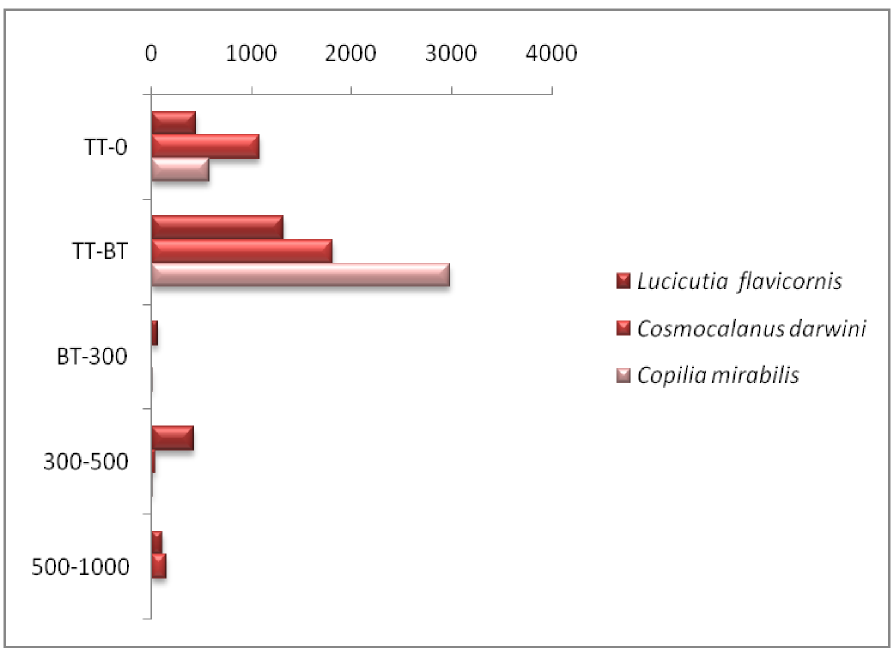
The cyclone of 1999 was the strongest occurred in the last 10 years. Hydrography during southwest monsoon showed upsloping of isotherms towards the coast, which indicated the signatures of upwelling at 11°N (off Karaikkal). During post cyclone period, along 15°N, offshore waters showed warm condition (28.6°C) compared to the inshore waters (27°C). The surface salinity prior to the cyclone was high (33.7 to 34.0 psu) with an increasing trend towards offshore. Prior to the cyclone, the nitrate values were low along 15°N and 13°N transects. Along 11°N nitrate value was high (2μM) indicating the signatures of upwelling. The surface chlorophyll *a* and corresponding column values were low during southwest monsoon period. During the post cyclone period, the nutrient enrichment caused the high surface chlorophyll *a* (maximum 0.97 mg m^3) and column chlorophyll *a* (maximum 24.4 mgm^2). After the cyclone the maximum surface and column primary production values of 69.1 mgC m^3d^{-1} and 1229 mgC m^3d^{-1} recorded off Chennai. The physical forcing of cyclone was reported to trigger very high primary production in response to nutrient enrichment due to mixing. This was followed by high zooplankton biomass and population density contributed mainly by copepods (Stephen, R.,Rashiba.A.P.et.al., 2006).

The composition of copepods before and after the cyclone is given in Table 5.20. Calanoid exhibited high density and diversity in the mixed layer. The average density recorded before the cyclone was 1525/ m^3 and after the cyclone the density doubled(3011/ m^3). Post cyclonic samples included species data that were recorded in the bathypelagic depths e.g. *Gaussia sewelli,* *Pleuromamma xiphias, Augaptilus longicaudatus, Heterostylites longicornis, H.major, Disseta palumboi and Lucicutia abyssalis.* Mesopelagic species like *Euchirella rostrata, Aetedius giesbrechti, Getanus miles, Scottocalanus securifrons, Scaphocalanus spp., Metridia princeps, Pleuromamma piski & P.xiphias* were also encountered in the mixed layer.The mesopelagic chaetognath *Sagitta decipeins* was also observed in the mixed layer. This study proved that episodic events were instrumental in accelerating the biological production of the surface waters.

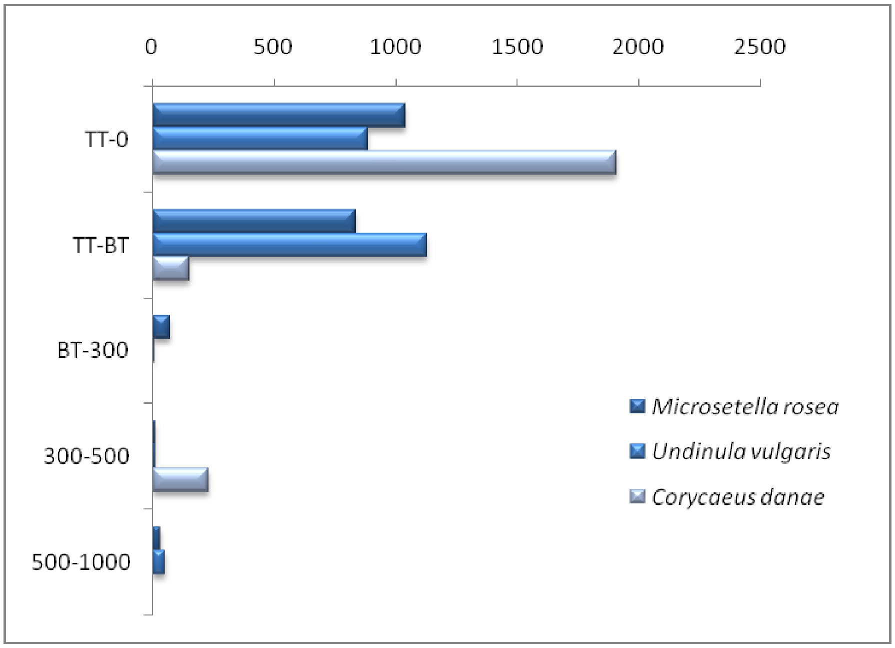
A table showing numerical abundance, average and percentage of various orders of copepod population is given in the Tab.5.21. Out of 133 species obtained from the surface layer of the BoB, before and after this super cyclone only 68 species were common to both periods. The copepod species obtained from the summer season, before cyclone documented only 24 species which were not present at the winter sample after cyclone. Forty-one species were recorded which were absent during summer season and found at the mixed layer after the cyclone, during winter season. The relatively higher density and diversity was due to the induction of mesopelagic calanoid dopepods due to cyclonic stirring.


0
200
400
600
800
1000
1200
TT-0
TT-BT
BT-300
300-500
500-1000
Nannocalanus minor
Subeucalanus mucronatus
Candacia bradyi

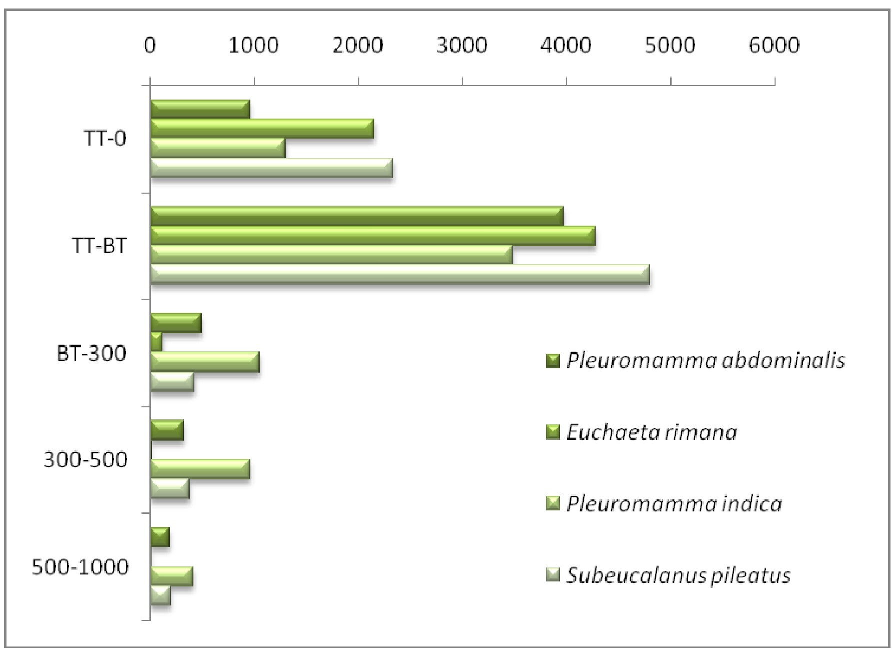
(a)


0
1000
2000
3000
4000
TT-0
TT-BT
BT-300
300-500
500-1000
Lucicutia flavicornis
Cosmocalanus darwini
Copilia mirabilis

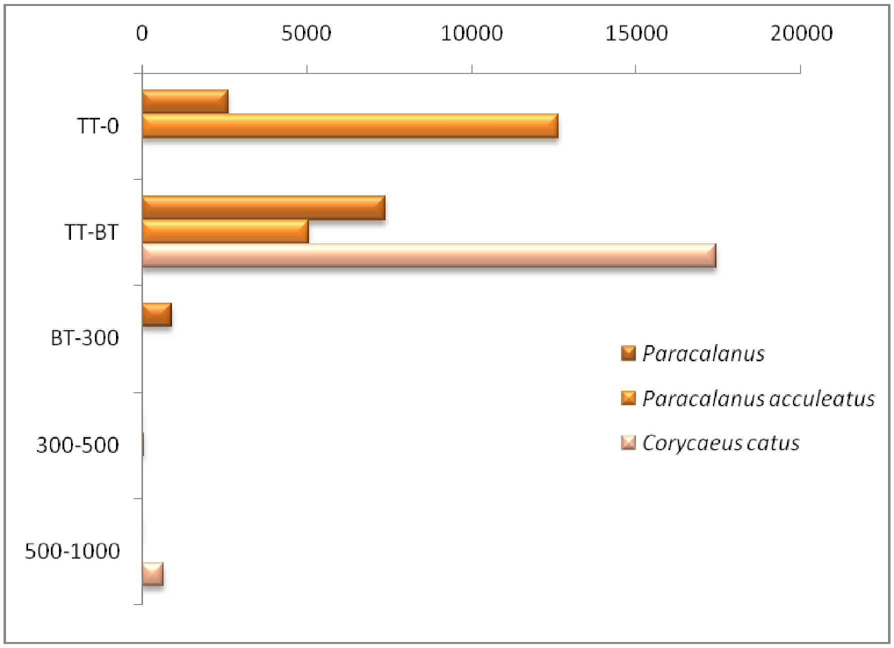
(b)


0
500
1000
1500
2000
2500
TT-0
TT-BT
BT-300
300-500
500-1000
Microsetella rosea
Undinula vulgaris
Corycaeus danae

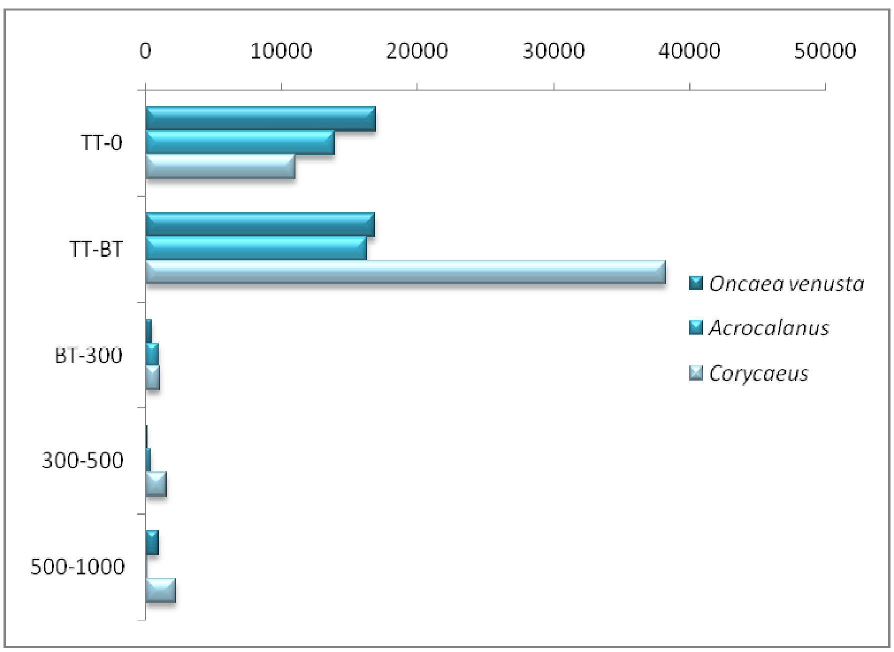
(c)


0
1000
2000
3000
4000
5000
6000
TT-0
TT-BT
BT-300
300-500
500-1000
Pleuromamma abdominalis
Euchaeta rimana
Pleuromamma indica
Subeucalanus pileatus

(d)

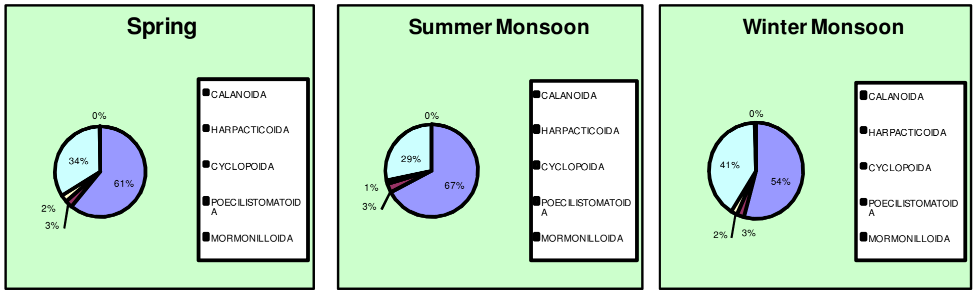


(e)

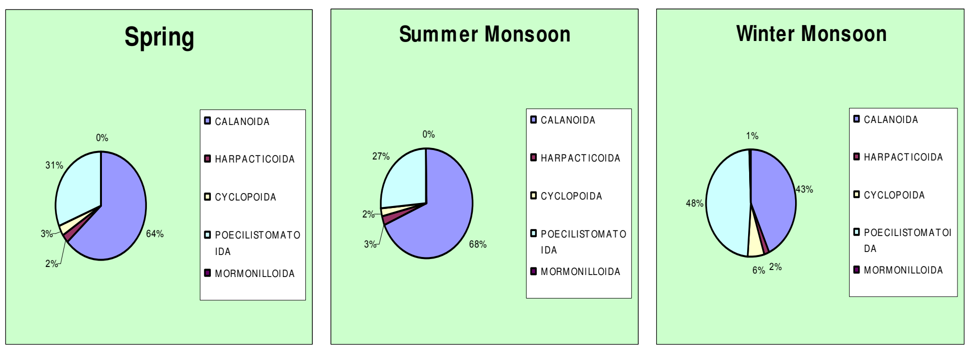


(f)

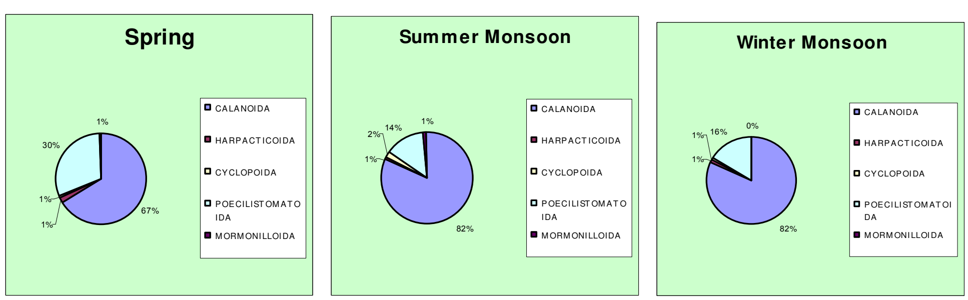
Fig. 5.1 a - f. Vertical distribution of some of the most dominant species of copepods at The BoB



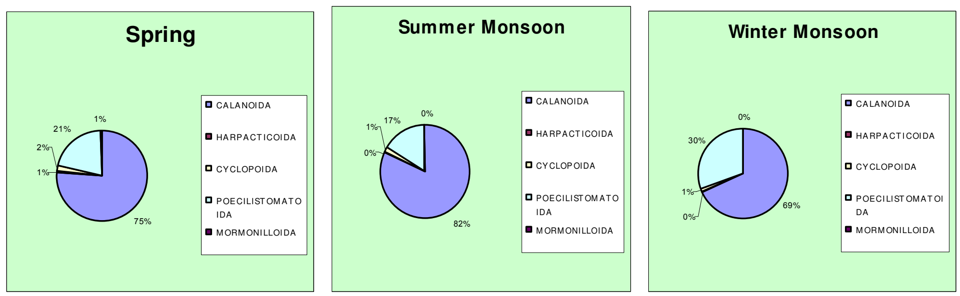
TT-0



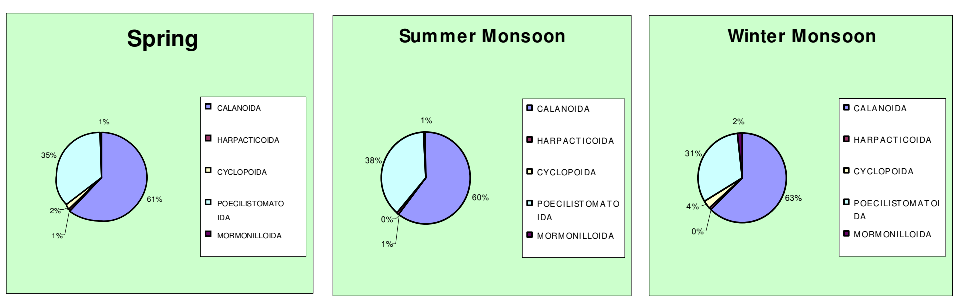
TT-BT



BT-300m



300-500m



500-1000m

Fig. 5.2. Temporal variation of the orders of copepods at five depth strata at The BoB

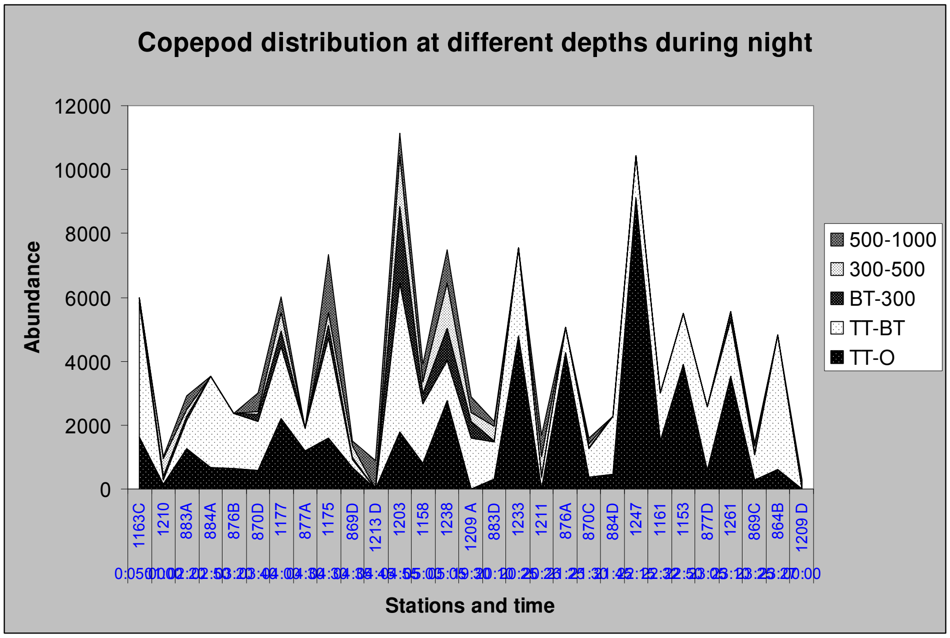


Fig. 5.3. Distribution of copepod at different depth during night

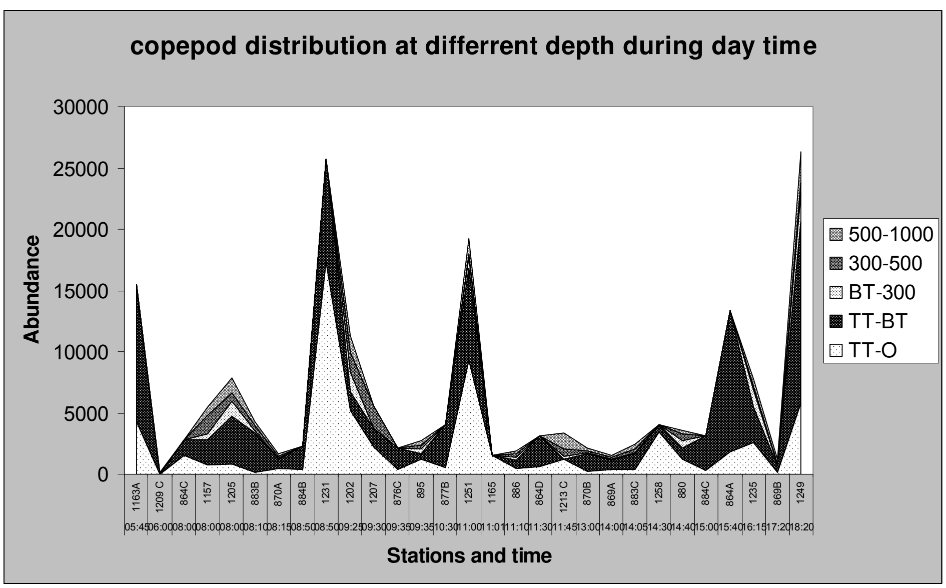


Fig. 5.4. Distribution of copepod at different depth during day time

Table. 5.1 SYSTEMATIC LIST OF SPECIES IDENTIFIED

SUB CLASS COPEPODA : MILINE EDWARD 1840

INFRA CLASS : PROGYMNOPLEA LANG 1948

ORDER PLANTYCOPIOIDA FOSSHAGEN 1985

INFRA CLASS : NEO COPEPODA

SUPER ORDER GYMNOPLEA GIESBRECHT 1882

ORDER CALANOIDA SARS 1903

SUPER FAMILY CALANOIDAE

FAMILY CALANIDAE DANA 1849

GENUS NANNOCALANUS SARS

1 Nannocalanus minor

Claus 1863

GENUS CANTHOCALANUS A.SCOTT

2 Canthocalanus pauper

Giesbrecht 1888

GENUS UNDINULA A.SCOTT

3 Undinula vulgaris

Dana 1849

4 Undinula vulgaris var

gieshbrecti

GENUS COSMOCALANUS

5 Cosmocalanus darwini

Lubbock 1860

GENUS NEOCALANUS

6 Neocalanus Dana 1849

FAMILY MEGACALANIDAE

GENUS MEGACALANUS WOLFENDEN

7 Megacalanus princeps

Wolfenden 1904

8 Megacalanus longicornis

Sars 1905

GENUS BRADYCALANUS A.SCOTT

9 Bradycalanus typicus

A.Scott 1909

FAMILY PARACALANIDAE
GIESBRECHT 1892

GENUS PARACALANUS BOEK 1864

10 Paracalanus spp

11 Paracalanus acculeatus
Giesbrecht1888

12 Paracalanus indicus
Wolfenden 1905

13 Paracalanus parvus
Claus 1863

GENUS ACROCALANUS GIESBRECHT

14 Acrocalanus spp

15 Acrocalanus gibber
Giesbrecht 1888

16 Acrocalanus gracilis
Giesbrecht1888

17 Acrocalanus longicornis
Giesbrecht 1888

18 Acrocalanus monachus
Giesbrecht1888

FAMILY MECYNOCERIDAE
ANDRONOV 1973

GENUS MECYNOCERA THOMPSON

19 Mecynocera clausi
Thompson 1888

GENUS CALOCALANUS GIESBRECHT

20 Calocalanus pavo
Dana 1849

21 Calocalanus Plumulosus
Claus 1863

22 Calocalanus styliramis
Giesbrecht 1888

SUPER FAMILY EUCALANOIDEA

FAMILY EUCALANIDE GIESBRECHT 1892

GENUS EUCALANUS DANA 1852

23 Eucalanus bungii
Giesbrecht 1892
24 Eucalanus elongatus
Dana 1849
25 Eucalanu hyalinus
Claus 1866
26 Eucalanus inermis
Giesbrecht 1892
27 Eucalanus longiceps
Mattews 1925
28 Eucalanus sewelly
Fleminger 1973
29 Pseudocalanus sps.
30 Eucalanus
pseudattenuatus

GENUS PAREUCALANUS FLEMING

31 Pareucalanus sewelli
Fleminger 1973
32 Pareucalanus attenuatus
Dana 1849

GENUS RHINCALANUS

33 Rhincalanus gigas
Brady 1883
34 Rhincalanus cornutus
Dana 1849
35 Rhincalanus nasutus
Giesbrecht 1888

GENUS SUBEUCALANUS GELETIN

36 Subeucalanus crassus
Giesbrecht1888
37 Subeucalanu longiceps
Mathews 1925
38 Subeucalanus mucronatus
Giesbrecht 1888
39 Subeucalanus pileatus
Giesbrecht 1888
40 Subeucalanus subcrassus

Giesbrecht1888

41 Subeucalanus subtenuis

Giesbrecht1888

FAMILY CLAUSOCALANIDAE

GENUS CLAUSOCALANUS

42 Clausocalanus arcuicornis

Dana 1849

43 Clausocalanus farrani

Sewell 1929

FAMILY PSEUDOCALANIDAE

GENUS DREPANOPSIS

44 Drepanopsis orbus

Tanaka,1956

GENUS MONACILLA

45 Monacilla typica

Sars 1905

GENUS SPINOCALANUS

46 Spinocalanus magnus

Wolfenden 1904

47 Spinocalanus spinosus

Farran 1908

GENUS CEPHALOPHANES

48 Cephalophanes frigidus

Wolfenden 1911

FAMILY AETIDEIDE

GENUS AETIDEUS

49 Aetideus armatus

Boeck 1872

50 Aetideus giesbrechti

Cleve 1904

51 Aetideus bradyi

A..Scott,1909

GENUS AETIDEIOPSIS

52 Aetidiopsis giesbrechti

Farran1929

53 Aetidiopsis acutus

A.Scott1909

GENUS CHIRIDIUS

54 Chiridius Gracilis

Farran 1908

GENUS UNDINELLA

55 Undinella spinifer

Tanaka 1960

GENUS GAETANUS

56 Gaetanus armiger

Giesbrecht 1888

57 Gaetanus kruppi

Giesvbecht 1903

58 Gaetanus latifrons

Sars 1905

59 Gaetanus miles

Giesbrecht 1903

60 Gaetanus minor

Farran 1905

61 Gaetanus pileatus

Farran 1903

GENUS GAIDIUS

62 Gaidius brevispinus

G. O. Sars 1900

63 Gaidius minutus G.

O. Sars 1907

64 Gaidius tenuispinus

G. O. Sars 1900

GENUS EUCHIRELLA

65 Euchirella amoena

Giesbrecht 1888

66 Euchirella unispina

Park,1968

67 Euchirella bella

Giesbrecht 1888

68 Euchirella bitumida

With 1915

69 Euchirella brevis G.

O. Sars 1905

70 Euchirella curticauda
Giesbrecht1888
71 Euchirella galeata
Giesbrecht 1888
72 Euchirella indica
Vervoot 1949
73 Euchirella messinensis
Claus 1863
74 Euchirella pulchera
Lubbock 1856
75 Euchirella rostrata
Claus 1866
76 Euchirella venusta
Giesbrecht 1888

GENUS PSEUDOCHIRELLA

77 Pseudochirella obesa,
Sars, 1920

GENUS CHIRUNDINA

78 Chirundina indica
Sewell 1929
79 Chirundina streetsi
Giesbrecht 1895

GENUS CHIRUDINELLA

80 Chirudinella magna
Wolfenden,1911

FAMILY EUCHAETIDA

GENUS VALDIVIELLA

81 Valdiviella oligarthra
Steuer 1904

GENUS EUCHAETA

82 Euchaeta concinna
Dana 1849
83 Euchaeta indica
Wolfenden 1905
84 Euchaeta longicornis
Giesbrecht 1888
85 Euchaeta media

Giesbrecht 1888

86 Euchaeta plana

Mori 1937

87 Euchaeta pubera

Sars 1907

88 Euchaeta rimana

Bradfort 1974

89 Euchaeta spinosa

Giesbrecht 1892

90 Euchaeta tenuis

Esterly 1906

91 Euchaeta wolfendeni

A. Scott 1909

GENUS PAREUCHAETA

92 Pareuchaeta barbata

Brady 1883

93 Pareuchaeta flava

Giesbrecht,1888

94 Pareuchaeta malayensis

Sewell 1929

95 Pareuchaeta scotti

Farran 1908

96 Pareuchaeta simplex

Tanaka 1958

GENUS UNEUCHAETA

97 Uneuchaeta bispinosa

Esterly,1911

98 Uneuchaeta major

Giesbrecht,1888

GENUS BRADYIDIUS

99 Bradyidius angustus

Tanaka,1957

FAMILY PHAENNIDAE

GENUS PHAENNA

100 Phaenna spinifera

Claus 1863

GENUS ONCHOCALANUS

101 Onchocalanus affinis
With 1915

GENUS XANTHOCALANUS

101 Xanthocalanus cornifer
Tanaka,1960

102 Xanthocalanus amabilis
Tanaka,1960

103 Xanthocalanus irritans
Tanaka,1960

FAMILY SCOLECITHRICIDAE

GENUS SCOTTOCALANUS

104 Scottocalanus australis
Farran 1936

105 Scottocalanus daughlishi
Sewell 1929

106 Scottocalanus helenae
Lubbock 1856

107 Scottocalanus elongates
A.Scott 1909

108 Scottocalanus farrani
A.Scott 1909

109 Scottocalanus
investigatoris
sewell 1929

110 Scottocalanus longifurca

111 Scottocalanus
longispinus

112 Scottocalanus
persecans
Giesbrecht 1895

113 Scottocalanus
securifrons
T.Scott 1894

114 Scottocalanus setosus
A.Scott,1909

115 Scottocalanus
terranovae

GENUS SCAPHOCALANUS

116 Scaphocalanus affinis
G.O.Sars 1905

117 Scaphocalanus elongatus

118 Scaphocalanus impar
Wolfenden,1911

119 Scaphocalanus
longifurca
Giesbrecht 1888

120 Scaphocalanus magnus
T. Scott 1894

GENUS LOPHOTHRIX

121 Lophothrix humilifrons
G.O.Sars 1905

122 Lophothrix frontalis
Giesbrecht 1895

GENUS SCOLECITHRIX

123 Scolecithrix bradyi
Giesbrecht 1888

124 Scolecithrix danae
Lubbock 1856

GENUS SCOLECITHRICELLA

125 scolecithricella abyssalis
Giesbrecht 1888

126 Solecithricella
nicobarica
Sewell,1929

127 Scolecithricella ctenopus
Giesbrecht 1888

128 Scolecithricella Bradyi
Giesbrecht 1888

129 Scolecithricella dentatta
Giesbrecht 1892

130 Scolecithricella
emarginata
Farran 1905

131 Scolecithricella
marginata
Giesbrecht1888
132 Scolecithricella modia
Tanaka, 1962
133 Scolecithricella
profunda
Giesbrecht1892
134 Scolecithricella
propinqua Sars 1920
135 Scolecithricella
tenuiserrata
Giesbrecht 1892

136 Scolecithricella
tropica
Grice1962
137 Scolecithricella vittatta
Giesbrecht 1892

GENUS SCOLECITRICHOPSIS

138 Scolecitrichopsis
ctenopus
Giesbrecht,1888
139 Scolecitrichopsis
tenuipus
T.Scott,1894

GENUS AMALOTHRIX

140 Amallothrix
emarginata
Farran 1905

141 Amallothrix indica
Sewell,1929
142 Amallothrix paravalida
Brodsky,1950
143 Amallothrix lophophora

Park 1970

144 Amallothrix valida
Farran,1908
145 Amallothrix acuta
Sars 1920

146 Amallothrix Obtusifrons
G.O.Sars 1905

GENUS PSEUDAMALLOTHRIX

147 Pseudamallothrix
laminata
Tanaka, 1962
148 Pseudoamallothrix
indica
Sewell,1929

FAMILY CENTROPAGIDAE

GENUS CENTROPAGES

149 Centropages furcatus
Dana1849
150 Centropages orsinii
Giesbrecht 1889
151 Centropages calaninus
Dana 1849
152 Centropages tenuiremis
Thompson and
Scott 1903
153 Centropages violaceous
Claus 1863

FAMILY PSEUDODIAPTOMUS

GENUS PSEUDODIAPTOMUS

154 Pseudodiaptomus
aurivilli
Cleve 1901
155 Pseudodiaptomus
serricaudatus
T.Scott 1894

FAMILY TEMORIDAE

GENUS TEMORA

156 Temora discaudata
Giesbrecht 1889

157 Temora turbinata
Dana 1849

158 Temora stylifera
Dana 1849

FAMILY METRIDIIDAE

GENUS METRIDIA

159 Metridia brevicauda
Giesbrecht 1889

160 Metridia okotensis
Brodsky 1950

161 Metridia pacefica
Brodsky 1950

162 Metridia princeps
Giesbrecht 1889

163 Metridia venusta
Giesbrecht 1889

GENUS PLUEROMAMMA

164 Pleuromamma
abdominalis
Lubbock 1856

165 Pleuromamma borealis
F. Dahl 1893

166 Pleuromamma gracilis
Claus 1863

167 Pleuromamma indica
Wolfenden 1905

168 Pleuromamma piseki
Farran 1929

169 Pleuromamma
quadrangulata

F.Dahl 1893

170 Pleuromamma xiphias

Giesbrecht 1889

GENUS GAUSSIA

171 Gaussia princeps

T. Scott 1894

172 Gaussia sewelli

Saraswathy1973

FAMILY LUCICUTIIDAE

GENUS LUCICUTIA

173 Lucicutia bicornuta

Wolfenden 1905

174 Lucicutia flavicornis

Claus 1863

175 Lucicutia Challenger

Sewell,1999

176 Lucicutia clausi

Giesbrecht 1889

177 Lucicutia curta

Farran 1904

178 Lucicutia longicornis

Giesbrecht 1889

179 Lucicutia longiserrata

Giesbrecht 1889

180 Lucicutia lucida

Farran 1908

181 Lucicutia macrocera

G. O. Sars 1920

182 Lucicutia magna

Wolfenden 1903

183 Lucicutia maxima

Steuer 1904

184 Lucicutia ovalis

Giesbrecht 1889

185 Lucicutia pacifica

Brodsky 1950

186 Lucicutia wolfendeni

Sewell 1932

187 Lucicutia ovalis

Giesbrecht,1889

*

FAMILY HETERORHABDIDAE

GENIUS HETERORHABDUS

188 Heterorhabdus abyssalis
Giesbrecht 1889

189 Heterorhabdus clausi
Giesbrecht 1889

190 Heterorhabdus
compactus
G. O. Sars 1900

191 Heterorhabdus
fistulosus
Tanaka 1964

192 Heterorhabdus
longicornis
Giesbrecht 1892

193 Heterorhabdus pacificus
Brodsky 1950

194 Heterorhabdus
pappiliger
Claus 1863

195 Heterorhabdus robustus
Farran 1908

196 Heterorhabdus
spinifrons
Claus 1863

197 Heterorhabdus
subspinifrons
Tanaka,1964

198 Heterorhabdus tanneri
Giesbrecht 1895

199 Heterorhabdus tenuis
Tanaka 1964

200 Heterorhabdus vipera
Giesbrecht 1889

GENUS DISSETA

201 Disseta palaumboi
Giesbrecht 1889

202 Disseta scopularis
Brady 1883

GENUS HETEROSTYLITES

203 Heterostylites
longicornis
Giesbrecht 1889

204 Heterostylites major
F. Dahl 1894

GENUS MESORHADBUS

205 Mesorhabdus angustuas
G.O.Sars 1907

206 Mesorhabdus
brevicaudatus
Wolfenden 1905

GENUS HEMIRHADBUS

207 Hemirhabdus spp.
Wolfenden 1911

208 Hemirhabdus
grimaldi
Richard 1893

GENUS CETNRAUGAPTILUS

209 Centraugaptilus
rattrayi
T. Scott 1894

GENUS ISIAS

210 Isias tropica
Sewell 1924

FAMILY AUGAPTILLIDAE

GENUS EUAUGAPTILUS

211 Euaugaptilus angustus
G.O.Sars 1905

212 Euaugaptilus bullifer
Giesbrecht 1892

213 Euaugaptilus digitatus
G. O. Sars 1920

214 Euaugaptilus farrani
G. O. Sars 1921

215 Euaugaptilus
hulsmannae
Mathews,1972

216 Euaugaptilus indicus
Sewell 1932

217 Euaugaptilus laticeps
G. O. Sars 1905

218 Euaugaptilus
longimanus
G.O. Sars 1905

219 Euaugaptilus magnus
Wolfenden 1904

220 Euaugaptilus mixtus
Brodsky 1950

221 Euaugaptilus nodifrons
G.O.Sars 1905

222 Euaugaptilus nudus
Tanaka,1964

223 Euaugaptilus oblongus
G.O. Sars 1905

224 Euaugaptilus squamatus
Giesbrecht 1889

GENUS AUGAPTILUS

225 Augaptilus anceps
Farran 1909

226 Augaptilus glacialis
G.O.Sars 1900

227 Augaptilus
longicaudatus
Claus 1863

228 Augaptilus simplex
Wolfenden, 1911

GENUS HALOPTILUS

229 Haloptilus acutifrons
Giesbrecht 1892
230 Haloptilus longiceps
Tanaka,1964
231 Haloptilus
Longicornis
Claus 1863
232 Haloptilus ornatus
Giesbrecht 1892
233 Haloptilus setuliger
Tanaka,1964
234 Haloptilus spiniceps
Giesbrecht 1892

GENUS PACHYPTILUS

235 Pachyptilus spp.
G.O. Sars 1920
236 Pachyptilus
giesbrechti

FAMILY ARIETELLIDAE

GENUS ARITELLUS

237 Aritellus setosus
Giesbrecht1892
238 Aritellus simplex
Sars 1905

GENUS NULLOSETIGERA

239 Nullosetigera bidentatus
Brady 1883
240 Nullosetigera
Giesbrechti
A.Scott,1909
241 Nullosetigera impar
Farran,1908
242 Nullosetigera muticus
G.O.Sars,1907

FAMILY CANDACIIDAE

GENUS CANDACIA

243 Candacia aethiopica
Dana 1849

244 Candacia bipinnata
Giesbrecht 1892
245 Candacia bradyi
A.Scott,1902
246 Candacia catula
Giesbrecht 1892
247 Candacia columbiae
Campell 1929
248 Candacia curta
Dana 1849
249 Candacia discaudata
A.Scott 1909
250 Candacia longimana
Claus 1863
251 Candacia pachydactyla
Dana 1849
252 Candacia pacifica
Camphell,1929
253 Candacia tenuimana
Giesbrecht 1889
254 Candacia truncata
Dana 1849

GENUS PARACANDACIA

255 Paracandacia bispinosa
Claus 1863
256 Paracandacia simplex
Giesbrecht 1888
257 Paracandacia truncata
Dana 1849

FAMILY PONTELLIDAE

GENUS CALANOPIA

258 Calanopia aurivilli
Cleve,1901
259 Calanopia elliptica
Dana 1849
260 Calanopia minor
A.Scott,1902

GENUS LABIDOCERA

261 Labidocera arcutifrons
Dana 1849
262 Labidocera detruncata
Dana 1849
263 Labidocera minuta,
Giesbrecht,1889
264 Labidocera pavo
Giesbrecht 1889
265 Labidocera pectinata
Thompson&Scott,1903

GENUS PONTELLINA

266 Pontellina plumata
Dana 1849

GENUS PONTELLOPSIS

267 Pontellopsis macronyx
A.Scott,1903
268 Pontellopsis
regalis Dana 18
269 Pontellopsis herdmani
Thompson&Scott,1903
270 Pontellopsis scotti
Sewell,1932
271 Pontellopsis armata
A.Scott,1909
272 Pontellopsis securifer
Brady 1883
273 Pontellopsis Spiniceps
Giesbrecht 1889

GENUS PONTELLA

274 Pontella investigatoris
Sewell,1932

FAMILY TORTANIDAE

GENUS TORTANUS

275 Tortanus sps
Giesbrecht 1898

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FAMILY ACARTIIDAE

GENUS ACARTIA

276 Acartia Danae

Giesbrecht 1889

277 Acartia minor,

Sewell,1919

278 Acartia negligens

Dana 1849

279 Acartia sewelli

Steuer,1934

FAMILY ECTIINOSOMIDAE

GENUS MICROSETELLA

280 Microsetella rosea

Dana 1849

281 Miracia efferata

Dana 1849

282 Macrosetella

A.Scott 1909

283 Macrosetella gracilis

Dana 1847

284 Macrosetella occulata

GENUS CLYTERMNESTRA

285 clytermnestra

Dana 1848

286 Clytermnestra

Scutellata

GENUS EUTERPINA

287 Euterpina acutifrons

Dana 1847

GENUS AEGISTHUS

288 Aegisthus mucronatus

Giesbrecht 1891

GENUS LONGIPEDIA

289 Longipedia weberi

,A.Scott,1909

GENUS METIS

290 Metis

Philippi 1843

FAMILY OITHOINIDAE

GENUS OITHONA

291 Oithona plumifera

Baird 1843

292 Oithona similis

Claus 1866

293 Oithona spinirostris

Claus 1863

FAMILY ONCAEIDAE

GENUS ONCEA

294 Oncaea venusta

Philippi 1843

295 Oncaea spp.

FAMILY CORYCAEIDAE

GENUS CORYCAEUS

296 Corycaeus

Dana 1846

297 Corycaeus catus

F.Dahl 1894

298 Corycaeus danae

Giesbrecht 1891

GENUS COPILIA

299 Copilia mirabilis

Dana 1849

300 Copilia quadrata

Dana 1849

301 Copilia vitera

Haeckel 1864

FAMILY SAPPHIRINIDAE

GENUS SAPHARINA

302 Sappharina sps

303 Sappharina auronitens

Claus 1863

304 Sappharina gemma

Dana1849

305 Sappharina nigromaculata

Claus 1863

306 Sappharina opalina
Dana1849
307 Sappharina
ovatolanceolata
Dana1849
308 Sappharina stelleta
Giesbrecht1891

FAMILY MORMONILLOIDA

GENUS MORMONILLA

309 Mormonilla phasma
Giesbrecht 1891
310 Mormonilla minor
Giesbrecht 1891

Table 5.2. Total No of copepods analysed from different depths strata of the BoB and The AndamanSea (No/1000m^3)

Total No of copepods analysed from different depth strata of the BoB and the Andamansea(No/1000m3)						
	SM`99	**WM`99**	**SIM**	**SM`02**	**WM`02**	**ANDAMAN**
TT-0	2781140	995060	2734303	2958875	4107458	541002
TT-BT			1499341	750576	2152871	595461
BT-300m			100656	149269	149682	200063
300-500m			87720	57000	57320	153540
500-1000m			32896	27928	43536	73480
Total	2781140	995060	4454916	3943648	6510867	1563546
Average	2781140	995060	890983.2	788729.6	1302173	312709.2

Table 5.3. Percentage composition of some abundant copepod species at five depth strata of the BoB

	Percentage Composition of Different Copepod Species at 5 Depth Strata of the BoB											
	TT-0	**%**	**TT-BT**	**%**	**BT-300**	**%**	**300-500**	**%**	**500-1000**	**%**	**TOTAL**	**%**
Cosmocalanus darwini	1076	1.090758	1813	1.462533	0	0	42	0.430946	152	1.16519739	3083	1.206342
Oithona plumifera	1498	1.518546	3045	2.456378	85	0.836203	25	0.256515	180	1.37983902	4833	1.891097
Corycaeus danae	1910	1.936197	2985	2.407977	0	0	230	2.359943	0	0	5125	2.005353
Pleuromamma abdominalis	965	0.978236	3971	3.203375	496	4.879488	326	3.344962	191	1.46416251	5949	2.327774
Euchaeta rimana	2155	2.184557	4282	3.454257	120	1.180521	19	0.194952	2	0.01533154	6578	2.573895
Pleuromamma indica	1300	1.31783	3479	2.806483	1056	10.38859	961	9.860456	410	3.14296665	7206	2.819624
Subeucalanus pileatus	2334	2.366012	4799	3.871316	430	4.230202	378	3.878514	197	1.51015715	8138	3.184305
Paracalanus	2632	2.668099	7380	5.953389	899	8.844073	25	0.256515	10	0.07665772	10946	4.283042
Paracalanus acculeatus	12637	12.81032	5080	4.097997	0	0	80	0.82085	0	0	17797	6.963759
*	6541	6.630714	16901	13.63391	1045	10.28037	943	9.675764	1774	13.5990801		10.64461
Acrocalanus	13908	14.09876	14300	11.5357	927	9.119528	345	3.539914	60	0.45994634	29540	11.55866
Corycaeus	11084	11.23602	17435	14.06468	1080	10.62469	1532	15.71927	2235	17.1330011	33366	13.05573
Oncaea venusta	16995	17.2281	16286	13.13779	425	4.181013	157	1.610917	970	7.43579916	34833	13.62975
All other sps	23612	23.93585	22207	17.91422	3602	35.43532	4683	48.05048	6864	52.6178612	60968	23.85607
Total	98647	100	123963	100	10165	100	9746	100	13045	100	255566	100

**Indicate immature, unidentified and broken parts of copepods*

Table 5.4. Spatial distribution of copepods in the mixed layer at the Bay of Bengal

Xanthocalanus cornifer	*Acartia minuta*	*Calocalanus plumulosus*	*Euchirella rostrata*	*Aegisthus mucronatus*	*Acartia Danae*	*Acrocalanus*
Euchirella unispina	*Pseudoamallothrix indica*	*Euchaeta plana*	*Pontellopsis scotti*	*clymnestra*	*Acartia negligens*	*Candacia bradyi*
Haloptilus longicornis	*Augaptilus glacialis*	*Euchirella curticauda*	*Scolecithricella nicobarica*	*Euchaeta longicornis*	*Acartia sewelli*	*Canthocalanus pauper*
Haloptilus ornatus	*Calanopia aurivilli*	*Haloptilus longiceps*		*Heterostylites longicornis*	*Aetideus armatus*	*Copilia mirabilis*
Heterorhabdus abyssalis	*Calocalanus styliramis*	*Heterorhabdus longicornis*		*Pontellopsis securifer*	*Calanopia minor*	*Corycaeus*
Llophothrix frontalis	*Chirudinella cara*	*Isias tropica*			*Calocalanus pavo*	*Corycaeus danae*
Oithona spinirostris	*Chirundina streetsi*	*Lucicutia clausi*			*Candacia columbiae*	*Cosmocalanus darwini*
Pareuchaeta simplex	*Eucalanu hyalinus*	*Lucicutia longiserrata*			*Candacia discaudata*	*Eucalanus attenuatus*
Pontellopsis regalis	*Euchaeta tenuis*	*Monacilla typica*			*Candacia pachydactyla*	*Euchaeta rimana*
Pseudodiaptomus aurivilli	*Gaetanus kruppi*	*Pontellopsis Spiniceps*			*Candacia tenuimana*	*Euchaeta wolfendeni*
Sappharina gemma	*Heterorhabdus pappiliger*	*Scaphocalanus elongatus*			*Candacia truncate*	*Labidocera pavo*
Subeucalanu longiceps	*Lucicutia challengeri*	*Amallothrix paravalida*			*Centropages furcatus*	*Macrosetella occulata*
	Sappharina stelleta	*Scottocalanus elongatus*			*Centropages tenuiremis*	*Microsetella rosea*
	Pseudoamallothrix indica	*Subeucalanus subtenuis*			*Clausocalanus arcuicornis*	*Nannocalanus minor*
	Scolecithricella vittatta				*Copilia quadrata*	*Oithona plumifera*
	Scottocalanus helenae				*Copilia vitera*	*Oncaea venusta*
					Eucalanus elongatus	*Paracalanus*
					Eucalanus inermis	*Paracalanus acculeatus*
					Eucalanus pseudattenuatus	*Paracandacia truncata*
					Euchaeta concinna	*Pleuromamma indica*
					Euchirella amoena	*Rhincalanus cornutus*
					Euchirella brevis	*Rhincalanus nasutus*
					Euchirella messinensis	*Sappharina ovatolanceolata*

11N	13N	15N	17N	19N	Others	Common
Aetidiopsis acutus	*Chirundina streetsi*	*Eucalanus longiceps*	*Eucalanus sewelli*	*Candacia truncata*	*Acartia sewelli*	*Candacia bradyi*
Aetideus bradyi	*Euchirella galeata*	*Euchaeta plana*	*Gaidius minutus*		*Aegisthus mucronatus*	*Copilia mirabilis*
Candacia columbiae	*Haloptilus setuliger*	*Euchirella areata*			*Calocalanus pavo*	*Corycaeus*
Candacia tenuimana	*Heterorhabdus clause*	*Euchirella bitumida*			*Candacia curta*	*Corycaeus catus*
Centropages aurisini	*Labidocera minuta*	*Euchirella indica*			*Candacia discaudata*	*Cosmocalanus darwini*
Corycaeus danae	*Lucicutia clause*	*Heterorhabdus compactus*			*Candacia pachydactyla*	*Eucalanus attenuatus*
Euchaeta media	*Nullosetigera bidentatus*	*Heterorhabdus pacificus*			*Canthocalanus pauper*	*Eucalanus elongatus*
Euchirella curticauda	*Pleuromamma xiphias*	*Metridia venusta*			*Centropages furcatus*	*Euchaeta concinna*
Gaetanus kruppi	*Rhincalanus gigas*	*Scottocalanus dauglishi*			*Centropages tenuiremis*	*Euchaeta rimana*
Gaetanus miles	*Sappharina nigromaculata*				*Centropages violaceous*	*Euchaeta wolfendeni*
Gaetanus minor	*Scottocalanus securifrons*				*Clausocalanus arcuicornis*	*Euchirella amoena*
Haloptilus acutifrons	*Spinocalanus spinosus*				*Clausocalanus farrani*	*Euchirella brevis*
Haloptilus spiniceps	*Temora stylifera*				*clymnestra*	*Euchirella pulchera*
Hemirhabdus grimaldi					*Copilia quadrata*	*Haloptilus ornatus*
Labidocera pectinata					*Copilia vitera*	*Heterorhabdus subspinifrons*
Mesorhabdus brevicaudatus					*Eucalanus inermis*	*Lucicutia flavicornis*
Oithona spinirostris					*Eucalanus pseudattenuatus*	*Macrosetella occulata*
Paracandacia simplex					*ParPareuchaeta flava*	*Microsetella rosea*
Pleuromamma						

Table 5.6. Spatial distribution of copepods in the BT-300 layer at the Bay of Bengal during the selected seasons

11°N	13°N	15°N	17°N	19°N	Others	Common
Acartia minuta	*Heterorhabdus compactus*	*Aetideus armatus*	*Eucalanus inermis*	*Aegisthus mucronatus*	*Amallothrix emarginata*	*Acrocalanus*
Candacia longimana	*Heterorhabdus pacificus*	*Eucalanu hyalinus*	*Heterorhabdus spinifrons*	*Calocalanus plumulosus*	*Calocalanus pavo*	*Corycaeus*
Haloptilus ornatus	*Amallothrix paravalida*	*Eucalanus pseudattenuatus*	*Scolecithricella bradyi*	*Candacia truncate*	*Candacia bipinnata*	*Eucalanus elongatus*
Labidocera minuta		*Euchaeta concinna*		*Clymenestra scutellata*	*Canthocalanus pauper*	*Euchaeta rimana*
Lucicutia longicornis		*Euchirella curticauda*		*Haloptilus acutifrons*	*Centropages furcatus*	*Nannocalanus minor*
Pareuchaeta simplex		*Euchirella indica*		*Lucicutia clause*	*Clausocalanus arcuicornis*	*Oithona plumifera*
		Gaidius tenuispinus		*Paracandacia simplex*	*Copilia quadrata*	*Oithona similis*
		Labidocera detruncata		*Sappharina auronitens*	*Pareucalanus attenuatus*	*Oncaea venusta*
		Labidocera pectinata		*Scottocalanus elongates*	*Euchaeta longicornis*	*Paracalanus*
		Lucicutia wolfendeni			*Euchaeta wolfendeni*	*Pleuromamma abdominalis*
		Mecynocera clausi			*Euchirella bitumida*	*Pleuromamma indica*
		Metridia okotensis			*Euchirella brevis*	*Scaphocalanus magnus*
		Metridia princeps			*Euchirella messinensis*	*Subeucalanus mucronatus*
		Scolecithrix bradyi			*Euchirella pulchera*	*Subeucalanus pileatus*
		Scottocalanus longifurca			*Euchirella rostrata*	*Subeucalanus subtenuis*

					Gaetanus miles	
					Haloptilus longicornis	
					Heterorhabdus abyssalis	
					Heterorhabdus clausi	
					Heterorhabdus fistulosus	
					Heterorhabdus longicornis	
					Heterorhabdus pappiliger	
					Heterorhabdus subspinifrons	
					Heterostylites longicornis	
					Heterostylites major	
					Lucicutia challengeri	
					Lucicutia flavicornis	
					Lucicutia lucida	
					Lucicutia ovalis	
					Macrosetella	
					Metridia brevicauda	
					Metridia venusta	
					Microsetella rosea	
					Mormonilla Phasma	
					Phaenna spinifera	
					Pleuromamma gracilis	
					Rhincalanus cornutus	
					Rhincalanus nasutus	
					Sappharina sps	
					Scaphocalanus affinis	
					Scolecithricella ctenopus	

					Scolecithricella marginata	
					Scolecithricella propinqua	
					Amallothrix valida	
					Scolecithrix danae	
					Scottocalanus dauglishi	
					Subeucalanu longiceps	
					Subeucalanus crassus	
					Subeucalanus subcrassus	
					Temora turbinate	
					Undinella spinifer	
					Undinula vulgaris	

Table 5.7. Spatial distribution of copepods in the 300-500m layer at the Bay of Bengal during the selected seasons

11°N	13°N	15°N	17°N	19°N	*Common*
Centraugaptilus rattrayi	*Candacia bradyi*	*Acartia sewelli*	*Eucalanus inermis*	*Chiridius gracilis*	*Acrocalanus*
Chirundina streetsi	*Euaugaptilus Farrani*	*Aritellus simplex*	*Heterorhabdus tanneri*	*Copilia vitera*	*Corycaeus*
Heterorhabdus vipera	*Euaugaptilus oblongus*	*Calocalanus plumulosus*	*Metis*	*Drepanopsis orbus*	*Cosmocalanus darwini*
Macrosetella gracilis	*Euchirella unispina*	*Eucalanus longiceps*	*Scolecitrichopsis tenuipus*	*Heterorhabdus robustus*	*Eucalanus elongatus*
Mesorhabdus angustuas	*Euchirella amoena*	*Euchirella rostrata*	*Scolecitrichopsis tenuipes*	*Lucicutia maxima*	*Euchirella bitumida*
Oithona plumifera	*Gaetanus latifrons*	*Heterorhabdus tenuis*	*Scolecithricella nicobarica*	*Lucicutia ovalis*	*Lucicutia challengeri*
Pareuchaeta scotti	*Gaetanus miles*	*Lophothrix humilifrons*	*Undinula vulgaris*	*Lucicutia wolfendeni*	*Lucicutia flavicornis*
Phaenna spinifera	*Gaidius tenuispinus*	*Lucicutia curta*		*Microsetella rosea*	*Oithona similis*
Scolecithricella marginata	*Haloptilus longicornis*	*Lucicutia longiserrata*		*Paracalanus acculeatus*	*Pleuromamma abdominalis*
Scolecithricella modia	*Longipedia weberi*	*Mecynocera clausi*			*Pleuromamma indica*
Scottocalanus terranovae	*Macrosetella*	*Metridia princeps*			*Scolecitrichopsis ctenopus*
Subeucalanus subtenuis	*Miracia efferata*	*Scolecithricella bradyi*			*Subeucalanus crassus*
	Pareuchaeta barbata	*Scottocalanus setosus*			*Subeucalanus mucronatus*
	Pleuromamma borealis				*Subeucalanus pileatus*
					Subeucalanus subcrassus

Others		
Amallothrix emarginata	*Heterorhabdus fistulosus*	*Pachyptilus*
Augaptilus glacialis	*Heterorhabdus longicornis*	*Paracalanus*
Canthocalanus pauper	*Heterorhabdus pacificus*	*Pareuchaeta malayensis*
Clausocalanus arcuicornis	*Heterorhabdus pappiliger*	*Pleuromamma gracilis*
Copilia mirabilis	*Heterorhabdus spinifrons*	*Pleuromamma piseki*
Corycaeus danae	*Heterorhabdus subspinifrons*	*Pleuromamma xiphias*
Euaugaptilus nodifrons	*Heterostylites longicornis*	*Rhincalanus cornutus*
Eucalanus attenuates	*Lucicutia ovalis*	*Rhincalanus nasutus*
Eucalanus bungii	*Llophothrix frontalis*	*Sappharina ovatolanceolata*
Euchaeta concinna	*Lucicutia clause*	*Scaphocalanus affinis*
Euchaeta rimana	*Lucicutia longicornis*	*Scaphocalanus elongatus*
Euchirella brevis	*Lucicutia lucida*	*Scaphocalanus impar*
Euchirella curticauda	*Lucicutia macrocera*	*Scolecithricella ctenopus*
Euchirella pulchera	*Lucicutia magna*	*Scolecithricella emarginata*
Gaetanus armiger	*Macrosetella occulata*	*Amallothrix paravalida*
Gaetanus kruppi	*Mesorhabdus brevicaudatus*	*Scolecithricella propinqua*
Gaetanus minor	*Metridia brevicauda*	*Amallothrix valida*
Gaetanus pileatus	*Metridia okotensis*	*Scolecithrix bradyi*
Gaussia princeps	*Metridia venusta*	*Scolecithrix danae*
Haloptilus longiceps	*Mormonilla minor*	*Scottocalanus dauglishi*
Heterorhabdus abyssalis	*Mormonilla Phasma*	*Scottocalanus elongates*
Heterorhabdus clause	*Nannocalanus minor*	*Scottocalanus securifrons*
Heterorhabdus compactus	*Oithona spinirostris*	*Undinella spinifer*

Table 5.8. Spatial distribution of copepods in the 500-1000m layer at the Bay of Bengal during the selected seasons

11°N	13°N	15°N	17°N	19°N	Common
Xanthocalanus irritans	*Cephalophanes frigidus*	*Euaugaptilus bullifer*	*Copilia vitera*	*Acrocalanus*	*Corycaeus*
Aritellus simplex	*Euaugaptilus oblongus*	*Euaugaptilus laticeps*	*Eucalanus Sewelly*	*Candacia bradyi*	*Gaetanus kruppi*
Chiridius Gracilis	*Euchaeta spinosa*	*Euchirella bella*	*Euchaeta concinna*	*Candacia columbiae*	*Heterorhabdus compactus*
Eucalanus longiceps	*Euchirella venusta*	*Macrosetella gracilis*	*Scaphocalanus impar*	*Centraugaptilus Rattrayi*	*Lucicutia challenger*
Euchaeta rimana	*Gaidius brevispinus*	*Mecynocera clausi*	*Temora discaudata*	*Cosmocalanus darwini*	*Lucicutia flavicornis*
Hemirhabdus	*Gaidius tenuispinus*	*Nullosetigera bidentatus*		*Euaugaptilus nudus*	*Lucicutia lucida*
Monacilla typica	*Longipedia weberi*	*Scolecithrix bradyi*		*Euaugaptilus squamatus*	*Mesorhabdus angustuas*
Pareucalanus sewelli	*Lucicutia ovalis*			*Euchaeta longicornis*	*Metridia brevicauda*
Pareuchaeta simplex	*Scottocalanus farrani*			*Euchirella curta*	*Pleuromamma indica*
Nullosetigera impar	*Spinocalanus spinosus*			*Heterorhabdus abyssalis*	*Scaphocalanus magnus*
Pleuromamma piseki	*Undinula vulgaris*			*Lucicutia maxima*	*Scolecithricella ctenopus*
Pleuromamma xiphias				*Mormonilla minor*	*Scottocalanus elongatus*
Rhincalanus gigas				*Paracalanus*	*Subeucalanus pileatus*
Scottocalanus longifurca				*Scaphocalanus elongatus*	
Scottocalanus persecans				*Scolecitrichopsis tenuipus*	
				Scolecithricella tropica	
				Scolecithricella vittatta	
				Scottocalanus australis	

Others		
Acartia negligens	*Haloptilus longicornis*	*Oithona plumifera*
Pseudoamallothrix indica	*Haloptilus ornatus*	*Oithona similis*
Augaptilus anceps	*Haloptilus setuliger*	*Oncaea venusta*
Augaptilus glacialis	*Haloptilus spiniceps*	*Pareuchaeta barbata*
Augaptilus longicaudatus	*Heterorhabdus clause*	*Pareuchaeta malayensis*
Clausocalanus arcuicornis	*Heterorhabdus fistulosus*	*Phaenna spinifera*
Corycaeus catus	*Heterorhabdus longicornis*	*Nullosetigera mutates*
Disseta palaumboi	*Heterorhabdus pacificus*	*Pleuromamma abdominalis*
Disseta scopularis	*Heterorhabdus pappiliger*	*Pleuromamma gracilis*
Drepanopsis orbus	*Heterorhabdus robustus*	*Rhincalanus cornutus*
Euaugaptilus Angustus	*Heterorhabdus spinifrons*	*Rhincalanus nasutus*
Euaugaptilus Farrani	*Heterorhabdus subspinifrons*	*Sappharina ovatolanceolata*
Euaugaptilus indicus	*Heterorhabdus Tanneri*	*Scolecithricella bradyi*
Euaugaptilus magnus	*Heterostylites longicornis*	*Scolecithricella dentatta*
Euaugaptilus mixtus	*Heterostylites major*	*Scolecithricella emarginata*
Euaugaptilus nodifrons	*Lucicutia ovalis*	*Amallothrix paravalida*
Eucalanus attenuates	*Llophothrix frontalis*	*Scolecithricella propinqua*
Eucalanus elongatus	*Lucicutia clause*	*Amallothrix valida*
Euchaeta plana	*Lucicutia curta*	*Scolecithrix danae*
Euchirella areata	*Lucicutia longicornis*	*Scottocalanus dauglishi*
Euchirella bitumida	*Lucicutia wolfendeni*	*Scottocalanus helenae*
Euchirella brevis	*Lucicutia bicornuta*	*Scottocalanus longispinus*
Euchirella messinensis	*Mesorhabdus brevicaudatus*	*Scottocalanus securifrons*
Euchirella pulchera	*Metridia okotensis*	*Spinocalanus magnus*
Euchirella rostrata	*Metridia princeps*	*Subeucalanus crassus*
Euterpina acutifrons	*Metridia venusta*	*Subeucalanus mucronatus*
Gaetanus armiger	*Microsetella rosea*	*Subeucalanus subcrassus*
Gaetanus pileatus	*Miracia efferata*	*Subeucalanus subtenuis*

Table 5.9. Vertical distribution of copepods in all the depth strata at the BoB		
Common to all depth	**TT-0**	**300-500**
Acrocalanus	*Acartia danae*	*Gaetanus latifrons*
Clausocalanus arcuicornis	*Xanthocalanus cornifer*	*Heterorhabdus tenuis*
Corycaeus	*Calanopia aurivilli*	*Heterorhabdus vipera*
Cosmocalanus darwini	*Calanopia minor*	*Lophothrix humilifrons*
Eucalanus attenuatus	*Candacia columbiae*	*Lucicutia macrocera*
Eucalanus elongatus	*Centropages calanicus*	*Lucicutia magna*
Euchaeta concinna	*Chirundina streetsi*	*Metis*
Euchaeta rimana	*Euchaeta tenuis*	*Pachyptilus*
Euchirella bitumida	*Isias tropica*	*Pareuchaeta scotti*
Euchirella brevis	*Pontellopsis regalis*	*Scolecithricella tenuiserrata*
Euchirella pulchera	*Pontellopsis scotti*	*Scolecitrichopsis ctenopus*
Euchirella rostrata	*Pontellopsis securifer*	*Scottocalanus setosus*
Gaussia princeps	*Pseudocalanus sps.*	*Scottocalanus terranovae*
Haloptilus longicornis	*Pseudodiaptomus aurivilli*	
Haloptilus ornatus	*Pseudoamallothrix indica*	
Heterorhabdus longicornis		
Heterorhabdus pappiliger		
Lucicutia clausi		
Lucicutia flavicornis	***TT-BT***	***500-1000***
Lucicutia lucida	*Aetidiopsis acutus*	*Xanthocalanus irritans*
Lucicutia ovalis	*Aetideus bradyi*	*Augaptilus anceps*
Mecynocera clausi	*Candacia curta*	*Augaptilus longicaudatus*
Metridia brevicauda	*Centropages aurisini*	*Cephalophanes frigidus*
Microsetella rosea	*Chirundina indica*	*Disseta palaumboi*
Mormonilla phasma	*ParPareuchaeta flava*	*Disseta scopularis*
Oithona plumifera	*Euchaeta indica*	*Euaugaptilus angustus*
Oithona similis	*Euchaeta media*	*Euaugaptilus bullifer*
Paracalanus	*Euchaeta minuta*	*Euaugaptilus digitatus*
Phaenna spinifera	*Euchirella galeata*	*Euaugaptilus indicus*
Pleuromamma abdominalis	*Gaidius minutes*	*Euaugaptilus laticeps*
Pleuromamma gracilis	*Hemirhabdus grimaldi*	*Euaugaptilus longimanus*
Pleuromamma indica	*Pontellopsis macronyx*	*Euaugaptilus magnus*
Pleuromamma piseki		*Euaugaptilus mixtus*
Rhincalanus cornutus		*Euaugaptilus nudus*
Rhincalanus nasutus		*Euaugaptilus squamatus*
Scolecithricella bradyi	***BT-300***	*Euchaeta spinosa*
Scolecithricella ctenopus	*Clymenestrascutellata*	*Euchirella bella*
Amallothrix paravalida		*Euchirella curta*
Scolecithrix bradyi		*Gaidius brevispinus*

Scolecithrix danae		*Hemirhabdus*
Subeucalanus crassus		*Nullosetigera impar*
Subeucalanus mucronatus		*Nullosetigera mutatus*
Subeucalanus pileatus		*Scolecithricella dentatta*
Subeucalanus subcrassus		*Scolecithricella tropica*
Subeucalanus subtenuis		*Scottocalanus farrani*
Undinula vulgaris		*Scottocalanus longispinus*
		Scottocalanus persecans
		Spinocalanus magnus
		Xanthocalanus amabilis

	SIM	SM	WM	Total
Nannocalanus minor	229	75	705	1009
Canthocalanus pauper	82	515	405	1002
Undinula vulgaris	347	249	290	886
Cosmocalanus darwini	541	270	265	1076
Paracalanus sp.	2632	0	0	2632
Paracalanus acculeatus	0	3467	9170	12637
Acrocalanus sp.	2403	2930	8575	13908
Mecynocera clausi	40	0	0	40
Calocalanus pavo	11	95	0	106
Calocalanus plumulosus	0	24	0	24
Calocalanus styliramis	0	10	0	10
Eucalanus attenuatus	310	84	47	441
Eucalanus elongatus	13	14	60	87
Eucalanu hyalinus	2	0	0	2
Eucalanus inermis	0	57	25	82
Pseudocalanus sps.	0	2	0	2
Eucalanus pseudattenuatus	6	36	0	42
Rhincalanus cornutus	78	10	130	218
Rhincalanus nasutus	20	2	0	22
Subeucalanus crassus	65	38	125	228
Subeucalanu longiceps	0	10	30	40
Subeucalanus mucronatus	117	20	50	187
Subeucalanus pileatus	799	705	830	2334
Subeucalanus subcrassus	99	50	265	414
Subeucalanus subtenuis	0	55	0	55
Clausocalanus arcuicornis	51	20	220	291
Monacilla typica	25	0	0	25
Aetideus armatus	184	5	0	189
Undinella spinifer	45	0	0	45
Gaetanus kruppi	1	0	0	1
Euchirella amoena	8	0	10	18
Euchirella unispina	0	0	20	20
Euchirella bitumida	0	3	0	3
Euchirella brevis	9	0	90	99
Euchirella curticauda	1		0	1
Euchirella messinensis	6	0	0	6
Euchirella pulchera	13	0	0	13
Euchirella rostrata	1	5	0	6
Chirundina streetsi	8	0	0	8
Chirudinella cara	8	0	0	8
Euchaeta concinna	25	10	200	235
Euchaeta longicornis	20	0	0	20
Euchaeta plana	0	0	25	25
Euchaeta rimana	870	550	735	2155
Euchaeta tenuis	80	0	0	80
Euchaeta wolfendeni	114	120	75	309
Pareuchaeta simplex	2	0	0	2
Phaenna spinifera	11	88	53	152
Xanthocalanus cornifer	0	0	5	5
Scottocalanus dauglishi	10	0	0	10

Table 5.11. Temporal variations of numerical abundance Copepods at Thermocline layer of the BoB

	SIM	SM	WM	Total
Nannocalanus minor	241	300	0	541
Canthocalanus pauper	5	0	10	15
Undinula vulgaris	428	40	660	1128
Cosmocalanus darwini	1638	150	25	1813
Neocalanus sp.	0	5	0	5
Paracalanus sp.	7380	0	0	7380
Paracalanus acculeatus	0	2360	2720	5080
Acrocalanus sp.	7295	3295	3710	14300
Mecynocera clausi	5	62	50	117
Calocalanus pavo	15	75	0	90
Calocalanus styliramis	0	15	0	15
Eucalanus attenuatus	79	72	60	211
Eucalanus bungii	0	0	1	1
Eucalanus elongatus	82	109	28	219
Eucalanus inermis	2	0	15	17
Eucalanus longiceps	20	0	0	20
Eucalanus sewelli	0	0	1	1
Eucalanus pseudattenuatus	19	80	0	99
Pareucalanus sewelli	0	0	8	8
Rhincalanus gigas	0	5	0	5
Rhincalanus cornutus	133	88	64	285
Rhincalanus nasutus	49	22	6	77
Subeucalanus crassus	254	48	117	419
Subeucalanu longiceps	0	15	0	15

Subeucalanus mucronatus	165	250	644	1059
Subeucalanus pileatus	1865	1388	1546	4799
Subeucalanus subcrassus	298	195	120	613
Subeucalanus subtenuis	22	60	156	238
Clausocalanus arcuicornis	240	160	210	610
Monacilla typica	0	21	0	21
Spinocalanus spinosus	7	0	0	7
Aetideus armatus	5	0	0	5
Aetidiopsis acutus	1	0	0	1
Aetideus bradyi	3	0	0	3
Gaetanus kruppi	1	0	0	1
Gaetanus miles	5	5	0	10
Gaetanus minor	152	0	0	152
Gaidius minutus	0	0	20	20
Gaidius tenuispinus	10	10	0	20
Euchirella amoena	157	25	28	210
Euchirella areata	10	0	0	10
Euchirella bitumida	3	0	0	3
Euchirella brevis	58	47	137	242
Euchirella curticauda	0	5	0	5
Euchirella galeata	0	0	20	20
Euchirella indica	5	0	20	25
Euchirella messinensis	21	20	15	56
Euchirella pulchera	103	41	33	177
Euchirella rostrata	45	19	82	146
Euchirella venusta	28	0		28
Chirundina indica	0	0	4	4
Chirundina streetsi	7	0	0	7
Euchaeta concinna	141	435	39	615
ParPareuchaeta flava	15	0	0	15
Euchaeta indica	0	200	0	200

Euchaeta media	15	0	0	15
Euchaeta minuta	65	0	0	65
Euchaeta plana	92	50	0	142
Euchaeta rimana	2945	1096	241	4282
Euchaeta wolfendeni	435	305	105	845
Pareuchaeta simplex	1	0	0	1
Phaenna spinifera	65	40	60	165
Scottocalanus australis	0	0	2	2
Scottocalanus securifrons	1	0	0	1
Scaphocalanus elongatus	3	0	105	108
Scaphocalanus magnus	10	0	50	60
Scolecithrix bradyi	2	0	340	342
Scolecithrix danae	297	71	520	888
Scolecithricella nicobarica	134	10	60	204
Scolecithricella ctenopus	209	0	300	509
Scolecithricella bradyi	82	120	0	202
Amallothrix paravalida	2	0	40	42
Scolecithricella propinqua	6	0	60	66
Amallothrix valida	21	0	0	21
Centropages furcatus	27	50	0	77
Centropages aurisini	1	0	0	1
Centropages tenuiremis	0	30	30	60
Centropages violaceous	1	0	20	21
Temora discaudata	166	0	10	176
Temora turbinata	140	0	30	170
Temora stylifera	1	0	0	1
Metridia brevicauda	28	25	40	93
Metridia venusta	11	0	0	11
Pleuromamma abdominalis	1751	1115	1105	3971
Pleuromamma gracilis	143	0	60	203
Pleuromamma indica	1634	1145	700	3479

Pleuromamma piseki	15	0	50	65
Pleuromamma xiphias	5	0	0	5
Gaussia princeps	1	0	2	3
Lucicutia flavicornis	235	1040	45	1320
Lucicutia clausi	0	60	0	60
Lucicutia lucida	280	20	60	360
Lucicutia ovalis	180	180	0	360
Heterorhabdus clausi	0	0	30	30
Heterorhabdus compactus	21	0	0	21
Heterorhabdus longicornis	30	10	50	90
Heterorhabdus pacificus	5	0	0	5
Heterorhabdus pappiliger	40	5	30	75
Heterorhabdus subspinifrons	45	0	20	65
Mesorhabdus brevicaudatus	0	20	0	20
Hemirhabdus grimaldi	0	0	2	2
Haloptilus acutifrons	0	10	0	10
Haloptilus longiceps	15	0	0	15
Haloptilus longicornis	61	120	65	246
Haloptilus ornatus	14	45	5	64
Haloptilus setuliger	0	0	25	25
Haloptilus spiniceps	5	0	5	10
Nullosetigera bidentatus	4	0	0	4
Candacia bipinnata	0	0	15	15
Candacia bradyi	559	181	205	945
Candacia curta	15	0	20	35
Candacia discaudata	20	0	0	20
Candacia longimana	7	0	0	7
Candacia pachydactyla	22	0	0	22
Candacia pacifica	3	0	0	3
Candacia tenuimana	1	0	0	1
Candacia truncata	0	0	80	80

Paracandacia simplex	0	1	0	1
Paracandacia truncata	100	50	5	155
Labidocera arcutifrons	2	1	0	3
Labidocera minuta	30	0	0	30
Labidocera pavo	51	25	0	76
Labidocera pectinata	1	0	0	1
Pontellina plumata	25	0	0	25
Pontellopsis macronyx	0	1	0	1
Pontellopsis Spiniceps	25	0	0	25
Acartia negligens	21	60	0	81
Acartia sewelli	74	60	0	134
Microsetella rosea	273	85	480	838
Miracia efferata	22	445	7	474
Macrosetella	55	0	151	206
Macrosetella gracilis	309	0	0	309
Macrosetella occulata	172	70	0	242
Clymnestra sp.	21	20	0	41
Euterpina acutifrons	51	20	35	106
Aegisthus mucronatus	282	0	30	312
Longipedia weberi	24	58		82
Oithona plumifera	534	459	2052	3045
Oithona similis	680	0	0	680
Oithona spinirostris	150	0	0	150
Oncaea venusta	7247	2955	6084	16286
Corycaeus sp.	7040	0	10395	17435
Corycaeus catus	150	0	0	150
Corycaeus danae	0	2985	0	2985
Copilia mirabilis	313	0	0	313
Copilia quadrata	23	0	0	23
Copilia vitera	29	10	0	39
Sappharina sps	0	12	0	12

Sappharina auronitens	57	0	40	97
Sappharina gemma	5	0	0	5
Sappharina nigromaculata	103	28	0	131
Sappharina opalina	49	0	0	49
Sappharina ovatolanceolata	289	114	410	813
Sappharina stelleta	0	2	0	2
Mormonilla Phasma	3	45	150	198
Mormonilla minor	55	81	180	316
Immature	6075	4435	6391	16901
Total	**55223**	**27392**	**41546**	**124161**

Table 5.12. Temporal variations of numerical abundance Copepods at BT-300m layer of the BoB

	SIM	SM	WM	Total
Nannocalanus minor	35	0	0	35
Canthocalanus pauper	16	0	0	16
Undinula vulgaris	0	10	0	10
Cosmocalanus darwini	20	20	2	42
Paracalanus sp.	25	0	0	25
Paracalanus acculeatus	0	80	0	80
Acrocalanus	135	75	135	345
Mecynocera clause	20	0	0	20
Calocalanus plumulosus	10	0	0	10
Eucalanus attenuates	3	2	0	5
Eucalanus bungii	1	0	10	11
Eucalanus elongatus	235	108	8	351
Eucalanus inermis	0	0	2	2
Eucalanus longiceps	5	0	0	5
Rhincalanus cornutus	131	30	22	183
Rhincalanus nasutus	7	19	5	31
Subeucalanus crassus	93	3	19	115
Subeucalanus mucronatus	209	80	14	303
Subeucalanus pileatus	108	220	50	378
Subeucalanus subcrassus	25	9	0	34

Subeucalanus subtenuis	17	80	0	97
Clausocalanus arcuicornis	3	80	88	171
Drepanopsis orbus	0	2	0	2
Chiridius Gracilis	2	0	0	2
Undinella spinifer	20	0	0	20
Gaetanus armiger	2	2	2	6
Gaetanus kruppi	9	10	1	20
Gaetanus latifrons	1	0	0	1
Gaetanus miles	3	0	0	3
Gaetanus minor	8	2	0	10
Gaetanus pileatus	2	15	0	17
Gaidius tenuispinus	2	0	0	2
Euchirella amoena	1	0	0	1
Euchirella unispina	2	0	0	2
Euchirella bitumida	36	8	5	49
Euchirella brevis	17	30	0	47
Euchirella curticauda	5	0	2	7
Euchirella pulchera	15	26	0	41
Euchirella rostrata	3	0	2	5
Chirundina streetsi	0	25	0	25
Euchaeta concinna	10	0	0	10
Euchaeta rimana	19	0	0	19
Pareuchaeta barbata	4	0	0	4
Pareuchaeta malayensis	2	2	0	4
Pareuchaeta scotti	1	0	0	1
Phaenna spinifera	4	0	0	4
Scottocalanus dauglishi	2	2	0	4
Scottocalanus elongates	0	12	0	12
Scolecitrichopsis ctenopus	23	16	12	51
Scottocalanus securifrons	8	0	0	8
Scottocalanus setosus	2	0	0	2
Scottocalanus terranovae	3	0	0	3
Scaphocalanus affinis	2	0	8	10
Scaphocalanus elongates	45	0	10	55
Scaphocalanus impar	4	0	0	4
Lophothrix humilifrons	2	0	0	2
Llophothrix frontalis	5	0	0	5
Scolecithrix bradyi	7	0	0	7
Scolecithrix danae	42	60	0	102
Scolecithricella nicobarica	0	0	2	2
Scolecithricella ctenopus	4	8	55	67

Scolecithricella bradyi	0	0	30	30
Scolecithricella emarginata	7	0	0	7
Scolecithricella marginata	3	0	0	3
Scolecithricella modia	0	0	2	2
Amallothrix paravalida	14	0	200	214
Scolecithricella propinqua	5	8	0	13
Scolecitrichopsis tenuipus	12	0	0	12
Scolecithricella tenuiserrata	0	0	2	2
Amallothrix valida	4	0	0	4
Amallothrix emarginata	0	7	0	7
Metridia brevicauda	40	215	50	305
Metridia okotensis	25	0	35	60
Metridia princeps	0	0	1	1
Metridia venusta	35	30	0	65
Pleuromamma abdominalis	246	65	15	326
Pleuromamma borealis	2	0	0	2
Pleuromamma gracilis	11	4	0	15
Pleuromamma indica	456	345	160	961
Pleuromamma piseki	1	62	0	63
Pleuromamma xiphias	11	0	0	11
Gaussia princeps	4	6	2	12
Lucicutia bicornuta	2	0	0	2
Lucicutia flavicornis	106	80	232	418
Lucicutia challenger	75	48	51	174
Lucicutia clause	0	90	20	110
Lucicutia curta	48	0	0	48
Lucicutia longicornis	0	6	4	10
Lucicutia longiserrata	35	0	0	35
Lucicutia lucida	33	52	70	155
Lucicutia macrocera	0	3	0	3
Lucicutia magna	26	0	0	26
Lucicutia maxima	15	0	0	15
Lucicutia ovalis	8	0	0	8
Lucicutia wolfendeni	20	4	0	24
Lucicutia ovalis	0	35	0	35
Heterorhabdus abyssalis	7	0	25	32
Heterorhabdus clause	2	0	0	2
Heterorhabdus compactus	10	0	30	40
Heterorhabdus fistulosus	0	33	27	60
Heterorhabdus longicornis	25	5	3	33
Heterorhabdus pacificus	3	0	2	5

Heterorhabdus pappiliger	5	60	125	190
Heterorhabdus robustus	0	0	3	3
Heterorhabdus spinifrons	12	0	17	29
Heterorhabdus subspinifrons	2	0	18	20
Heterorhabdus tanneri	5	0	0	5
Heterorhabdus tenuis	10	0	0	10
Heterorhabdus vipera	2	0	0	2
Heterostylites longicornis	15	2	5	22
Heterostylites major	0	10	0	10
Mesorhabdus angustuas	0	10	0	10
Mesorhabdus brevicaudatus	1	0	5	6
Centraugaptilus Rattrayi	2	0	0	2
Euaugaptilus Farrani	2	0	0	2
Euaugaptilus nodifrons	1	2	8	11
Euaugaptilus oblongus	2	0	0	2
Augaptilus glacialis	1	0	2	3
Haloptilus longiceps	55	0	0	55
Haloptilus longicornis	2	0	0	2
Pachyptilus sp.	2	2	0	4
Aritellus simplex	0	0	10	10
Candacia bradyi	2	0	0	2
Tortanus sps	2	0	0	2
Acartia sewelli	5	0	0	5
Microsetella rosea	10	0	0	10
Miracia efferata	2	0	0	2
Macrosetella	2	0	0	2
Macrosetella gracilis	4	0	0	4
Macrosetella occulata	10	0	0	10
Longipedia weberi	0	5	0	5
Metis sp.	0	0	10	10
Oithona plumifera	0	25	0	25
Oithona similis	50	10	0	60
Oithona spinirostris	10	0	25	35
Oncaea venusta	77	80	0	157
Corycaeus sp.	672	370	490	1532
Corycaeus danae	0	0	230	230
Copilia mirabilis	3	0	0	3
Copilia vitera	5	0	0	5
Sappharina ovatolanceolata	9	2	0	11
Mormonilla Phasma	6	3	0	9
Mormonilla minor	28	0	3	31

Immature	308	135	500	943
Total	**4030**	**2850**	**2866**	**9746**

Table 5.13. Temporal variations of numerical abundance Copepods at 300-500m layer of the BoB

	SIM	SM	WM	Total
Nannocalanus minor	35	0	0	35
Canthocalanus pauper	16	0	0	16
Undinula vulgaris	0	10	0	10
Cosmocalanus darwini	20	20	2	42
Paracalanus sp.	25	0	0	25
Paracalanus acculeatus	0	80	0	80
Acrocalanus	135	75	135	345
Mecynocera clause	20	0	0	20
Calocalanus plumulosus	10	0	0	10
Eucalanus attenuates	3	2	0	5
Eucalanus bungii	1	0	10	11
Eucalanus elongatus	235	108	8	351
Eucalanus inermis	0	0	2	2
Eucalanus longiceps	5	0	0	5
Rhincalanus cornutus	131	30	22	183
Rhincalanus nasutus	7	19	5	31
Subeucalanus crassus	93	3	19	115
Subeucalanus mucronatus	209	80	14	303
Subeucalanus pileatus	108	220	50	378
Subeucalanus subcrassus	25	9	0	34
Subeucalanus subtenuis	17	80	0	97
Clausocalanus arcuicornis	3	80	88	171
Drepanopsis orbus	0	2	0	2
Chiridius Gracilis	2	0	0	2
Undinella spinifer	20	0	0	20
Gaetanus armiger	2	2	2	6
Gaetanus kruppi	9	10	1	20
Gaetanus latifrons	1	0	0	1
Gaetanus miles	3	0	0	3
Gaetanus minor	8	2	0	10
Gaetanus pileatus	2	15	0	17
Gaidius tenuispinus	2	0	0	2
Euchirella amoena	1	0	0	1

Euchirella unispina	2	0	0	2
Euchirella bitumida	36	8	5	49
Euchirella brevis	17	30	0	47
Euchirella curticauda	5	0	2	7
Euchirella pulchera	15	26	0	41
Euchirella rostrata	3	0	2	5
Chirundina streetsi	0	25	0	25
Euchaeta concinna	10	0	0	10
Euchaeta rimana	19	0	0	19
Pareuchaeta barbata	4	0	0	4
Pareuchaeta malayensis	2	2	0	4
Pareuchaeta scotti	1	0	0	1
Phaenna spinifera	4	0	0	4
Scottocalanus dauglishi	2	2	0	4
Scottocalanus elongates	0	12	0	12
Scolecitrichopsis ctenopus	23	16	12	51
Scottocalanus securifrons	8	0	0	8
Scottocalanus setosus	2	0	0	2
Scottocalanus terranovae	3	0	0	3
Scaphocalanus affinis	2	0	8	10
Scaphocalanus elongates	45	0	10	55
Scaphocalanus impar	4	0	0	4
Lophothrix humilifrons	2	0	0	2
Llophothrix frontalis	5	0	0	5
Scolecithrix bradyi	7	0	0	7
Scolecithrix danae	42	60	0	102
Scolecithricella nicobarica	0	0	2	2
Scolecithricella ctenopus	4	8	55	67
Scolecithricella bradyi	0	0	30	30
Scolecithricella emarginata	7	0	0	7
Scolecithricella marginata	3	0	0	3
Scolecithricella modia	0	0	2	2
Amallothrix paravalida	14	0	200	214
Scolecithricella propinqua	5	8	0	13
Scolecitrichopsis tenuipus	12	0	0	12
Scolecithricella tenuiserrata	0	0	2	2
Amallothrix valida	4	0	0	4
Amallothrix emarginata	0	7	0	7
Metridia brevicauda	40	215	50	305
Metridia okotensis	25	0	35	60
Metridia princeps	0	0	1	1

Metridia venusta	35	30	0	65
Pleuromamma abdominalis	246	65	15	326
Pleuromamma borealis	2	0	0	2
Pleuromamma gracilis	11	4	0	15
Pleuromamma indica	456	345	160	961
Pleuromamma piseki	1	62	0	63
Pleuromamma xiphias	11	0	0	11
Gaussia princeps	4	6	2	12
Lucicutia bicornuta	2	0	0	2
Lucicutia flavicornis	106	80	232	418
Lucicutia challenger	75	48	51	174
Lucicutia clause	0	90	20	110
Lucicutia curta	48	0	0	48
Lucicutia longicornis	0	6	4	10
Lucicutia longiserrata	35	0	0	35
Lucicutia lucida	33	52	70	155
Lucicutia macrocera	0	3	0	3
Lucicutia magna	26	0	0	26
Lucicutia maxima	15	0	0	15
Lucicutia ovalis	8	0	0	8
Lucicutia wolfendeni	20	4	0	24
Lucicutia ovalis	0	35	0	35
Heterorhabdus abyssalis	7	0	25	32
Heterorhabdus clause	2	0	0	2
Heterorhabdus compactus	10	0	30	40
Heterorhabdus fistulosus	0	33	27	60
Heterorhabdus longicornis	25	5	3	33
Heterorhabdus pacificus	3	0	2	5
Heterorhabdus pappiliger	5	60	125	190
Heterorhabdus robustus	0	0	3	3
Heterorhabdus spinifrons	12	0	17	29
Heterorhabdus subspinifrons	2	0	18	20
Heterorhabdus tanneri	5	0	0	5
Heterorhabdus tenuis	10	0	0	10
Heterorhabdus vipera	2	0	0	2
Heterostylites longicornis	15	2	5	22
Heterostylites major	0	10	0	10
Mesorhabdus angustuas	0	10	0	10
Mesorhabdus brevicaudatus	1	0	5	6
Centraugaptilus Rattrayi	2	0	0	2
Euaugaptilus Farrani	2	0	0	2

Euaugaptilus nodifrons	1	2	8	11
Euaugaptilus oblongus	2	0	0	2
Augaptilus glacialis	1	0	2	3
Haloptilus longiceps	55	0	0	55
Haloptilus longicornis	2	0	0	2
Pachyptilus sp.	2	2	0	4
Aritellus simplex	0	0	10	10
Candacia bradyi	2	0	0	2
Tortanus sps	2	0	0	2
Acartia sewelli	5	0	0	5
Microsetella rosea	10	0	0	10
Miracia efferata	2	0	0	2
Macrosetella	2	0	0	2
Macrosetella gracilis	4	0	0	4
Macrosetella occulata	10	0	0	10
Longipedia weberi	0	5	0	5
Metis sp.	0	0	10	10
Oithona plumifera	0	25	0	25
Oithona similis	50	10	0	60
Oithona spinirostris	10	0	25	35
Oncaea venusta	77	80	0	157
Corycaeus sp.	672	370	490	1532
Corycaeus danae	0	0	230	230
Copilia mirabilis	3	0	0	3
Copilia vitera	5	0	0	5
Sappharina ovatolanceolata	9	2	0	11
Mormonilla Phasma	6	3	0	9
Mormonilla minor	28	0	3	31
Immature	308	135	500	943
Total	**4030**	**2850**	**2866**	**9746**

Table 5.14 Temporal variations of numerical abundance Copepods at 500-1000m layer of the BoB

	SIM	SM	WM	Total
Undinula vulgaris	50	0	0	50
Cosmocalanus darwini	2	150	0	152
Paracalanus sp.	10	0	0	10

Acrocalanus	10	50	0	60
Mecynocera clausi	10	0	0	10
Eucalanus attenuatus	28	7	18	53
Eucalanus bungii	2	0	0	2
Eucalanus elongatus	66	5	8	79
Eucalanus longiceps	18	0	0	18
Eucalanus Sewelly	0	0	3	3
Pareucalanus sewelli	5	0	0	5
Rhincalanus gigas	2	0	0	2
Rhincalanus cornutus	10	8	18	36
Rhincalanus nasutus	18	0	15	33
Subeucalanus crassus	82	0	0	82
Subeucalanus mucronatus	65	20	25	110
Subeucalanus pileatus	87	75	35	197
Subeucalanus subcrassus	10	80	25	115
Subeucalanus subtenuis	8	2	0	10
Clausocalanus arcuicornis	20	0	0	20
Drepanopsis orbus	3	12	1	16
Monacilla typica	2	0	0	2
Spinocalanus magnus	5	2	15	22
Spinocalanus spinosus	6	0	0	6
Cephalophanes frigidus	2	0	0	2
Chiridius Gracilis	2	0	0	2
Gaetanus armiger	9	0	45	54
Gaetanus kruppi	10	0	47	57
Gaetanus pileatus	0	5	60	65
Gaidius brevispinus	2	0	0	2
Gaidius tenuispinus	0	3	0	3
Euchirella areata	8	18	0	26
Euchirella bella	2	0	0	2
Euchirella bitumida	12	8	4	24
Euchirella brevis	3	5	0	8
Euchirella curta	2	0	0	2
Euchirella messinensis	1	0	2	3
Euchirella pulchera	63	20	0	83
Euchirella rostrata	35	2	10	47
Euchirella venusta	3	0	0	3
Euchaeta concinna	4	0	0	4
Euchaeta longicornis	2	0	0	2
Euchaeta plana	0	0	5	5
Euchaeta rimana	2	0	0	2

Euchaeta spinosa	4	0	0	4
Pareuchaeta barbata	4	0	1	5
Pareuchaeta malayensis	18	3	0	21
Pareuchaeta simplex	1	0	0	1
Phaenna spinifera	2	0	9	11
Xanthocalanus amabilis	3	0	1	4
Scottocalanus australis	0	0	5	5
Scottocalanus dauglishi	11	0	5	16
Scottocalanus helenae	5	0	5	10
Scottocalanus elongatus	19	0	20	39
Scottocalanus farrani	2	0	0	2
Scottocalanus longifurca	1			1
Scottocalanus longispinus	2	0	2	4
Scottocalanus persecans	1	5	0	6
Scottocalanus securifrons	0	2	1	3
Scaphocalanus elongatus	0	0	15	15
Scaphocalanus impar	0	2	0	2
Scaphocalanus magnus	16	11	125	152
Llophothrix frontalis	1	0	30	31
Scolecithrix bradyi	0	0	150	150
Scolecithrix danae	30	0	0	30
Scolecithricella ctenopus	65	49	20	134
Scolecithricella bradyi	15	0	115	130
Scolecithricella dentatta	3	6	0	9
Scolecithricella emarginata	6	0	0	6
Scolecithricella modia	0	0	10	10
Amallothrix paravalida	22	30	15	67
Scolecithricella propinqua	0	60	0	60
Scolecitrichopsis tenuipus	0	0	2	2
Scolecithricella tropica	0	0	10	10
Amallothrix valida	3	0	20	23
Scolecithricella vittatta	2	0	5	7
Pseudoamallothrix indica	0	12	0	12
Xanthocalanus irritans	0	5	0	5
Temora discaudata	0	0	40	40
Metridia brevicauda	142	200	125	467
Metridia okotensis	24	10	8	42
Metridia princeps	17	2	12	31
Metridia venusta	31	95	40	166
Pleuromamma abdominalis	51	95	45	191
Pleuromamma gracilis	8	10	0	18

Pleuromamma indica	140	270	0	410
Pleuromamma piseki	3	0	0	3
Pleuromamma xiphias	2	15	0	17
Gaussia princeps	8	2	4	14
Lucicutia bicornuta	35	75	0	110
Lucicutia flavicornis	50	20	39	109
Lucicutia challengeri	385	60	420	865
Lucicutia clausi	15	0	125	140
Lucicutia curta	13	0	25	38
Lucicutia longicornis	0	0	105	105
Lucicutia lucida	80	20	23	123
Lucicutia maxima	0	15	0	15
Lucicutia ovalis	0	0	40	40
Lucicutia wolfendeni	2	48	0	50
Lucicutia ovalis	2	65	80	147
Heterorhabdus abyssalis	2	6	0	8
Heterorhabdus clausi	0	0	22	22
Heterorhabdus compactus	6	13	55	74
Heterorhabdus fistulosus	5	0	0	5
Heterorhabdus longicornis	10	0	31	41
Heterorhabdus pacificus	27	0	4	31
Heterorhabdus pappiliger	0	0	127	127
Heterorhabdus robustus	2	10	0	12
Heterorhabdus spinifrons	3	2	0	5
Heterorhabdus subspinifrons	6	5	55	66
Heterorhabdus tanneri	6	0	0	6
Disseta palaumboi	11	8	14	33
Disseta scopularis	3	0	12	15
Heterostylites longicornis	6	8	0	14
Heterostylites major	2	12	11	25
Mesorhabdus angustuas	6	35	27	68
Mesorhabdus brevicaudatus	2	0	21	23
Hemirhabdus sp.	2	0	0	2
Centraugaptilus Rattrayi	4	0	0	4
Euaugaptilus Angustus	6	0	4	10
Euaugaptilus bullifer	3	0	0	3
Euaugaptilus digitatus	0	2	0	2
Euaugaptilus Farrani	4	0	5	9
Euaugaptilus indicus	0	0	3	3
Euaugaptilus laticeps	2	0	0	2
Euaugaptilus longimanus	0	15	0	15

Euaugaptilus magnus	8	6	4	18
Euaugaptilus mixtus	0	23	4	27
Euaugaptilus nodifrons	1	2	10	13
Euaugaptilus nudus	12	0	0	12
Euaugaptilus oblongus	0	0	15	15
Euaugaptilus squamatus	8	0	0	8
Augaptilus anceps	9	0	4	13
Augaptilus glacialis	8	2	0	10
Augaptilus longicaudatus	0	0	29	29
Haloptilus longicornis	3	16	285	304
Haloptilus ornatus	25	3	9	37
Haloptilus setuliger	11	0	5	16
Haloptilus spiniceps	6	8	0	14
Aritellus simplex	2	0	0	2
Nullosetigera bidentatus	2	0	0	2
Nullosetigera impar	0	6	0	6
Nullosetigera mutatus	16	0	0	16
Candacia bradyi	12	40	0	52
Candacia pacifica	0	8	0	8
Tortanus sps	6	0	0	6
Acartia negligens	0	0	90	90
Microsetella rosea	0	20	10	30
Miracia efferata	14	0	0	14
Macrosetella gracilis	4	0	0	4
Euterpina acutifrons	2	0	10	12
Longipedia weberi	1	0	0	1
Oithona plumifera	0	12	168	180
Oithona similis	54	0	0	54
Oithona spinirostris	5	0	0	5
Oncaea venusta	75	520	375	970
Corycaeus sp.	1160	0	1075	2235
Corycaeus catus	0	680	0	680
Copilia vitera	2	0	0	2
Sappharina ovatolanceolata	4	0	0	4
Mormonilla Phasma	15	30	90	135
Mormonilla minor	5	0	0	5
Immature	599	340	835	1774
Total	**4112**	**3491**	**5442**	**13045**

Table 5.15 a to e. Time zone based vertical abundance of Orders of sub class Copepod from the BoB

Order calanoida	17-19 hrs	19-22 hrs	22-02 hrs	02-06 hrs	06-09 hrs	09-11 hrs	11-14 hrs	14-17 hrs
TT-0	96	3414	932	2932	1238	372	432	1551
TT-BT	403	3077	3062	5070	5006	2492	2724	8094
BT-300	40	61	38	233	93	0	63	108
300-500	74	419	166	413	439	0	86	407
500-1000	158	137	52	528	185	0	170	356

(a)

Order Cyclopoida	17-19 hrs	19-22 hrs	22-02 hrs	02-06 hrs	06-09 hrs	09-11 hrs	11-14 hrs	14-17 hrs
TT-0	1	208	45	98	49	15	12	37
TT-BT	2	24	290	237	55	100	40	625
BT-300	0	3	1	5	0	0	2	1
300-500	2	7	2	20	3	0	0	1
500-1000	10	20	1	3	5	0	10	3

(b)

Order Harpacticoida	17-19 hrs	19-22 hrs	22-02 hrs	02-'06 hrs	06-'09 hrs	09-11 hrs	11-14 hrs	14-17 hrs
TT-0	0	49	0	282	53	31	15	30
TT-BT	20	219	95	148	35	25	152	452

BT-300	0	3	0	5	0	0	0	0
300-500	0	0	0	6	8	0	0	4
500-1000	0	3	0	8	0	0	1	4

(c)

Order Mormonilloida	17-19 hrs	19-22 hrs	22-02 hrs	02-'06 hrs	06-'09 hrs	09-11 hrs	11-14 hrs	14-17 hrs
TT-0	2	0	0	6	6	0	0	4
TT-BT	0	3	2	48	0	0	2	0
BT-300	0	0	4	1	2	0	0	3
300-500	0	16	0	4	5	0	0	3
500-1000	15	0	0	0	0	0	0	0

(d)

Order Poecilistomatoida	17-19 hrs	19-22 hrs	22-02 hrs	02-'06 hrs	06-'09 hrs	09-11 hrs	11-14 hrs	14-17 hrs
TT-0	24	1493	403	1497	923	448	167	848
TT-BT	100	1048	3032	1794	1535	880	876	5467
BT-300	10	28	17	143	58	0	17	40
300-500	13	97	48	184	126	0	13	68
500-1000	120	99	7	460	210		62	98

(e)

Table 5.16. Time zone based vertical abundance of families coming under the order calanoida from the BoB

Acartiidae	17-19 hrs	19-22 hrs	22-02 hrs	02-'06 hrs	06-'09 hrs	09-11 hrs	11-14 hrs	14-17 hrs
TT-0	10	0	0	35	16	0	10	69

TT-BT	0	3	12	10	0	0	0	45
BT-300	0	0	2	0	0	0	0	0
300-500	0	0	0	0	0	0	0	5
500-1000	0	0	0	0	0	0	0	0

Aetideidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	2	248	3	20	3	0	0	6
TT-BT	5	34	42	97	81	50	45	240
BT-300	1	0	1	7	2	0	0	3
300-500	5	15	2	9	12	0	16	30
500-1000	5	11	4	70	6	0	6	21

Aritellidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	0	0	0	0	0	0	0	0
TT-BT	0	0	0	0	0	0	4	0
BT-300	0	0	0	0	0	0	0	0
300-500	0	0	0	0	0	0	0	0
500-1000	6	0	0	8	6	0	0	0

Augaptilidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	0	5	15	0	0	0	0	0
TT-BT	5	5	5	55	8	0	2	15

BT-300	0	0	0	0	0	0	0	0
300-500	0	0	0	4	4	0	1	1
500-1000	0	9	0	37	5	0	8	12

Candacidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	5	55	47	104	47	15	2	39
TT-BT	3	94	75	232	155	20	30	98
BT-300	0	2	0	0	0	0	3	5
300-500	0	0	0	0	2	0	0	0
500-1000	0	0	0	0	0	0	0	0

Centropagidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	0	240	19	40	2	35	2	17
TT-BT	0	15	0	3	0	0	1	10
BT-300	0	0	0	2	0	0	0	0
300-500	0	0	0	0	0	0	0	0
500-1000	0	0	0	0	0	0	0	0

Clausocalanidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	0	0	15	0	0	0	0	36
TT-BT	0	0	150	20	0	0	0	70
BT-300	0	0	2	0	0	0	0	0

300-500	0	0	0	3	0	0	0	0
500-1000	0	0	0	10	0	0	0	10

Eucalanidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	4	565	125	381	107	34	50	90
TT-BT	130	296	328	371	458	485	195	552
BT-300	26	11	21	65	10	0	15	0
300-500	29	120	81	211	132	0	41	87
500-1000	73	3	12	142	2	0	13	62

Euchaetidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	10	362	106	283	67	38	12	152
TT-BT	20	260	287	620	295	355	212	1456
BT-300	0	5	0	2	2	0	3	5
300-500	0	0	2	10	19	0	0	5
500-1000	3	0	0	11	0	0	5	5

Calanidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	7	169	21	518	48	8	28	226
TT-BT	0	165	95	235	321	120	185	1073

BT-300	0	0	0	14	2	0	8	4
300-500	0	5	0	10	6	0	3	7
500-1000	0	0	0	0	50	0	0	0

Heterorhabdidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	0	157	10	0	0	0	2	1
TT-BT	15	1	0	0	15	0	2	55
BT-300	1	5	0	27	5	0	4	0
300-500	3	3	2	15	20	0	8	27
500-1000	4	15	4	20	7	0	3	5

Lucicutiidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	0	345	25	70	14	0	15	30
TT-BT	0	125	0	25	35	0	40	405
BT-300	0	3	0	3	1	0	0	5
300-500	3	102	0	5	87	0	0	22
500-1000	40	52	3	87	78	0	90	110

Mecynoceridae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	3	0	0	38	5	0	5	0
TT-BT	0	0	10	5	0	0	0	5

BT-300	0	2	1	0	1	0	0	2
300-500	0	30	0	0	0	0	0	0
500-1000	0	10	0	0	0	0	0	0

Metridiidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	20	401	22	97	28	0	0	165
TT-BT	105	1018	115	917	760	25	110	475
BT-300	8	23	8	54	64	0	28	17
300-500	18	127	60	119	142	0	6	146
500-1000	6	33	9	100	27	0	0	113

Paracalanidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	35	630	475	1165	828	200	285	570
TT-BT	115	960	1830	2430	2735	1245	1580	3290
BT-300	4	4	0	48	0	0	0	48
300-500	0	5	15	0	0	0	0	50
500-1000	0	0	0	0	0	0	0	0

Phaennidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**

TT-0	0	10	0	0	1	0	0	0
TT-BT	0	0	0	0	0	0	60	5
BT-300	0	0	1	0	3	0	0	0
300-500	4	0	0	0	0	0	0	0
500-1000	3	0	0	0	1	0	0	1

Pontellidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	0	42	9	67	34	6	16	11
TT-BT	0	3	25	6	20	9	71	0
BT-300	0	0	0	2	0	0	0	1
300-500	0	0	0	0	0	0	0	0
500-1000	0	0	0	0	0	0	0	0

Pseudocalanidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	0	0	0	0	0	0	0	0
TT-BT	0	0	0	7	0	0	0	0
BT-300	0	0	0	0	0	0	0	0
300-500	0	0	0	0	0	0	0	0
500-1000	5	0	4	9	0	0	0	0

Scolecithricidae	**17-19 hrs**	**19-22 hrs**	**22-02**	**02-06**	**06-09**	**09-11 hrs**	**11-14**	**14-17 hrs**

			hrs	hrs	hrs		hrs	
TT-0	0	145	30	43	7	2	0	97
TT-BT	5	46	38	37	78	142	117	295
BT-300	0	5	2	9	2	0	2	18
300-500	12	12	4	25	15	0	11	27
500-1000	13	4	16	28	3	0	45	17

Temoridae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	0	40	10	71	31	34	5	42
TT-BT	0	52	50	0	45	41	70	5
BT-300	0	1	0	0	1	0	0	0
300-500	0	0	0	0	0	0	0	0
500-1000	0	0	0	0	0	0	0	0

Tortanidae	**17-19 hrs**	**19-22 hrs**	**22-02 hrs**	**02-06 hrs**	**06-09 hrs**	**09-11 hrs**	**11-14 hrs**	**14-17 hrs**
TT-0	0	0	0	0	0	0	0	0
TT-BT	0	0	0	0	0	0	0	0
BT-300	0	0	0	0	0	0	0	0
300-500	0	0	0	2	0	0	0	0
500-1000	0	0	0	6	0	0	0	0

Comapring Calanoid Copepods at Mixed layer Depth					
Table 5.17 SM			**Table 5.18 WM**		
species	SM`99	SM`02	species	WM`99	WM`02
Nannocalanus minor	672	75	Nannocalanus minor	118	705
Canthocalanus pauper	1621	515	Canthocalanus pauper	828	405
Undinula vulgaris	624	249	Undinula vulgaris	293	290
Undinula darwini	1091	270	Undinula darwini	172	265
Eucalanus attenuatus	69	84	Eucalanus attenuatus	195	47
E.elongatus	49	14	E.elongatus	596	60
E.inermis		57	E.inermis	0	25
Pseudocalanus sps.		2	Rhincalanus cornutus	42	130
E. pseudattenuatus		36	R.nasutus	109	0
R.cornutus	185	10	Subeucalanus crassus	90	125
R.nasutus	22	2	S.longiceps	0	30
Subeucalanus crassus	295	38	S.mucronatus	194	50

S.longiceps	0	10	S.pileatus	2922	830
S.mucronatus	100	20	S.subcrassus	150	265
S.pileatus	4239	705	S.subtenuis	130	0
S.subcrassus	2189	50	Paracalanus acculeatus	300	9170
S.subtenuis	167	55	P.indicus	10430	0
Paracalanus	1105	0	P.parvus	1135	0
P.acculeatus	11409	3467	Acrocalanus	0	8575
P.indicus	2075	0	Acrocalanus gibber	4381	0
P.parvus	867	0	A.gracilis	600	0
Acrocalanus	1290	2930	A.longicornis	353	0
Acrocalanus gibber	5946	0	A.monachus	150	0
A.longicornis	35	0	A.giesbrechti	1	0
A.monachus	558	0	Gaetanus kruppi	4	0
Aetideus armatus	20	5	Euchirella amoena	3	10
Aetidiopsis giesbrechti	25	0	E.acuta	0	20
A.bradyi	8	0	E.bitumida	3	0
G. miles	1	0	E.brevis	0	90
E.bitumida	8	3	E.messinensis	41	0
E.indica	4	0	E.pulchera	53	0
E.messinensis	32	0	E.rostrata	10	0
E.pulchera	13	0	E.venusta	2	0
E.rostrata	16	5	C.streetsi	80	0
C.sewelli	1	0	Euchaeta concinna	318	200
C.streetsi	5	0	E.plana		25
Euchaeta concinna	439	10	E.rimana	777	735
E.rimana	642	550	E.wolfendeni	305	75
E.wolfendeni	209	120	Uneuchaeta bispinosa	10	0
Uneuchaeta	128	0	Phaenna spinifera	0	53

bispinosa					
U.amonea	200	0	Calocalanus farrani	1400	0
Phaenna spinifera	0	88	Calocalanus pavo	9	0
Mecynocera clausi	1	0	Scottocalanus dauglishi	1	0
Clausocalanus arcuicornis	54	20	S.farrani	3	0
Calocalanus pavo	407	95	S.persecans	2	0
C. plumulosus	5	24	S.securifrons	34	0
C. styliramis	0	10	Scaphocalanus affinis	20	0
S.elongatus	0	20	S.elongatus	67	150
S.securifrons	2	0	S.furcatus	2	0
Scaphocalanus affinis	1		Lophothrix frontalis	1	200
S.furcatus	2		Scolecithrix bradyi	68	150
L.frontalis	1	0	S.danae	110	150
Scolecithrix bradyi	24	25	S.nicobarica	3	520
S.danae	112	110	scolecithricella abyssalis	27	0
S.nicobarica	6	0	S. ctenopus	30	850
S. ctenopus	66	0	S.indica		500
Centropages furcatus	776	85	Amallothrix indica	1	0
Pseudodiaptomus aurivilli	127	10	Xanthocalanus cornifer	0	5
P.serricaudatus	300	0	Centropages furcatus	363	10
Temora discaudata	244	95	C.calanicus	29	0
T.turbinata	2002	405	C.tenuiremis	3	25
T.stylifera	0	85	Temora discaudata	1896	375
Pleuromamma	529	25	T.turbinata	68	25

abdominalis					
p.gracilis	498	0	T.stylifera	0	25
p.indica	1949	25	Metridia brevicauda		120
P.piseki	0	1	Pleuromamma abdominalis	398	685
P.xiphias	1	0	P.borealis		22
Gaussia princeps	0	2	p.gracilis	330	0
Lucicutia bicornuta	10	0	p.indica	1217	925
L. flavicornis	229	0	P.piseki	3	0
L.clausi	60	0	P.xiphias	8	200
L.ovalis		55	Gaussia sewelli	2	0
H. longicornis		120	Lucicutia bicornuta	3	0
H.pappiliger	260	0	L. flavicornis	387	0
H.robustus	8		L.clausi	47	15
H.subspinifrons	1		L.longiserrata		125
Heterostylites longicornis		4	L.lucida	0	250
H.longiceps		40	L.macrocera		0
Candacia aethiopica	2		L.magna		0
C.bradyi	328	220	L.maxima	20	0
C.catula	7		L.ovalis		615
C.curta	18		L.pacifica	1	0
C.discaudata	344		L.wolfendeni	2	0
C.pachydactyla	0	50	Heterorhabdus abyssalis	2	0
C.truncata	4		H.clausi	4	0
Paracandacia bispinosa	1		H.pappiliger	312	0
P.simplex	308	12	Disseta palaumboi	1	0
P.truncata		50	D.scopularis	11	0

Calanopia aurivilli		15	Heterostylites longicornis	2	0
C.elliptica	142	0	H.major	21	0
C.minor	29	30	Augaptiluslongicaudatus	1	0
Labidocera arcutifrons	2	1	Haloptiluslongiceps	10	0
L.detruncata	7	0	H.longicornis	21	0
L.minuta	0	10	H.ornatus	10	0
L.pavo	91	15	H.spiniceps	7	0
L.pectinata	10	0	Candacia bradyi	15	390
Pontellina plumata	0	70	C.columbiae	119	220
Acartia Danae		25	C.curta	5	0
A. minuta		80	C.discaudata	49	8
A. negligens	30	50	C.pachydactyla	0	2
			C.truncata	3	15
			Paracandacia truncata	48	163
			Calanopia.elliptica	11	0
			C.minor	10	0
			Labidocera arcutifrons	142	8
			L.detruncata	19	20
			L.minuta	3	0
			L.pavo	0	135
			L.pectinata	0	30
			Pontellina plumata	74	230
			P.herdmani	12	0
			Pontella investigatoris	19	0
			P.armata	56	0
			Acartia negligens	8	75
			A. sewelli		140

Table 5.19. Seasonal occurrence of copepods in the EEZ of eastcoast of India

	SIM	SM	WM	AD-MF
Nannocalanus minor	+	+	+	+
Canthocalanus pauper	+	+	+	+
Undinula vulgaris	+	+	+	+
U. vulgaris var gieshbrecti	-	-	-	+
Cosmocalanus darwini	+	+	+	+
Bradycalanus typicus	-	-	-	+
Neocalanus sp.	+	+	-	-
Megacalanus princeps	-	-	-	+
Megacalanus longicornis	-	-	-	+
Paracalanus spp.	+	+	+	+
P. acculeatus.	-	+	+	+
Acrocalanus spp.	+	+	+	+
Mecynocera clausi	+	+	+	+
Calocalanus pavo	+	+	-	-
C. plumulosus	+	+	+	-
C. styliramis	-	+	-	-
Eucalanus attenuatus	+	+	+	+
E. bungii	+	-	+	+
E. elongatus	+	+	+	+
E. hyalinus	+	-	-	-
E. inermis	+	+	+	+
E. longiceps	+	-	-	-
E. sewelli	-	-	+	-
Pseudocalanus spp.	-	+	-	-
E. pseudattenuatus	+	+	+	+
Pareucalanus sewelli	+	-	+	-
Rhincalanus gigas	+	+	-	-
R. cornutus	+	+	+	+
R. nasutus	+	+	+	+
Subeucalanus crassus	+	+	+	+
S. longiceps	-	+	+	-
S. mucronatus	+	+	+	+
S. pileatus	+	+	+	+
S. subcrassus	+	+	+	+
S. subtenuis	+	+	+	+
Clausocalanus arcuicornis	+	+	+	+
C. farrani	-	-	-	+
Drepanopsis orbus	+	+	+	+

Monacilla typica	+	+	-	+
Spinocalanus magnus	+	+	+	+
S.spinosus	+	-	-	+
Cephalophanes frigidus	+	-	-	+
Aetideus armatus	+	+	-	-
A. giesbrechti	-	-	-	+
Aetidiopsis giesbrechti	-	-	-	+
A. acutus	+	-	-	+
A. bradyi	+	-	-	+
Chiridius gracilis	+	-	-	-
Undinella spinifer	+	-	-	-
Gaetanus armiger	+	+	+	+
G. kruppi	+	+	+	+
G. latifrons	+	-	-	+
G. miles	+	+	-	+
G. minor	+	+	-	+
G. pileatus	+	+	+	+
Gaidius brevispinus	+	-	-	+
G. minutus	-	-	+	+
G. tenuispinus	+	+	-	-
Euchirella amoena	+	+	+	+
E. acuta	+	-	+	-
E. areata	+	+	-	+
E. bella	+	-	-	-
E. bitumida	+	+	+	+
E. brevis	+	+	+	-
E. curta	+	-	-	-
E. curticauda	+	+	+	+
E. galeata	-	-	+	-
E. indica	+	-	+	+
E. messinensis	+	+	+	+
E.pulchera	+	+	+	+
E. rostrata	+	+	+	+
E. venusta	+	-	-	+
Pseudochirella obesa	-	-	-	+
Chirundina indica	-	-	+	+
C. sewelli	-	-	-	+
C. streetsi	+	+	-	+
Chirudinella cara	+	-	-	+
Valdiviella oligarthra	-	-	-	+
Euchaeta concinna	+	+	+	+

E. flava	+	-	-	+
E. indica	-	+	-	-
E. longicornis	+	-	-	-
E. media	+	-	-	+
E. minuta	+	-	-	-
E. plana	+	+	+	+
E. pubera	-	-	-	+
E. rimana	+	+	+	+
E. spinosa	+	-	-	+
E. tenuis	+	-	-	-
E. wolfendeni	+	+	+	+
Pareuchaeta barbata	+	-	+	+
P. malayensis	+	+	-	+
P. scotti	+	-	-	+
P. simplex	+	-	-	-
Uneuchaeta bispinosa	-	-	-	+
U. major	-	-	-	+
U. amonea	-	-	-	+
Bradyidius angustus	-	-	-	+
Phaenna spinifera	+	+	+	+
Xanthocalanus cornifer	-	-	+	+
Onchocalanus affinis	-	-	-	+
Xanthocalanus amabilis	+	-	+	+
Scottocalanus australis	-	-	+	-
S. dauglishi	+	+	+	+
S. helenae	+	-	+	+
S. elongatus	+	+	+	+
S. farrani	+	-	-	+
S. investigatoris	-	-	-	+
S. longifurca	+	-	-	-
S. longispinus	+	-	+	+
S. magnus	+	+	+	-
S. persecans	+	+	-	+
S. securifrons	+	+	+	+
S. setosus	+	-	-	+
S. terranovae	+	-	-	-
Scaphocalanus affinis	+	-	+	-
S. elongatus	+	-	+	-
S. impar	+	+	-	-
S. magnus	+	+	+	+
Lophothrix humilifrons	+	-	-	+

L. frontalis	+	-	+	+
Scolecithrix bradyi	+	+	+	+
S. danae	+	+	+	+
S. nicobarica	+	+	+	+
S. ctenopus	+	+	+	+
S. arcuata	-	-	-	+
S. bradyi	+	+	+	+
S. dentatta	+	+	-	-
S. emarginata	+	-	-	+
S. indica	-	-	+	-
S. lamellifer	-	-	-	+
S. lophophora	-	-	-	+
S. marginata	+	-	-	-
S. modia	-	-	+	+
S. paravalida	+	+	+	+
S. profunda	-	-	-	+
S. propinqua	+	+	+	+
S. tenuipus	+	-	+	+
S. tenuiserrata	-	-	+	-
S. tropica	-	-	+	-
S.valida	+	-	+	+
S.vittatta	+	-	+	+
Amallothrix emarginata	+	+	-	+
A. indica	+	+	-	+
A. irritans	-	+	-	-
A. obtusifrons	-	-	-	+
Centropages furcatus	+	+	+	-
C. aurisini	+	-	-	-
C. calanicus	+	-	-	-
C. tenuiremis	+	+	+	-
C. violaceous	+	-	+	-
Pseudodiaptomus aurivilli	-	+	-	-
P. serricaudatus	-	-	-	-
Temora discaudata	+	+	+	-
T. turbinata	+	+	+	-
T. stylifera	+	+	+	-
Metridia brevicauda	+	+	+	+
M. okotensis	+	+	+	-
M. pacefica	-	-	-	+
M. princeps	+	+	+	+
M. venusta	+	+	+	-

Pleuromamma abdominalis	+	+	+	+
P. borealis	+	-	+	-
P. gracilis	+	+	+	+
P. indica	+	+	+	+
P. piseki	+	+	+	+
P. quadrangulata	-	-	-	+
P. xiphias	+	+	+	+
Gaussia princeps	+	+	+	+
Lucicutia bicornuta	+	+	-	+
L. flavicornis	+	+	+	+
L. challengeri	+	+	+	+
L. clausi	+	+	+	+
L. curta	+	-	+	-
L. longicornis	-	+	+	+
L. longiserrata	+	-	+	+
L. lucida	+	+	+	-
L. macrocera	-	+	-	+
L. magna	+	-	-	+
L. maxima	+	+	-	+
L. ovalis	+	+	+	-
L. wolfendeni	+	+	-	+
Lucicutia ovalis	+	+	+	+
Heterorhabdus abyssalis	+	+	+	+
H. clausi	+	+	+	+
H. compactus	+	+	+	+
H. fistulosus	+	+	+	+
H. longiceps	-	-	-	+
H. longicornis	+	+	+	+
H. pacificus	+	-	+	+
H. pappiliger	+	+	+	+
H. robustus	+	+	+	-
H. spinifrons	+	+	+	+
H. subspinifrons	+	+	+	+
H. tanneri	+	-	-	-
H. tenuis	+	-	-	+
H. vipera	+	-	-	-
Disseta palaumboi	+	+	+	+
D. scopularis	+	-	+	+
Heterostylites longicornis	+	+	+	+
H. major	+	+	+	-
Mesorhabdus angustuas	+	+	+	+

M. brevicaudatus	+	+	+	+
Hemirhabdus sp.	+	-	-	-
Hemirhabdus grimaldi	-	-	+	-
Centraugaptilus rattrayi	+	-	+	-
Isias tropica	+	-	-	-
Euaugaptilus Angustus	+	-	+	-
E. bullifer	+	-	-	-
E. digitatus	-	+	-	-
E. farrani	+	-	+	-
E. hulsmannae	-	-	-	+
E. indicus	-	-	+	-
E. laticeps	+	-	-	-
E. longimanus	-	+	-	+
E. magnus	+	+	+	+
E. mixtus	-	+	+	-
E. nodifrons	+	+	+	+
E. nudus	+	-	-	-
E. oblongus	+	-	+	-
E. squamatus	+	-	-	-
Augaptilus anceps	+	-	+	-
A. glacialis	+	+	+	+
A. longicaudatus	-	-	+	+
Haloptilus acutifrons	-	+	+	+
H. longiceps	+	+	-	+
H. longicornis	+	+	+	+
H. ornatus	+	+	+	+
H. setuliger	+	-	+	+
H. spiniceps	+	+	+	+
H. spinifer	-	-	-	+
Pachyptilus sp.	+	+	-	-
P. simplex	-	-	-	+
Aritellus setosus	-	-	-	+
Aritellus simplex	+	-	+	+
Nullosetigera bidentatus	+	-	-	+
P. giesbrechti	-	-	-	+
P. impar	-	+	-	-
P. mutatus	+	-	-	+
Candacia aethiopica	-	-	-	+
C. bipinnata	+	-	+	-
C. bradyi	+	+	+	+
C. catula	-	-	-	+

C. columbiae	-	-	+	+
C. curta	+	-	+	-
C. discaudata	+	-	+	+
C. longimana	+	-	-	-
C. pachydactyla	+	+	+	+
C. pacifica	+	+	-	-
C. tenuimana	+	-	-	-
C. truncata	+	-	+	+
P. simplex	+	+	-	-
P. truncata	+	+	+	-
Calanopia aurivilli	-	+	-	-
C. elliptica	-	-	-	+
C. minor	+	+	-	-
Labidocera acutifrons	+	+	+	-
L. detruncata	+	-	+	-
L. minuta	+	+	-	-
L. pavo	+	+	+	+
L. pectinata	+	+	+	-
Pontellina plumata	+	+	+	-
Pontellopsis macronyx	-	+	-	-
P. regalis	+	-	-	-
P. scotti	+	-	-	-
P. securifer	+	-	-	-
P. spiniceps	+	-	-	-
Tortanus sps.	+	-	-	-
Acartia Danae	+	+	-	-
A. minuta	+	+	-	+
A. negligens	+	+	+	+
A. sewelli	+	+	+	-
Microsetella rosea	+	+	+	+
Miracia efferata	+	+	+	-
Macrosetella	+	-	+	+
M. gracilis	+	-	-	-
M.occulata	+	+	-	+
Clytemnestra sp.	+	+	+	-
Clymenestra scutellata	+	-	-	+
Euterpina acutifrons	+	+	+	+
Aegisthus mucronatus	+	-	+	-
Longipedia weberi	+	+	+	-
Metis sp.	-	-	+	+
Oithona plumifera	+	+	+	+

O. similis	+	+	-	-
O. spinirostris	+	-	+	-
Oncaea venusta	+	+	+	+
Corycaeus spp.	+	+	+	+
C. catus	+	+	+	+
C. danae	+	+	+	+
Copilia mirabilis	+	+	+	+
C. quadrata	+	-	+	-
C. vitera	+	+	+	+
Sappharina spp.	+	+	-	+
S. auronitens	+	+	+	-
S. gemma	+	-	+	-
S. nigromaculata	+	+	+	+
S. opalina	+	+	+	+
S. ovatolanceolata	+	+	+	+
S. stelleta	+	+	+	+
Mormonilla phasma	+	+	+	+
M. minor	+	+	+	+
Immature	+	+	+	+

Table 5.20 Speceis composition of copepods before and after the cyclone in the Bay of Bengal

Before Cyclone	After Cyclone	Common
Aetideus bradyi	Amallothrix indica	A. negligens
Acrocalanus	Aetidiopsis giesbrechti	A. longicornis
Aetideus armatus	Augaptilus gracilis	A.monachus
Aetidiopsis giesbrechti	A. longicornis	Acrocalanus gibber
Calocalanus plumulosus	Aegisthus mucronatus	C. bradyi
Candacia catula	Calanopia calaninus	C. curta
C.sewelli	Candacia columbiae	C. danae
Candacia aethiopica	C. farrani	C. discaudata
Corycaeus sp.	C. tenuiremis	C. elliptica
E. indica	Clytemnestra sp.	C.minor
Euterpina acutifrons	Disseta palaumboi	C.streetsi
G. miles	D. scopularis	C. truncata
H. robustus	Euchirella amoena	C. vitera
H. subspinifrons	E. venusta	Calocalanus pavo
L. pavo	Gaetanus kruppi	Canthocalanus pauper
L. pectinata	G. sewelli	Centropages furcatus
Mecynocera clausi	Heterorhabdus clause	Clausocalanus arcuicornis
P. serricaudatus	H. longicornis	E. bitumida
P. simplex	H. ornatus	E. elongatus
Paracalanus sp.	Haloptilus longiceps	E. messinensis
Pseudodiaptomus aurivilli	H. spiniceps	E. rimana
Sappharina sps	Heterorhabdus abyssalis	E. rostrata
S. stelleta	Heterostylites longicornis	E. wolfendeni
U. amonea	H. major	Eucalanus attenuatus
	Lucicutia maxima	Euchaeta concinna
	L. minuta	H. pappiliger
	L. pacifica	L. flavicornis
	L. wolfendeni	L. clausi
	Mormonilla minor	L. detruncata
	Metis sp.	L. frontalis
	Pontellopsis armata	Labidocera arcutifrons
	P. herdmani	Lucicutia bicornuta
	Pleuromamma piseki	M. occulata
	Paracandacia truncate	Macrosetella sp.
	Pontella investigatoris	Microsetella rosea
	Pontellina plumata	Miracia efferata
	S. dauglishi	Nannocalanus minor
	S. elongates	Oithona plumifera

	S. farrani	Oncaea venusta
	S. persecans	P. acculeatus
	Scolecithricella abyssalis	P. gracilis
	Scaphocalanus echinatus	P. indica
	S.affinis	P. indicus
	S.furcatus	P. parvus
	Pontellopsis armata	P. xiphias
	Euchirella pulchra	Paracandacia bispinosa
	E.bitumida	Pleuromamma abdominalis
		R. cornutus
		R. nasutus
		S. ctenopus
		S. danae
		S. furcatus
		S. mucronatus
		S. nicobarica
		S. ovatolanceolata
		S. pileatus
		S. securifrons
		S. subcrassus
		S. subtenuis
		Scaphocalanus affinis
		Scolecithrix bradyi
		Subeucalanus crassus
		T. turbinata
		Temora discaudata
		Undinula darwini
		Undinula vulgaris
		Uneuchaeta bispinosa

Table5. 21. A table showing numerical abundance, average and percentage of various orders of copepod population in the mixed layer at the BoB before and after a super cyclone

Orders	Summer monsoon/before cyclone			Winter monsoon/after cyclone		
	Total	Average	%	Total	Average	%
ORDER CALANOIDA	45357	1194	57.3	32545	2712	66.3
ORDER HARPACTICOIDA	706	19	0. 9	211	18	0.43
ORDER CYCLOPOIDA	1325	35	1. 7	3138	262	6.46
ORDER POECILOSTOMATIOIDA	21085	555	26.6	7420	618	15.1
ORDER MORMONILLOIDA	0	0	0	7	7	0.01
IMMATURE	10682	297	13. 5	5765	524	11.7
TOTAL	79155	2100	100	49086	4141	100

Chapter VI

The Andaman Sea

6.1. Introduction

The Andaman Sea is the small and partially isolated portion of the northeastern Indian Ocean which lies enclosed between the coasts of Burma, Thailand and Malaysia on the east and the chains of the Andaman and Nicobar Islands and Sumatra on the west. Its narrowest part has a width of 35km and depth of 30m. It occupies an area of 6.02×10^5 km^2 and has a volume of 6.6×10^3 km^3 and an average depth of 1096m. The Andaman Sea contains a relatively extensive basin with a maximum depth of 4360m and uneven bottom topography. A north-south arc of volcanic islands and sea-mounts, including the Barren and Narcondam islands in the Andaman Sea, delimits this basin from 2 smaller basins on the north and south.

The feature which demarcates the Andaman Sea from the Bay of Bengal lies in the geological history of emergence and development of these two regions. The island arc forms a kind of barrier between Bay of Bengal which has more or less an even bottom topography and the Andaman Sea with its three major basins.

6.2. Results

6.2.1. Biological Environment of the Andaman Sea

During inter monsoon fall, the average surface and column primary productivity varied between 0.1 to 0.24 mgCm^{-3}d^{-1}. Biomass variation at different stations of the Andaman Sea ranged between 33-233 ml/1000m^3 in mixed layer depth where as 14 to 111 ml/1000m^3, 15 to 110 ml/1000m^3, 5 to 40 ml/1000m^3 and 4 to 67 ml/1000m^3 were the range of biomass at thermocline layer, BT–300m, 300-500m and 500-1000m depth strata respectively. An average of 55 ml/1000m^3 of biomass was recorded at different stations and different depth strata. Minimum deviations were observed at 300-500m depth strata (11.18 ml/1000m^3). Maximum deviations were obtained at mixed layer depth (163.11 ml/1000 m^3). The highest biomass recorded was at surface waters (233 ml/1000m^3) of the southern most station in the west of the Andaman (Fig 6.1).

The southern region of the Andaman Sea recorded more secondary productivity than northern side (av. 63.263 ml/1000m^3 against 43.44 ml/1000m^3). The western side of the Andaman Sea was more productive than the eastern side (60.78 ml/1000 m^3 at western side and 41.96 ml/1000m^3 at eastern side (Fig 6.2). The average zooplankton biomass at mixed layer during night exceeded the day value. But the mixed layer had the highest average biomass during day and night. Least biomass was recorded at 500-1000m depth (19.8 ml/1000m^3 during day and 7.2 ml/1000m^3 during night). The zooplankton concentrations at thermocline layer were lower than the upper (Fig 6.3). The lower layer of thermocline during day and night except at day sample of north western end of the Andaman stations (station no : 1213). The decrease of zooplankton biomass observed at the mixed layer might be to avoid high heat and light during day time.

During inter monsoon fall, percentage of copepods were higher at 500-1000m depth strata and the minimum value obtained was at BT-300m depth strata. Copepods constitute 86% of the zooplankton obtained from the mixed layer depth. Then it reduced to 72% at thermocline layer. At BT-300m layer it reached 67% and after that the percentage of copepods in zooplankoton reached its maximum value of 88% (Fig 6.4).

Ostracods were the second dominant group up to the third strata. But in the lower two strata, Chartognaths came next to replacing ostracods. Chaetognaths were found maximum at the lower most strata (9.19%). Ostracods were found maximum at third strata (9.7%). Percentage of fish eggs and larvae were less than 2% in all the depth strata in all stations (Fig 6.4). Maximum percentage of Ichthyoplankton was obtained at the surface layer. Considering the spatial difference between zooplankton biomass at the East and West Andaman

Sea, copepod constitute 97% at the East while at the West Andaman sea, they were represented by only 93% (Fig.6.5 &. Fig.6.6)

6.2.2. Copepods of the Andaman Sea

Out of 23 families of the order Calanoida recorded from the BoB, Four families *viz;* Centropagidae, Diaplomidae, Temoridae and Tortanidae were not present in the inter monsoon fall season from the Andaman Sea. A total of 200 copepods belonging to 19 families were represented (Table 6.1) in all the depth strata of the Andaman Sea during inter monsoon fall. Vertical distribution of mesozooplankton, especially calanoid copepods in the eastern Andaman Sea was studied by Padmavati *et.al .,* 2008 during Inter monsoon Fall in 1996, six year before this study. They listed only 120 copepod species during their study period. Five deeper living calanoid copepod species such as *Tharybis sagamiensis, Aetideus acutus, Temorites brevis*, *Pseudoaugaptilus orientalis* and *Candacia columbiae* were obtained during that study while *Heterorhabdus pacificus, H. setuliger* and *Euaugaptilus squamatus.* While *Bradycalanus typicus, Onchocalanus affinis, Cephalophanes frigidus, Euchirella venusta, E.maxima, Pareucheata scotti, Scottocalanus investigatoris, Scolecithricella propinqua, Metridia pacifica, Lucicutia macrocera, L.lucida, Heterorhabdus pacificus, Mesorhabdus angustus, M. brevicauda, Dissetta palumboi, D.scopularis, Euaugaptilus facilis,Nullosetigera helgae* and *Aritellus giesbrechti.* were obtained during the present study which are not only deeper living calanoid copepod but also reported first time from the study area. Endemic species obtained during the study period include, *Centropages tenuiremis, Acartia minor, A.sewelli, Scottocalanus daughlishi, Pontellopsis scotti* and *Pontella investigatoris.*

Acartiidae (BT-300m), Mecynoceridae (500-1000m) and Clausocalanidae (300-500m) were recorded from single depth strata. Megacalanidae, Pseudocalanidae and Pontellidae were recorded from 2 depth strata both from lower most 2 depth strata and Megacalanidae, Pseudocalanidae and Pontellidae from mixed layer depth as well as 300-500m depth. Phaennidae and Lucicutiidae were absent in the mixed layer but distributed in deeper strata. Family Candaciidae was absent in lower depth strata except for a minor representation at 500-1000m depth.

10 families of the order Calanidae were observed in all depth strata of the Andaman Sea (Table 6.2). They were Calanidae, Paracalanidae, Eucalanidae, Aetideidae, Euchaetidae, Scolecithricidae, Metrididae, Heterorhabdidae, Augaptilidae and Arietellidae. Of these Paracalanidae exhibited moderate distribution (average 30 No/depth strata) followed by Metrididae. In the abundance (average 29 No/depth strata) Augaptilidae and Arietellidae were the least distributed copepod family (average 1 No./depth strata).

Calanidae and Paracalanidae were abundant in the mixed layer where as Eucalanidae, Aetidedae, Euchaetidae, Scolecithricidae, heterorhatdidae and Augaptilidae showed preference to 300-500m depth strata.

11 families were found absent at the surface layer. They were Megacalanidae, Mecynoceridae, Clausocalanidae, Pseudocalanidae, Phaennidae, Lucicutidae and Acartiidae. In the thermocline layer, the order Calanidae were devoid of the following families *viz.,* Megacalanidae, Mecynoceriidae, Clausocalanidae, Pseudocalanidae, Pontellidae, Tortanidae and Acartiidae. At 300-BT layer, all the families were represented in the thermocline layer, except Candaciidae. The familiy Acartiidae was present only in the BT-300m layer and recorded only from a single station in the northwestern region. Out of the 19 families were present, a total of 17 families were recorded from the 300-500m layer. The two families, Mecynocerydae and Acartidae were absent from this layer. In the 500-1000m layer, Clausocalanidae, Candaciidae, Pontellidae and Acartidae were absent.

The most dominant families in the surface (TT-0) layer were Paracalanidae, Eucalanidae and Calanidae. Thermocline layer (TT-BT) was dominated by the families Paracalanidae, Metriidae and Euchaetidae, whereas BT-300m layer was dominated by Metriidae, Paracalanidae and Euchaetidae. The families Paracalanidae, Eucalanidae and Heterorhabdidae were the dominant families of the 300-500m layer. In the 500-1000m layer, the families Paracalnidae, Eucalanidae and Heterorhabdidae were the dominant families.

Mixed layer depth accounted for the presence of 69 species of copepods of which average abundance of *Paracalanus* and *Acrocalanus* were 274.2 and 150.8ml/1000m^3 respectively. The thermocline layer was inhibited by 68 species of copepods. *Nannocalanus minor* was reported from the Andaman occasionally. Their presence was recorded from the surface layer, BT-300 and 500-1000m depth strata. *Canthocalanus pauper* was reported from single depth strata of 500-300m (Fig 6.4).

South eastern side of the Andaman accounts for maximum species diversity (Table 6.2). From the results, it was revealed that 59 species of copepods were restricted only to the south eastern side of the Andaman Sea. An average of 13 species was found to be obtained from each depth as new species restricted to that particular area and depth. But maximum species were restricted in the mixed layer of the south western area (34 species).

It is observed that, when the northern side and southern side of Andaman sea correlated, it manifested little amount of restricted species. From surface layer of the northeastern Andaman Sea, all the copepod species obtained were common to other regions except the *Metis* sp., which was not revealed from the surface layer of other parts of the Andaman Sea. The southern side of the Andaman Sea was richer than the northern side both in bio-composition as well as abundance. This was similar to the eastern side (Fig 6.5) of the Andaman Sea over western side (Fig 6.6). But the north eastern side of the Andaman Sea had the claim to fame because of the presence of the following species only from that area *ie.*, *Xanthocalanus cornifer, Bradycalanus typicus, Disseta palaumboi, D.scopularis, Lucicutia ovalis, Megacalanus princeps, Megacalanus longicornis, Mesorhabdus angustus, Monacilla typica and Spinocalanus magnus*. Data deficient, endemic species like *Gaussia sewelli* together with *G. princeps* and *Valdiviella oligarthra* were also enriched this northeastern side of the Andaman Sea.

The vertical distribution of copepods in the Andaman Sea presented the following results (Fig 6.7 to Fig 6.12). Only 16 species of the copepods were common to all depths. It includes 4 species of *Pleuromamma viz., P. abdominalis, P. gracilis, P. indica and P. xiphias.* Presence of *Gaetanus miles,* *Heterorhabdus papilliger, H. abyssalis, Euchirella pulchera, E. rimana, acrocalanus* sp.*, Pareucalanus attenuatus, Subeucalanus mucronatus, S. pileatus, S. subcrassus and Undinula vulgaris* at all depths revealed that these species are abundant.

Out of 191 species of copepods encountered from the Andaman Sea, a total of 27 species were confined to 500-1000m depth. This lowest depth strata accounted for maximum species diversity and richness. The species obtained from this depth included *Bradycalanus typicus*, *Chirundina indica, Drepanospsis orbus, Megacalanus longicornis, Monacilla typica, Onchocalanus affinis, Pareuchaeta scotti, Xanthocalanus amabilis, Garidius brevispsinus, Lophothrix humilifrons, L. frontalis, etc.*

Species confined to 300-500m depth included *Euchirella areata, E. venusta*, *E. spinosa*, *Eucalanus bugii,Nullosetigera mutates, Pleuromamma quadrangulata, Scottocalanus investigatoris, Pseudamallothrix laminata, S. modia, S. profunda, Spinocalanus magnus, Undinopsis augustus and Metridia pacifica.*

BT-300m was the layer, which supported only limited species both in the case of abundance and diversity. Only 6 species of copepods were found to confined to this strata. They were *Acartia minuta, A. negligens, Clymenestra scutellata, ParPareuchaeta flava, Haloptilus longiceps* and *Scolecithicella lophophora.*

The mixed layer and thermocline layer sustained same number of species. In thermocline layer, species of Eucalanidae and Candacidae were present whereas *Undeuchaeta bispinosa*, *U. amoena* and Some *Paracalanus* species together with other common species showed preference to MLD. A detailed table showing the preference of copepods to specific depth strata are given in the Tables 6.3 to 6.7.

Species like *Cephalophanes frigidus, Disseta palamboi, D. scopularis, Eucalanus elongatus, Megacalanus princeps, Isochaeta ovalis* and *Gaussia princeps* were recorded from more than one depth strata which showed that they perform extensive vertical migration.

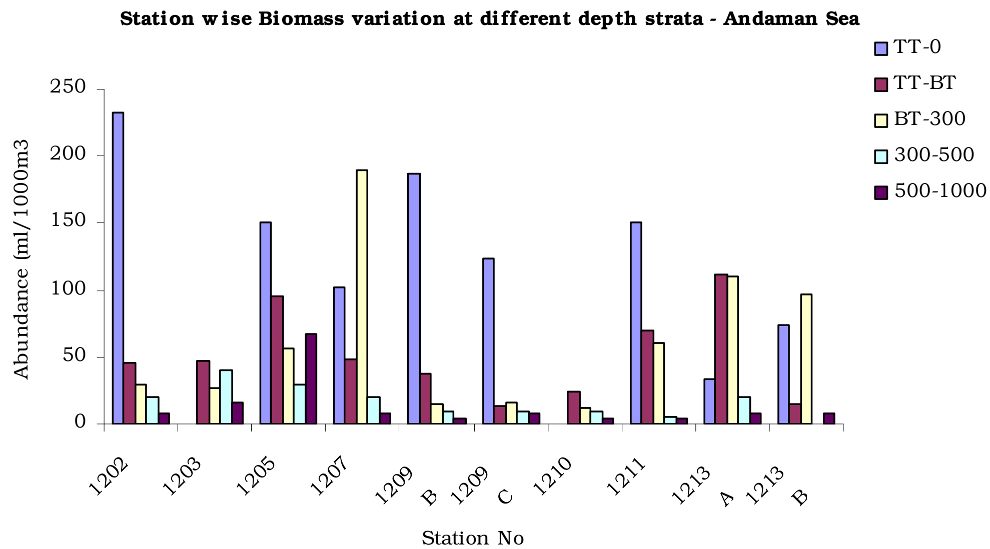

Fig. 6.1. Station wise biomass variations at different depth strata in the Andaman Sea

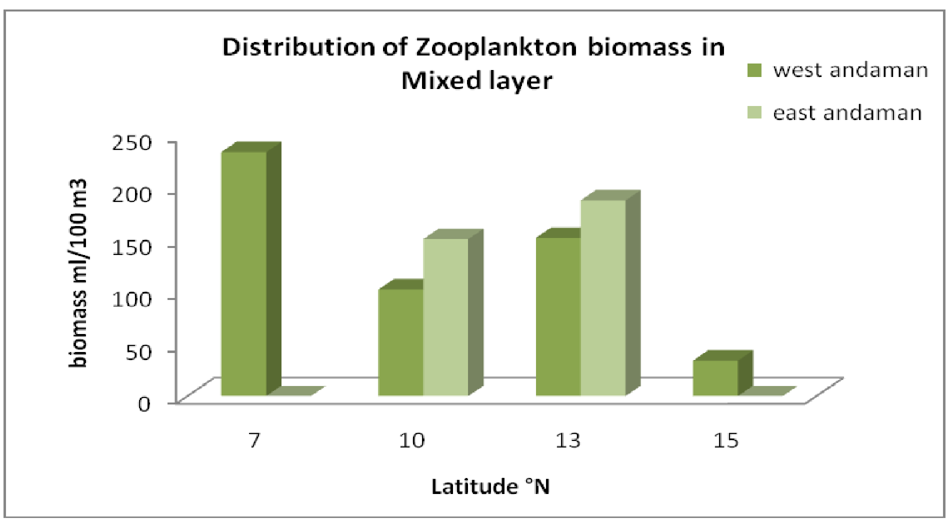

Fig. 6.2. Distribution of zooplankton biomass in the mixed layer of The Andaman Sea

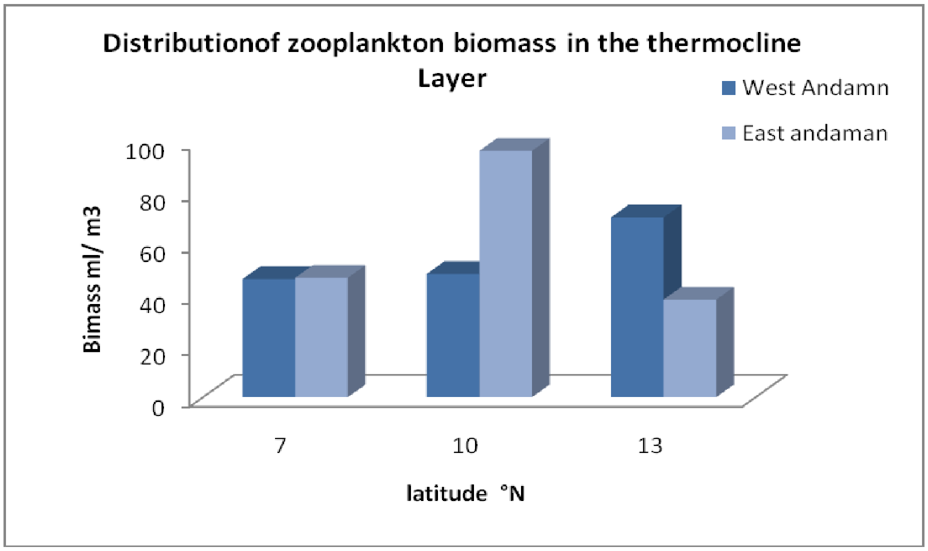

Fig. 6.3. Distribution of zooplankton biomass in the thermocline layer of The Andaman Sea

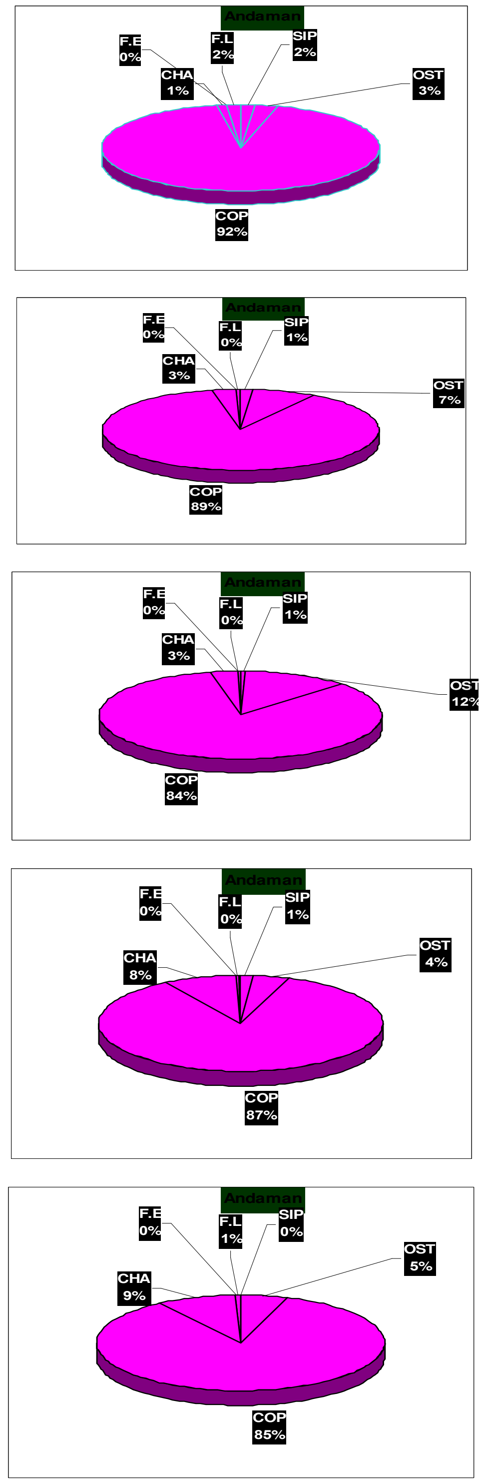

Fig. 6.4. Vertical distribution of percentage composition of zooplankton in the Andaman Sea

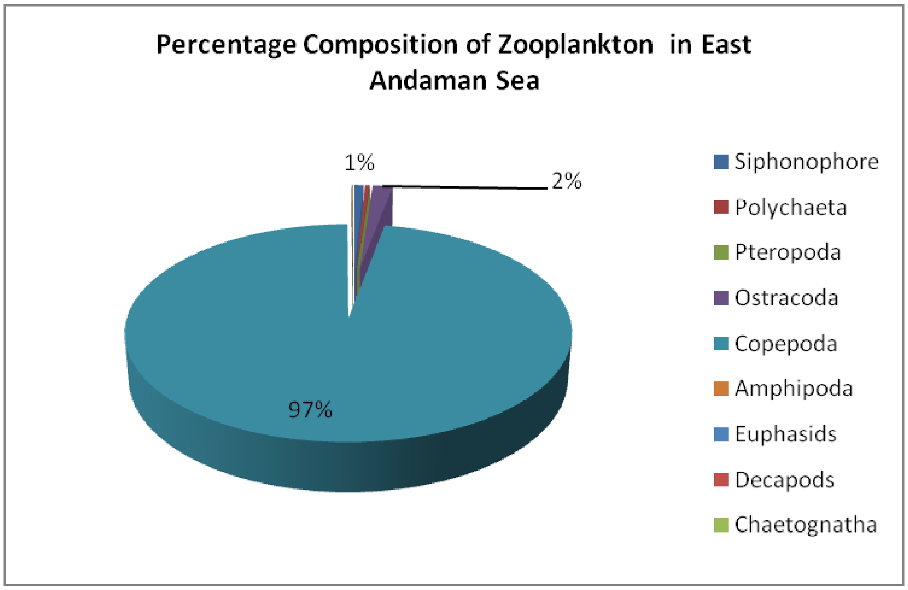

Fig. 6.5. Percentage composition of zooplankton biomass in eastern side of the Andaman Sea

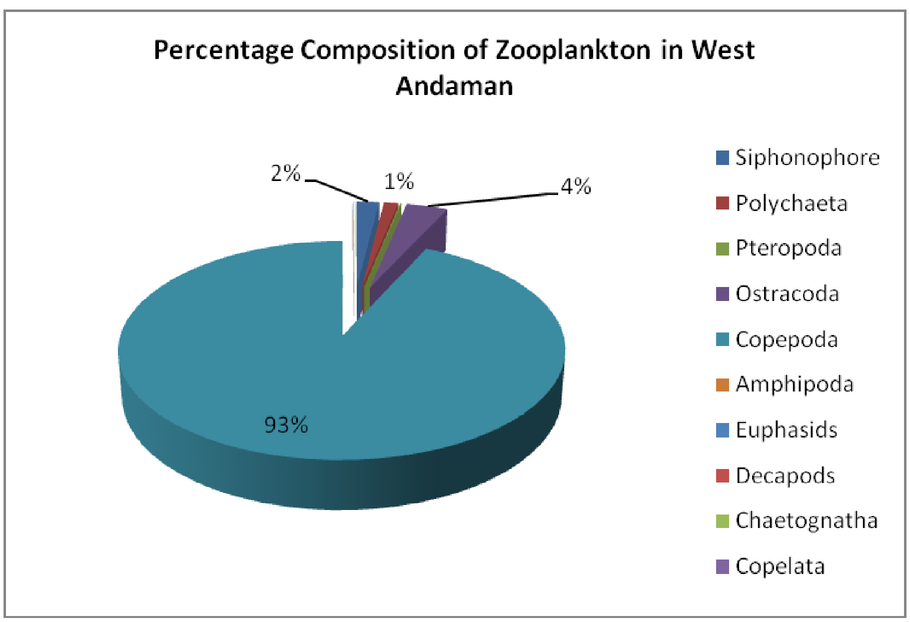

Fig. 6.6. Percentage composition of zooplankton biomass in western side of the Andaman Sea

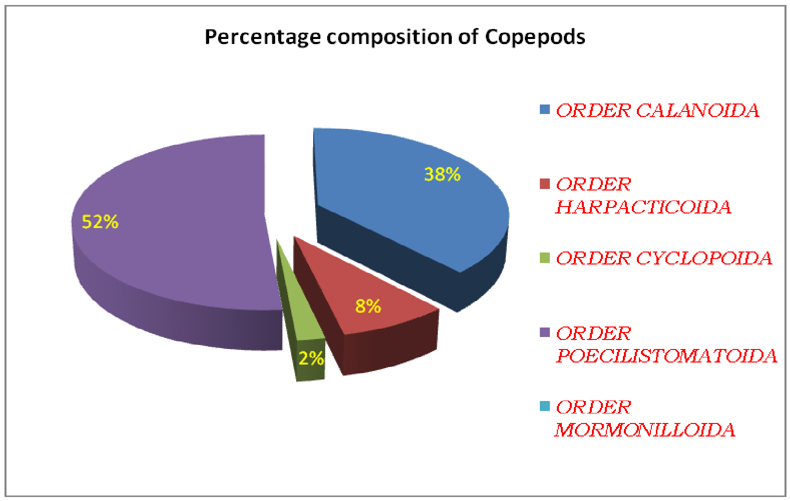

Fig. 6.7. Percentage composition of copepods in the Andaman Sea

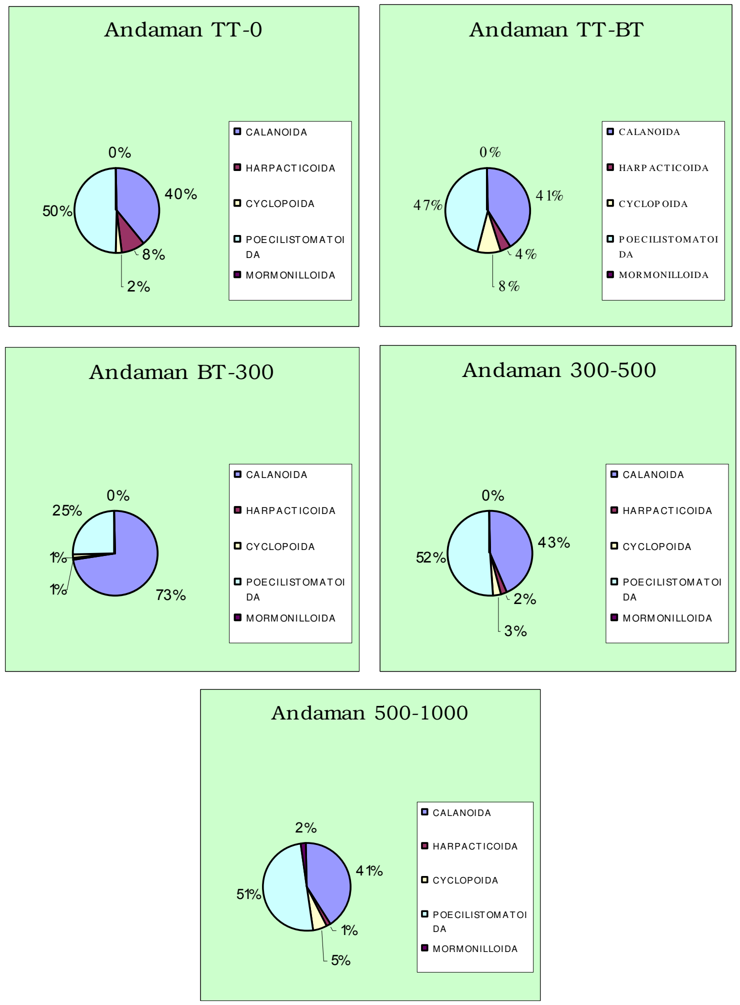

Fig. 6.8. Vertical distribution of different orders of copepod in the Andaman Sea

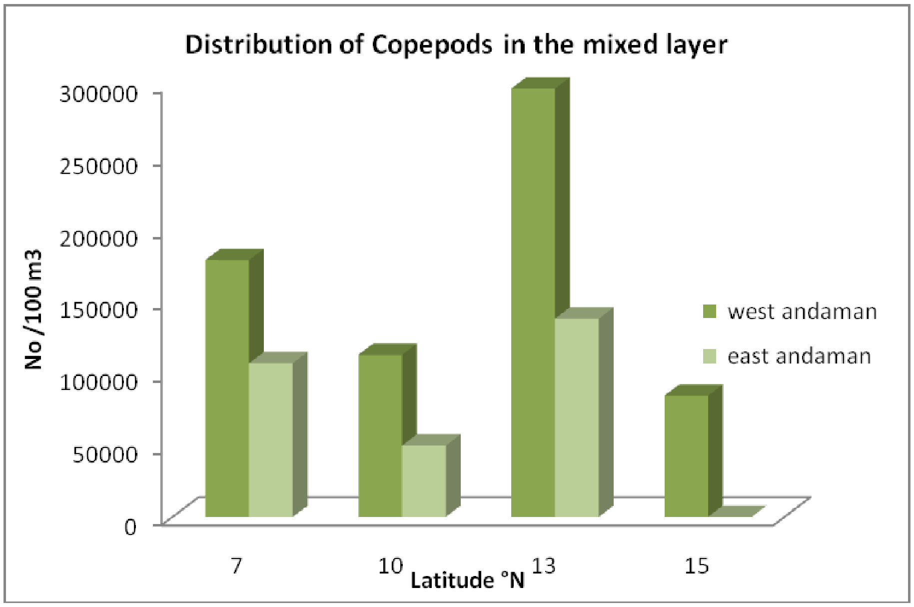

Fig. 6.9. Distribution of copepods in the mixed layer of the Andaman Sea

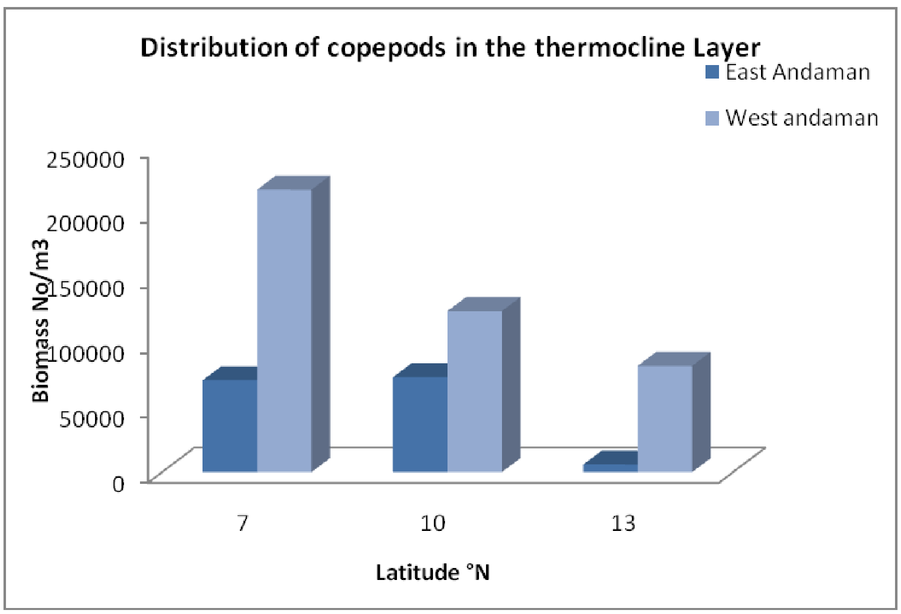

Fig. 6.10. Distribution of copepods in the mixed layer of the Andaman Sea

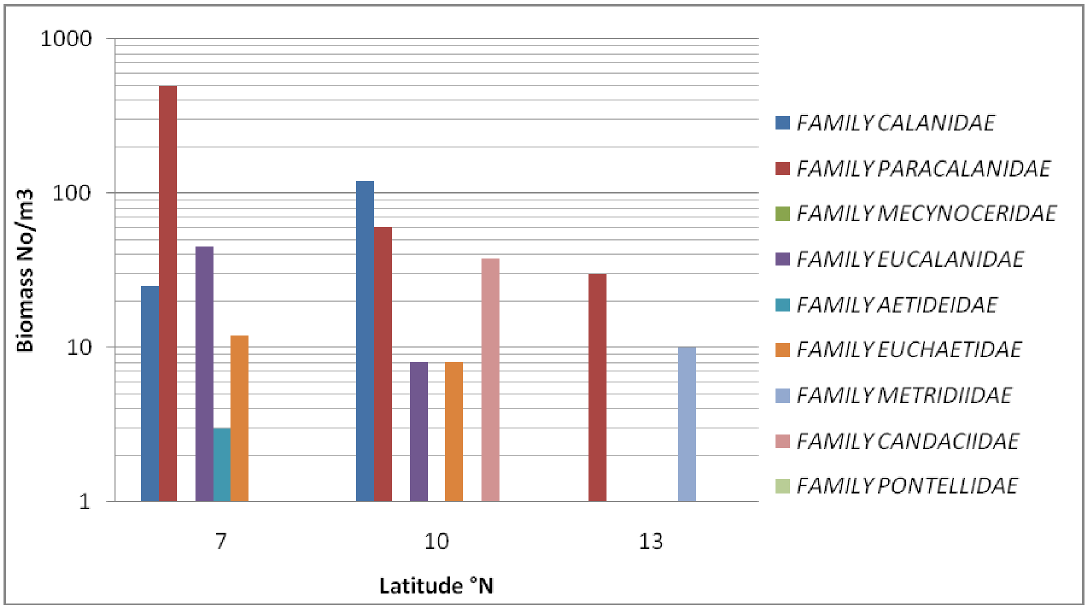

Fig. 6.11. Distribution of copepod families in the eastern side of

The Andaman Sea

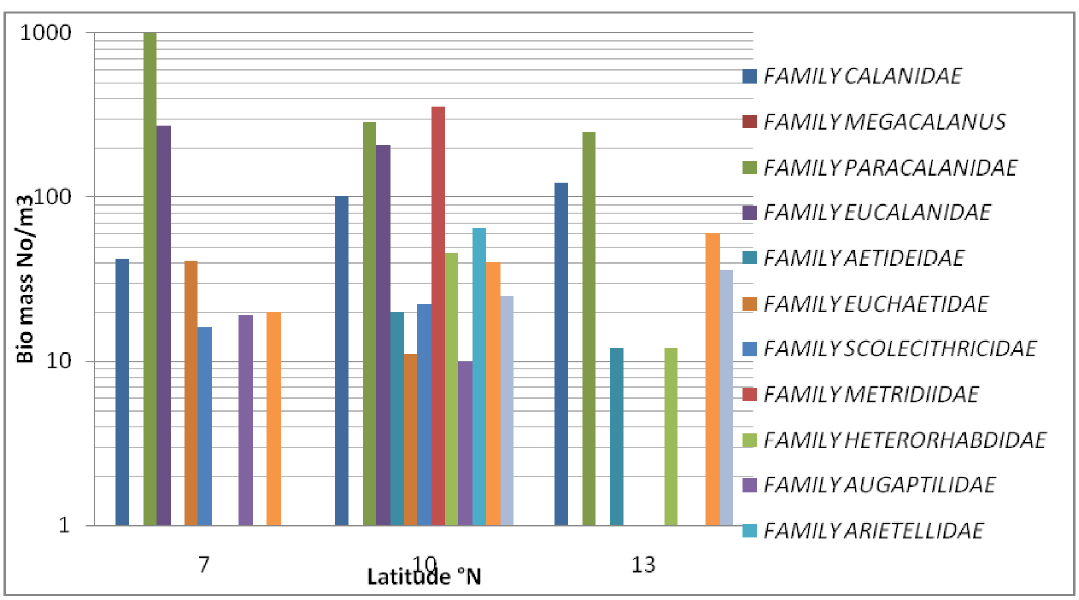

Fig. 6.12. Distribution of copepod families in the western side of

The Andaman Sea

Table 6.1. Distribution of copepod families in the different depth strata of the Andaman Sea

Table 6.2. Region wise distribution of species of copepods

Family	tt-o	tt-bt	bt-300	300-500	500-1000
Calanidae	+	+	+	+	+
Megacalanidae	-	-	-	+	+
Paracalanidae	+	+	+	+	+
Mecynoceridae	-	-	-	-	+
Eucalanidae	+	+	+	+	+
Clausocalanidae	-	-	-	+	-
Pseudocalanidae	-	-	-	+	+
Aetideidae	+	+	+	+	+
Euchaetidae	+	+	+	+	+
Phaennidae	-	+	+	+	+
Scolecithricidae	+	+	+	+	+
Metridiidae	+	+	+	+	+
Lucicutiidae	-	+	+	+	+
Heterorhabdidae	+	+	+	+	+
Augaptilidae	+	+	+	+	+
Arietellidae	+	+	+	+	+
Candaciidae	+	+	-	+	-
Pontellidae	+	-	-	+	-
Acartiidae	-	-	+	-	-

Region wise distribution of number of Copepod species confined to that particular area of the Andaman Sea at different depth strata				
	SW	**SE**	**NE**	**NW**
TT-O	34	8	1	5
TT-BT	7	17	4	5
BT-300	4	7	5	4
300-500	11	14	21	14
500-100	5	20	19	4
TOTAL	**61**	**66**	**50**	**32**
AVERAGE	**12.2**	**13.2**	**10**	**6.4**
Standard Deviation	**12.48**	**5.63**	**9.27**	**4.28**

Table 6.3. Table showing the region wise distribution of copepods in the mixed layer of the Andaman Sea

SW	SE	NE	NW	Common	Others
Augaptilus glacialis	*Candacia pachydactyla*	*Metis* sp	*Copilia vitera*	*Paracalanus acculeatus*	*Acrocalanus*
Candacia elliptica	*C.truncata*		*Euchirella bitumida*		*Candacia .bradyi*
Candacia aethiopica	*Corycaeus*		*Labidocera pavo*		*C. columbiae*
Chirudinella magna	*Eucheata plana*		*Sappharina nigromaculata*		*Corycaeus danae*
Eucalanus pseudattenuatus	*E. rimana*		*S. stelleta*		*Cosmocalanus darwini*
E. elongatus	*Microsetella rosea*				*Heterorhabdus pappiliger*
Pareucalanus attenuatus	*Subeucalanus subtenuis*				*Oithona plumifera*
Euchaeta concinna	*Sappharina* sps				*Pleuromamma abdominalis*
Eucheata rimana					*Pleuromamma gracilis*
E. wolfendeni					*P. indica*
Euterpina acutifrons					*P. xiphias*
Gaaetanus latifrons					*Subeucalanus mucronatus*
G. miles					*S. pileatus*
G. minor					*S. subcrassus*
Haloptilus acutifrons					*Undinula vulgaris*

H. longiceps					
H. ornatus					
Heterorhabdus abyssalis					
H. fistulosus					
Macrosetella occulata					
Nannocalanus minor					
Phyllopus giesbrechti					
Paracandacia simplex					
Scolecithrix bradyi					
Scolecithricella ctenopus					
S. paravalida					
Scaphoclanus elongates					
Scottocalanus magnus					
S. persecans					
S. securifrons					
Subeucalanus crassus					
Uneuchaeta amonea					
Uneuchaeta bispinosa					
U. major					

Table 6.4. Table showing the region wise distribution of copepods in the thermocline layer of the Andaman Sea

SW	SE	NE	NW	Common	Others
Pseudoamallothrix indica	*Aetidiopsis acutus*	*Euchirella amoena*	*Euchirella bitumida*	*Acrocalanus*	*Aetidiopsis giesbrechti*
Candaic . discaudata	*Augaptilus longicaudatus*	*Subeucalanus subcrassus*	*E. curticauda*	*Corycaeus danae*	*Candacia catula*
Euchirella messinensis	*Aritellus setosus*	*Scolecithrix bradyi*	*Heterorhabdus pacificus*	*Oithona plumifera*	*Cosmocalanus darwini*
E. pulchera	*Aritellus simplex*	*Valdiviella oligarthra*	*Heterostylites longicornis*	*Oncaea venusta*	*Eucalanus elongatus*
Euchaeta concinna	*Candacia bradyi*		*Scottocalauns magnus*	*Pleuromamma indica*	*Pareucalanus attenuatus*
Lucicutia clausi	*Eucalanus inermis*			*Paracalanus* sp.	*Eucheata rimana*
Undinula vulgaris	*Euaugaptilus longimanus*				*E. wolfendeni*
	E. nodifrons				*Euterpina acutifrons*
	Eucheata media				*Gaetanus miles*
	Euchirella . rostrata				*Heterorhabdus longicornis*
	Gaetanus kruppi				*H. pappiliger*
	Haloptilus spinifer				*H. setuliger*
	H. subspinifrons				*Heterorhabdus abyssalis*
	Lucicutia ovalis				*Haloptilus spiniceps*
	Microsetella rosea				*Lucicutia. flavicornis*
	Pareuchaeta barbata				*Macrosetella occulata*
	Sappharina nigromaculata				*Macrosetella*
					Pleuromamma gracilis
					P. piseki
					Phaenna spinifera
					Pleuromamma abdominalis
					Rhicalanus cornutus

					Scottocalanus dauglishi
					Subeucalanus mucronatus
					S. pileatus
					Sappharina ovatolanceolata

Andaman Sea

Table 6.5. Table showing the region wise distribution of copepods in the BT-300m layer of the Andaman Sea

SW	SE	NE	NW	Common	Others
Pseudoamallothrix indica	*Clymenestra scutellata*	*Hterorhabdus spinifrons*	*Acatia minuta*	*Corycaeus*	*Acrocalanus*
Euchaeta concinna	*Eucheata flava*	*Nannocalanus minor*	*A. negligens*	*Gaetanus miles*	*Eucalanus elongatus*
Heterorhabdus longiceps	*Heterorhabdus subspinifrons*	*Pleuromamma piseki*	*Aritellus simplex*	*Oncaea venusta*	*Pareucalanus attenuatus*
Lucicutia clausi	*Pareuchaeta barbata*	*Scolecithrix danae*	*Heterorhabdus clausi*	*Pleuromamma abdominalis*	*Euchirella pulchera*
	Subeucalanus pileatus	*Scolecithricella lophophora*		*P. indica*	*E. rostrata*
	Scolecithricella tenuipus			*P. gracilis*	*Eucheata rimana*
	S. valida			*Paracalanus*	*E. wolfendeni*
					Heterorhabdus abyssalis
					H. pappiliger
					H. setuliger
					Microsetella rosea
					Oithona plumifera
					Pareucheata malayensis

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					Pleuromamma xiphias
					Phaenna spinifera
					Rhicalanus cornutus
					R. nasutus
					Subeucalanus mucronatus
					S. subcrassus
					Scolecithricella propinqua
					Undinula vulgaris

Table 6.6. Table showing the region wise distribution of copepods in the 300-500m layer of the Andaman Sea

SW	SE	NE	NW	Common	Others
Candacia bradyi	*Aetidiopsis giesbrechti*	*Clausocalanus farrani*	*Aetiopsis .bradyi*	*Acrocalanus*	*Corycaeus danae*
Canthocalanus pauper	*Corycaeus* sp.	*Chirundina sewelli*	*Euaugaptilus nodifrons*	*Cosmocalanus darwini*	*Cephalophanes frigidus*
Heterorhabdus clausi	*Eucalanus bungii*	*C. streetsi*	*Gaetanus pileatus*	*Euchirella messinensis*	*Euchirella . bitumida*
H. fistulosus	*Eucheata spinosa*	*Candacia aethiopica*	*Gaetanus armiger*	*E. pulchera*	*Eucalanus . elongatus*
Metridia pacifica	*Euterpina acutifrons*	*Clausocalanus arcuicornis*	*Haloptilus longiceps*	*Oithona plumifera*	*Eucheata rimana*
Macrosetella	*Gaussia princeps*	*Disseta scopularis*	*Heterostylites longicornis*	*Oncaea venusta*	*Euchirella venusta*
Pleuromamma quadrangulata	*Metis* sp.	*Disseta palaumboi*	*Lucicutia macrocera*	*Pleuromamma gracilis*	*Pareucalanus attenuatus*
Scolecithricella . modia	*Microsetella rosea*	*Euchirella areata*	*L. magna*	*P. indica*	*Euchaeta concinna*
S. tenuipus	*Scottocalanus elongatus*	*Eucheata indica*	*L. maxima*	*P. xiphias*	*Gaetanus kruppi*
S. vittatta	*Scaphocalanus . magnus*	*Euchirell magnus*	*Scolecithricella arcuata*	*Paracalanus* sp.	*G. miles*
Undinula vulgaris	*Amallothrix paravalida*	*E. rostrata*	*Scottocalanus investigatoris*	*Pleuromamma abdominalis*	*G. minor*
	S. persecans	*Gaidius minutus*	*Scolecithricella lamellifer*	*Subeucalanus pileatus*	*H. compactus*
	Subeucalanus subcrassus	*Haloptilus longicornis*	*S. profunda*		*H. pappiliger*
	Bradyidius angustus	*Heterorhabdus longicornis*	*Scolecithrix bradyi*		*H. subspinifrons*
		Lucicutia ovalis			*Heterorhabdus abyssalis*
		Labidocera pavo			*L. clausi*
		Megacalanus princeps			*L. wolfendeni*
		Scolecithricella emarginata			*Lucicutia bicornuta*

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		S. propinqua			*Macrosetella occulata*
		Spinocalanus spinosus			*Metridia princeps*
		Spinocalanus magnus			*Pareucheata malayensis*
					Pleuromamma piseki
					Pareuchaeta barbata
					Phaenna spinifera
					Phyllopus bidentatus
					Rhincalanus cornutus
					R. nasutus
					Scolecithricella ctenopus
					Scottocalanus dauglishi
					S. helenae
					Scolecithrix danae
					Scottocalanus farrani
					Scottocalanus longispinus
					Subeucalanus mucronatus
					Scottocalanus securifrons
					Subeucalanus crassus
					Valdiviella oligarthra

Table 6.7. Table showing the region wise distribution of copepods in the 500-1000m layer of the Andaman Sea

SW	SE	NE	NW	Common	Others
Eucheata rimana	*Amallothrix obtusifrons*	*Xanthocalanus cornifer*	*Euaugaptilus hulsmannae*	*Augaptilus longicaudatus*	*Aetidius giesbrechti*
Pleuromamma gracilis	*Aetidiopsis giesbrechti*	*Bradycalanus typicus*	*Gaetanus miles*	*Corycaeus catus*	*Acrocalanus* sp.
Pareucheata malayensis	*Amallothrix emarginata*	*Disseta scopularis*	*Lucicutia magna*	*Disseta palaumboi*	*Chirundina streetsi*
Scolecithricella propinqua	*Chirundina indica*	*Eucalanus pseudattenuatus*	*Mormonilla phasma*	*Gaetanus kruppi*	*Copilia vitera*
Valdiviella oligarthra	*Drepanopsis orbus*	*Euchirella . rostrata*		*Heterorhabdus pappiliger*	*Cephalophanes frigidus*
	Eucheata indica	*Euchirella amoena*		*Oithona plumifera*	*Chirudinella magna*
	E. pubera	*Gaidius minutus*		*Oncaea venusta*	*Cosmocalanus darwini*
	E. wolfendeni	*Gaetanus armiger*		*Paracalanus*	*Euaugaptilus magnus*
	Euterpina acutifrons	*Haloptilus spinifer*		*Pleuromamma abdominalis*	*Euchirella messinensis*
	Gaidius brevispinus	*Heterorhabdus tenuis*			*E. pulchera*
	Haloptilus setuliger	*Lucicutia ovalis*			*Pareucalanus attenuatus*
	Lucicutia challengeri	*Lucicutia longicornis*			*Gaetanus minor*
	Lophothrix humilifrons	*Lucicutia longiserrata*			*Gaussia princeps*
	Marmonilla minor	*Mecynocera clausi*			*Heterorhabdus clausi*
	Phyllopus bidentatus	*Megacalanus longicornis*			*H. compactus*
	Scottocalanus helenae	*Mesorhabdus angustuas*			*H. fistulosus*
	Amallothrix acuta	*Monacilla typica*			*H. longiceps*
	Sappharina nigromaculata	*Phaenna spinifera*			*H. longicornis*
	Scolecithricella valida	*Scolecithrix nicobarica*			*H. spinifrons*
	S. vittatta				*Heterorhabdus abyssalis*

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					L. flavicornis
					L. clausi
					L. frontalis
					L. maxima
					L. wolfendeni
					Lucicutia bicornuta
					Mesorhabdus brevicaudatus
					Metridia princeps
					Macrosetella sp.
					Megacalanus princeps
					Metridia brevicauda
					Nannocalanus minor
					Onchocalanus affinis
					Pleuromamma indica
					P. piseki
					P. xiphias
					Pareuchaeta barbata
					P. scotti
					Pseudochirella obesa
					Rhincalanus cornutus
					R. nasutus
					Scolecithricella ctenopus
					Scottocalanus dauglishi

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					Scolecithrix bradyi
					S. danae
					Scaphocalanus . magnus
					Subeucalanus mucronatus
					Sappharina ovatolanceolata
					Scolecithricella paravalida
					Subeucalanus subcrassus
					Uneucheata major
					Undinula vulgaris
					Xanthocalanus amabilis

Chapter VII
Statistical Analysis

7.1. Introduction

Two-way Analysis of variance (ANOVA) can be explained as an extension of the *t-test. T-test* is a statistical test procedure to check whether there is any difference between the two populations of interest. In the *t-test,* statistical null hypothesis is the means of the two populations under study are equal ($H_0 : \mu_1 = \mu_2$) *i.e.* the two populations are not statistically different. The null hypothesis states that there are no differences between means of different classes ($H_0 : \mu_1 = \mu_2 = ... = \mu_n$) i.e. the two populations are not statistically different. The null hypothesis is accepted or rejected based on the *p*-value (alpha, normally taken to be as 0.05). If the *p*-value is greater than the significance level, we will accept the hypothesis that the populations are not significantly different. On the contrary, if the *p*-value is less than the significance level we conclude that the mean value is not same for all the population. There will be at least one population having a different mean from the other population groups.

The assessment of species diversity is essential for the study of an ecosystem and their interactions with the surrounding environment. This will also give an idea about the health of the ecosystem. In the large ecosystems such as open sea, the similarity indices give the idea about the similarities in spatio-temporal distribution of the organisms in the study area. The diversity indices calculated were species Margalef richness, Shannon diversity index, Pielou’s evenness and Simpson’s dominance.

7.2. Results

7.2.1. Two-way Analysis of Variance

Two-way Analysis of variance (ANOVA) can be explained as an extension of the *t-test*. *T-test* is a statistical test procedure to check whether there is any difference between the two populations of interest. There will be at least one population having a different mean from the other population groups. Two-way ANOVA would be able to assess both time and treatment in the same test. The null hypotheses for each of the sets are given below.

The two way ANOVA results shows (Table 7.1) the significant *p*-values ($p<0.05$) corresponding to season and depth for the orders of copepods in the Bay of Bengal during all the selected seasons. During SIM at the Bay of Bengal the ANOVA analysis of orders of the copepods showed (Table 7.2) that the *p*-value corresponding to interaction is greater than 0.05 ($p>0.05$). During SM, the ANOVA results (Table 7.3) showed that the *p*-values corresponding to station and depth are greater than the significance value 0.05 ($p<0.05$).

The *p*-values corresponding to station and depth are less than the significance value 0.05 ($p < 0.05$) during WM (Table 7.4).

The ANOVA results (Table 7.5) of the orders or copepods in Andaman Sea during inter monsoon fall revealed that the p-values corresponding to station is less than 0.05 ($p< 0.05$) and depth is greater than 0.05 ($p>0.05$).

Two Way ANOVA results for the families coming under the Order Calanoida at the Bay of Bengal during all the selected seasons (Table 7.6) have $p< 0.05$.

The p-values corresponding to station and depth are less than the significance value 0.05 during SIM for the families coming under the Order Calanoida at the Bay of Bengal (Table 7.7). During SM the p-values (Table 7.8) corresponding to station is greater than 0.05 ($p> 0.05$) and depth is less than 0.05 ($p< 0.05$). The p-values corresponding to station and depth are greater than the significance value 0.05 ($p> 0.05$) during WM in the case of families coming under the Order Calanoida in the Bay of Bengal (Table 7.9).

During inter monsoon fall, the ANOVA results (table 7.10) for the families coming under the Order Calanoida in the Andaman Sea revealed that the p-values corresponding to station is less than 0.05 ($p< 0.05$) and depth is greater than 0.05 (($p> 0.05$).

In the case of pre cyclonic samples (Table 7.11), p-values corresponding to station is less than 0.05 ($p< 0.05$) for the numerical abundance of copepods in the Bay of Bengal. But in the case of the sample after the cyclone (Table 7.12), *p*-values corresponding to Station is greater than 0.05 ($p> 0.05$).

7.2.2. Correlation

Pearson's Correlation was done for finding out the interaction of zooplankton with the prevailing physical parameters during the SIM, SM and WM in the Bay of Bengal and during inter monsoon fall in the Andaman Sea. Also correlation was done for the samples obtained before and after the cyclone in the Bay of Bengal. Nutrient enrichment is a key factor regulating temporal variations in zooplankton (mostly copepods) in coastal environments. Further, phytoplankton is a source of nourishment of herbivorous copepods (Tan et al., 2004). But in the present study there was not much positive correlation obtained between physical parameters and copepods abundance. In some tropical embayments and estuaries in India, accelerate of zooplankton production during the periods of high salinity was documented by (Baidya and Choudhury, 1985; Tiwari and Nair 1993) and high temperature by (Li et al.,2008).

Spring Intermonsoon –BoB

Significant correlation was observed (Table 7.13) with salinity and the families Temoridae ($p< 0.01$) and Pontellidae ($p< 0.01$). Similarly, the family Paracalanidae showed significant correlation with sigma –T at 0.05 level and the families Temoridae and Candaciidae at 0.01 level. The family Lucicutiidae had significant correlation with SST ($p< 0.05$).

Summer Monsoon - BoB

During SM (table 7.14), significant correlation with SST and the families Euchaetidae ($p< 0.01$), Scolecithridae ($p< 0.05$), Temoridae ($p< 0.01$) and

Candaciidae ($p < 0.05$) were observed. The families Pontellidae ($p < 0.05$), Candaciidae ($p < 0.05$), Temoridae ($p < 0.05$) and Paracalanidae ($p < 0.01$) showed significant correlation with sigma – T. The families Mecynoceridae, Phaennidae, Centropagidae, Metridiidae, Candaciidae and Pontellidae did have significant correlation with salinity.

Winter Monsoon –BoB

At 0.05 level, the copepod families Scolecithricidae and Centropagidae showed significant correlation with SST; the family Pontellidae with sigma – T and the families Euchaetidae, Temoridae, Heterorhabdidae, Candaciidae and Pontellidae with salinity. The families Paracalanidae, Euchaetidae, Heterorhabdidae and Candaciidae showed significant correlation with sigma – T (Table 7.15).

Intermonsoon Fall – Andaman Sea

There is no significant correlation between physical parameters (temperature and salinity) with copepod families (Table 7.17 and 7.18).

7.2.3. Diversity and Similarity Indices

Diversity indices were calculated both for the coastal and oceanic stations separately (Figs. 7.1 to 7.4 and 7.5 to 7.8) and for the spring inter monsoon, summer monsoon and winter monsoon in the BoB and for the inter monsoon fall season in the Andaman Sea (Table. 7.19) The diversity indices calculated were the species richness (d), Shannon index (H' $\log_2$), evenness and dominance (1-λ') during the inter monsoon fall season in the Bay of Bengal.

For finding out the similarities between seasonal and spatial aspects, multidimensional scaling (MDS) and Bray-Curtis similarity indices were found out (Figs. 7.9 to 7.22). These indices were represented by the MDS plot and dendrogram respectively. Copepod diversity and richness were related to copepod abundance inversely. Species richness was enhanced towards the oceanic stations of the bay (Fig.7.1 &Fig 7.5). Increase of diversity and richness indices in far from shore communities was common in Indian Ocean

(Madhupratap, 1986). This trend was observed in waters of Africa by (Okemwa, 1990) in Tudor Bay, (Mwaluma, 1997) in Kenya, (Osore, 1992; Osore, 1994) in Gazi Bay and (James et al., 2008) in Media creek. In India, in the Bay of Bengal and Cochin backwaters, the similar trend was reported by (Pillai et al., 1973; Nair et al. 1981; Tiwari and Vijayyalakshmi, 1993), who attributed this high diversity to the calmer, more stable oceanic waters. In this study, Oithona similis had much abundance throughout the year. This species was a euryhaline and euryterm species in tropical water (Nishida, 1985). Most abundance of copepod species during the study period irrespective of season belongs to Harpacticoida: Macrosetlla gracilis, Microsetella rosea ,Euterpina acutifrons and Corycaeus in particular .

.

i) The Bay of Bengal

a) Spring Inter monsoon

<u>*Diversity Indices*</u>

In the coastal stations, highest species richness of 6.27 was recorded in the station at 11°N in the depth strata of TT-0 and lowest, 2.27 in the depth range of TT-BT at 15°N (av. 4.62±2.03). Evenness was highest (0.81) at 13°N in the TT-BT layer and lowest (0.43) at 11°N TT-BT layer with an average value of 0.75±0.03. Highest species diversity of 4.56 was recorded at the station 13°N in the TT-0 depth strata (av. 3.82±0.63) and lowest, 2.86 was in the station at 15°N TT-BT layer. The dominance value was highest (0.5) at 13°N in the TT-0 layer and lowest (0.18) in the TT-BT layer of the station at 15°N (av. 0.11±0.04).

In the oceanic stations, highest species richness of 6.92 was recorded in the station at 11°N in the depth strata of 500-1000m and lowest, 2.58 in the depth range of TT-BT at 15°N (av. 4.04±1.13). Evenness was highest (0.9) at 11°N in the 500-1000m layer and lowest (0.7) at 13°N 500-1000m layer with an average value of 0.81±0.05. Highest species diversity of 4.56 was recorded at the station 11°N in the 500-1000m depth strata and lowest, 2.73 were in the station at 13°N in 500-1000m layer (3.71±0.42). The dominance value was highest (0.15) at 19°N in the TT-0 layer and lowest (0.05) in the 500-1000m layer of the station at 11°N (av. 0.11±0.04).

Similarity Indices

In the MDS analysis, for all the depth strata of all the coastal stations during SIM, it was found that overall stress value of 0.07 and that for all the oceanic stations was 0.18. Bray-Curtis similarity index showed a highest similarity of 59.09% in the abundance of copepods between the mixed layers of the coastal stations at 15°N and 17°N during SIM. Highest similarity of 69.9% was observed between the thermocline layers of the oceanic stations at 13°N and 19°N during this season.

b) Summer monsoon

Diversity Indices

In the coastal stations, highest species richness of 3.81 was recorded in the station at 13°N in the depth strata of TT-BT and lowest, 1.29 in the depth range of TT-BT at 15°N (av. 2.41±0.85). Evenness was highest (0.85) at 15°N in the BT-300m layer and lowest (0.65) at 11°N TT-0 layer with an average value of 0.79±0.07. Highest species diversity of 3.98 was recorded at the station 13°N in the TT-BT depth strata (av. 3.3±0.38) and lowest, 2.84 was in the station at 11°N TT-0 layer. The dominance value was highest (0.21) at 11°N in the TT-0 layer and lowest (0.08) in the TT-BT layer of the station at 13°N (av. 0.14±0.04).

In the oceanic stations, highest species richness of 5.24 was recorded in the station at 11°N in the depth strata of 500-1000m and lowest, 2.10 in the depth range of BT-300 at 11°N (av. 3.45±0.89). Evenness was highest (0.9) at 17°N in the BT-300m layer and lowest (0.69) at 17°N 500-1000m layer with an average value of 0.81±0.06. Highest species diversity of 4.44 was recorded at the station 13°N in the TT-0 depth strata and lowest, 2.61 was in the station at 17°N in 500-1000m layer (3.67±0.45). The dominance value was highest (0.24) at 17°N in the 500-1000m layer and lowest (0.06) in the TT-0 layer of the station at 13°N (av. 0.11±0.04).

Similarity Indices

In the MDS analysis, for all the depth strata of all the coastal stations during SM, it was found that overall stress value of 0.01 and that for all the oceanic stations was 0.14. Bray-Curtis similarity index showed a highest similarity of 63.25% in the abundance of copepods between the mixed layers of the coastal stations at 11°N and 15°N during SM. Highest similarity of 60.04% was observed between the mixed layers of the oceanic stations at 17°N and 19°N during this season.

c) Winter monsoon

<u>Diversity Indices</u>

In the coastal stations, highest species richness of 2.9 was recorded in the station at 17°N in the depth strata of TT-BT and lowest, 1.53 in the depth range of TT-0 at 19°N (av. 2.23±0.49). Evenness was highest (0.8) at 11°N in the TT-0 layer and lowest (0.66) at 19°N TT-0 layer with an average value of 0.72±0.04. Highest species diversity of 3.47 was recorded at the station 15°N in the TT-0 depth strata and lowest, 2.64 was in the station at 19°N TT-0 layer (3.06±0.31). The dominance value was highest (0.22) at 19°N in the TT-0 layer and lowest (0.14) in the TT-0 layer of the station at 15°N (av. 0.17±0.03).

In the oceanic stations, highest species richness of 5.03 was recorded in the station at 19°N in the depth strata of 500-1000m and lowest, 1.78 in the depth range of TT-0 at 17°N (av. 2.02±0.93). Evenness was highest (0.91) at 11°N in the 300-500m layer and lowest (0.62) at 15°N 500-1000m layer with an average value of 0.75±0.08. Highest species diversity of 4.30 was recorded at the station 19°N in the 500-1000m depth strata and lowest, 2.81 were in the station at 13°N in TT-BT layer (av. 3.36±0.37). The dominance value was highest (0.24) at 13°N in the TT-BT layer and lowest (0.06) in the 500-1000m layer of the station at 19°N (av. 0.15±0.04).

<u>Similarity Indices</u>

In the MDS analysis, for all the depth strata of all the coastal stations during WM, it was found that overall stress value of 0.03 and that for all the oceanic stations was 0.19. Bray-Curtis similarity index showed a highest similarity of 63.48% in the abundance of copepods between the thermocline layer of the coastal stations at 11°N and 15°N during WM. Highest similarity of

58.15% was observed between the thermocline layers of the oceanic stations at 13°N and 15°N during this season.

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a) Diversity indices

The diversity indices calculated were the species richness (d), Shannon index (H' $\log_2$), evenness and dominance (1-λ') during the inter monsoon fall season in the Andaman Sea (Table 7.19). Highest richness of 6.22 was recorded in the station at 10°N - 95°E in the depth strata of 300-500m and lowest, 1.34 in the depth range of BT-300m at 15°N - 95°E (av. 3.39±1.68). Evenness was highest (0.97) at 13°N - 95°E in the BT-300m layer and lowest (0.43) at 10°N - 92°E in the 300-500m layer with an average value of 0.72±0.11. Highest species diversity of 4.12 was recorded at the station 10°N - 95°E in the 300-500m depth strata and the lowest value of 1.82 was in the station at 7N 94E in the BT-300 layer (av. 3.08±0.59). The dominance value was highest (0.43) at 10°N - 95°E at the TT-0 layer and lowest in the BT-300m layer of the station at 13°N - 95°E (av. 0.18±0.08).

b) Similarity Indices

In the MDS analysis for all the depth strata for all the stations showed an overall stress value of 0.2. Bray-Curtis similarity index showed a highest similarity of 61.04% between the BT-300m depth strata of the station at 7°N - 92°E and TT-BT of the station at 7°N - 94°E.

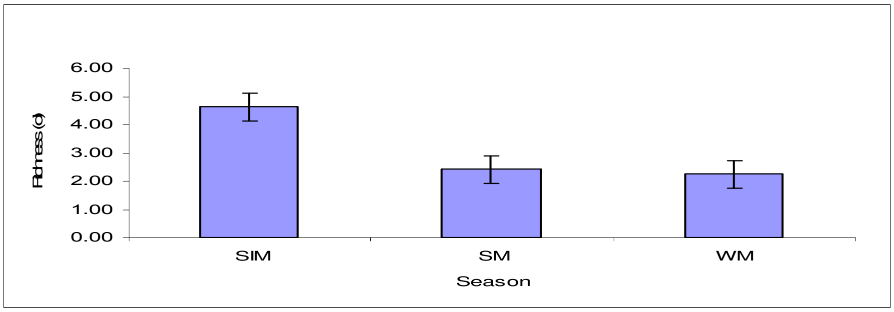

Fig. 7.1. Mean seasonal variations in species richness of copepods in the coastal stations of the Bay of Bengal

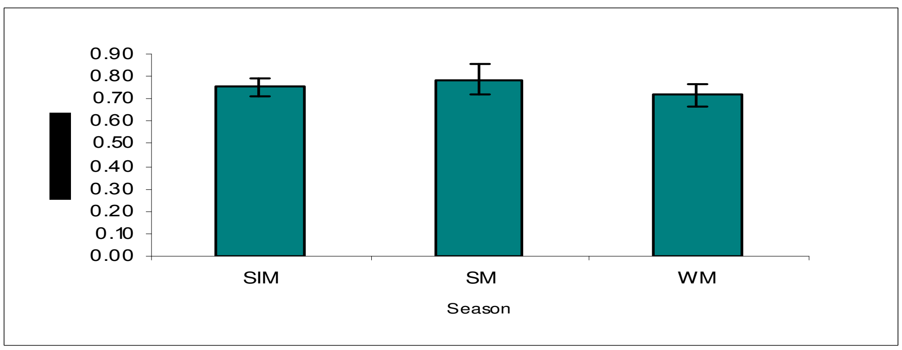

Fig. 7.2. Mean seasonal variations in evenness of copepods in the coastal stations of the Bay of Bengal

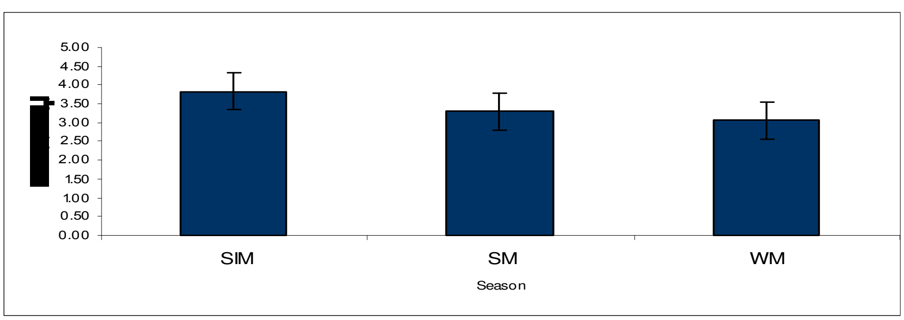

Fig. 7.3. Mean seasonal variations in species diversity of copepods in the coastal stations of the Bay of Bengal

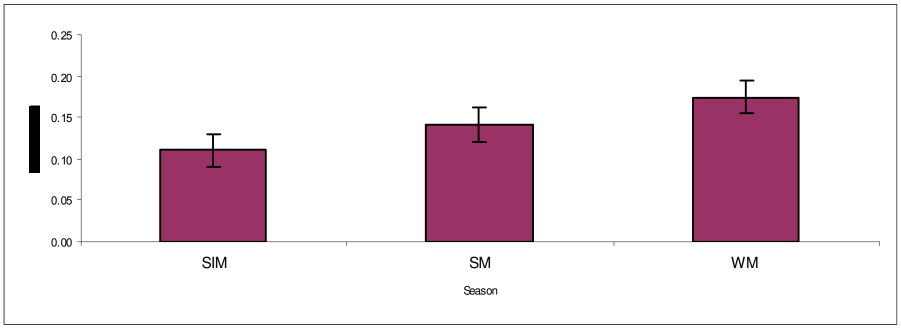

Fig. 7.4. Mean seasonal variations in dominance of copepods in the coastal stations of the Bay of Bengal

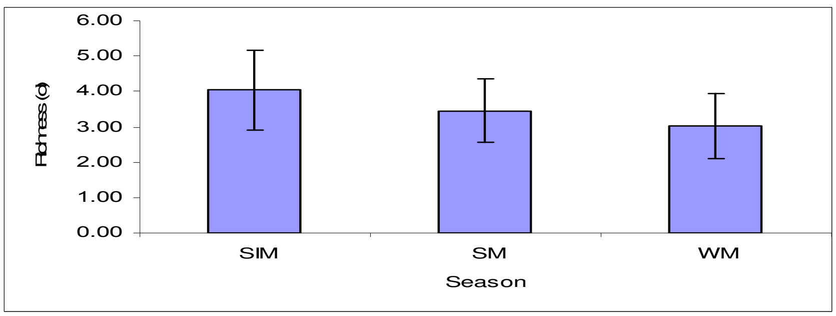

Fig. 7.5. Mean seasonal variations in species richness of copepods in the oceanic stations of the Bay of Bengal

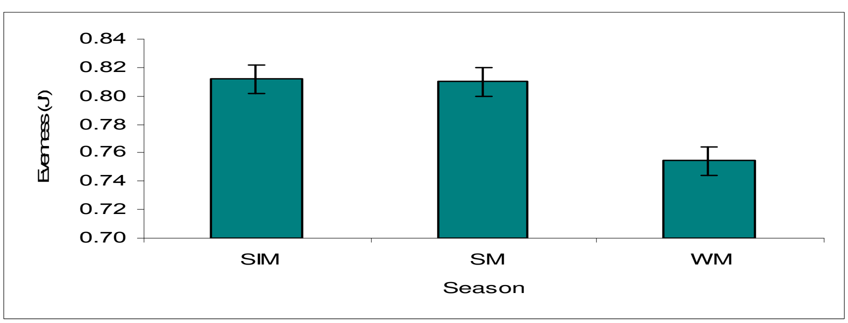

Fig. 7.6. Mean seasonal variations in evenness of copepods in the oceanic stations of the Bay of Bengal

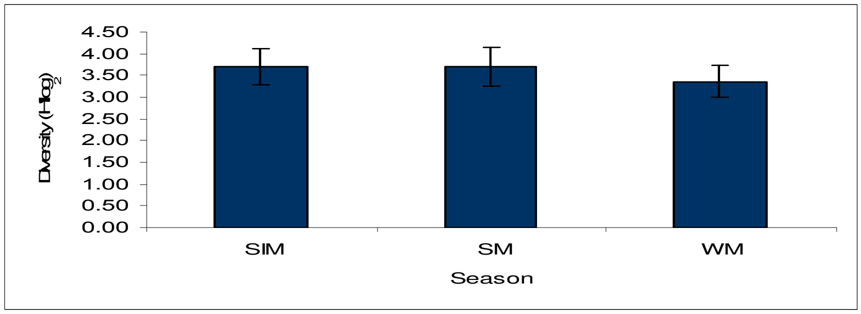

Fig. 7.7. Mean seasonal variations in species diversity of copepods in the oceanic stations of the Bay of Bengal

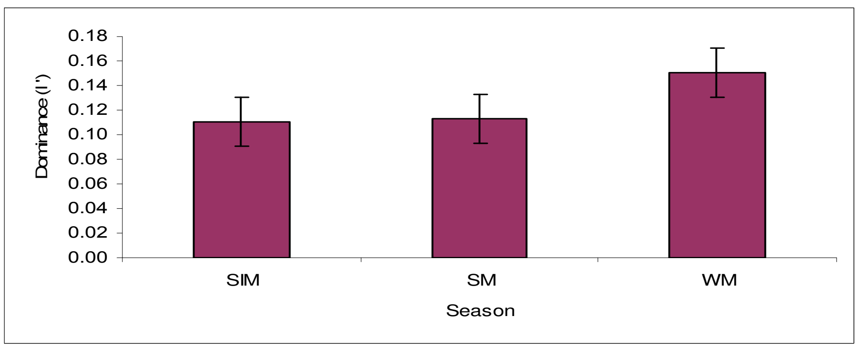

Fig. 7.8. Mean seasonal variations in dominance of copepods in the oceanic stations of the Bay of Bengal

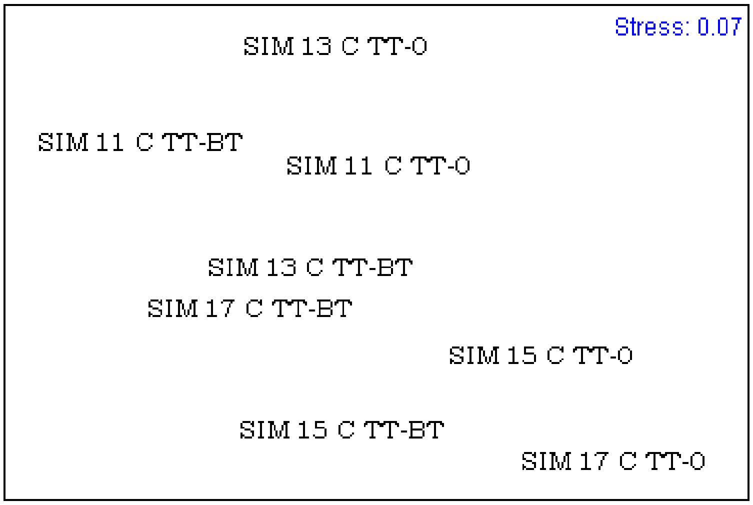

Fig. 7.9. MDS plot for the similarity in the abundance of copepods in the coastal stations of the Bay of Bengal during SIM

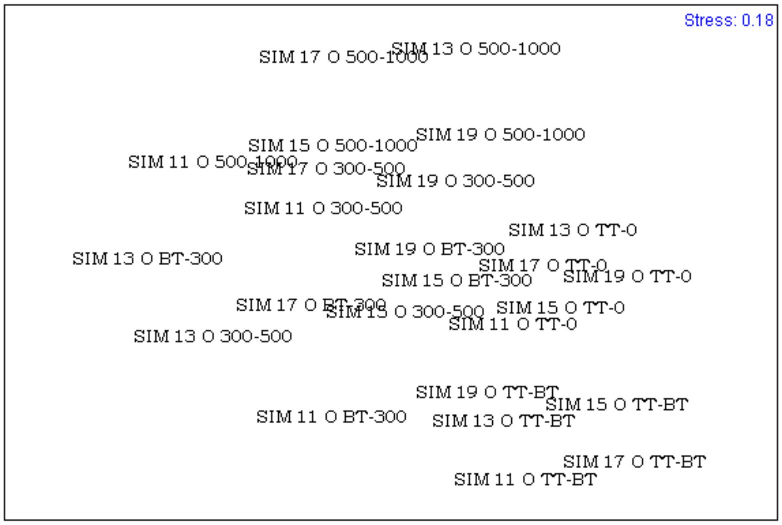

Fig. 7.10. MDS plot for the similarity in the abundanc eof copepods in the oceanic stations of the Bay of Bengal during SIM

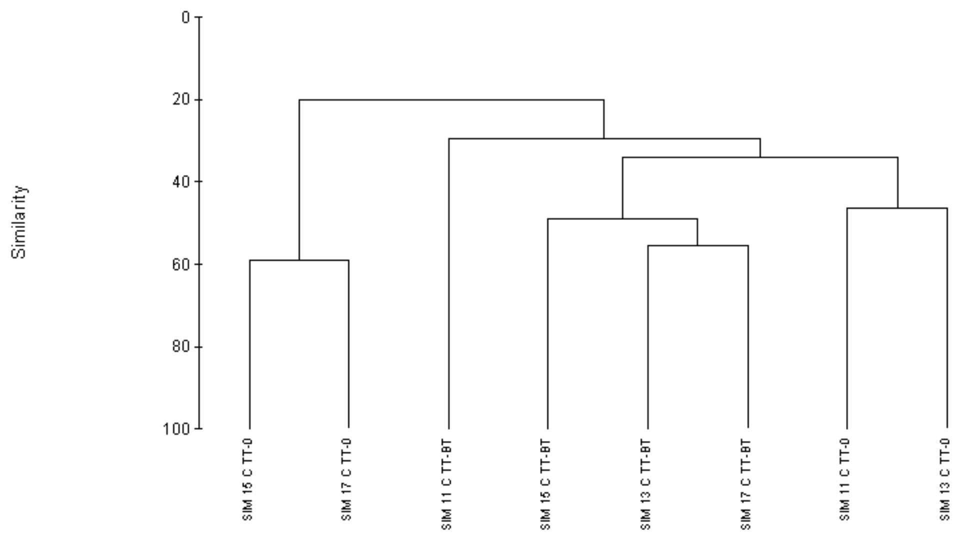

Fig. 7.11. Dendrogram showing the similarity indices of the abundance of copepods in the coastal stations during SIM

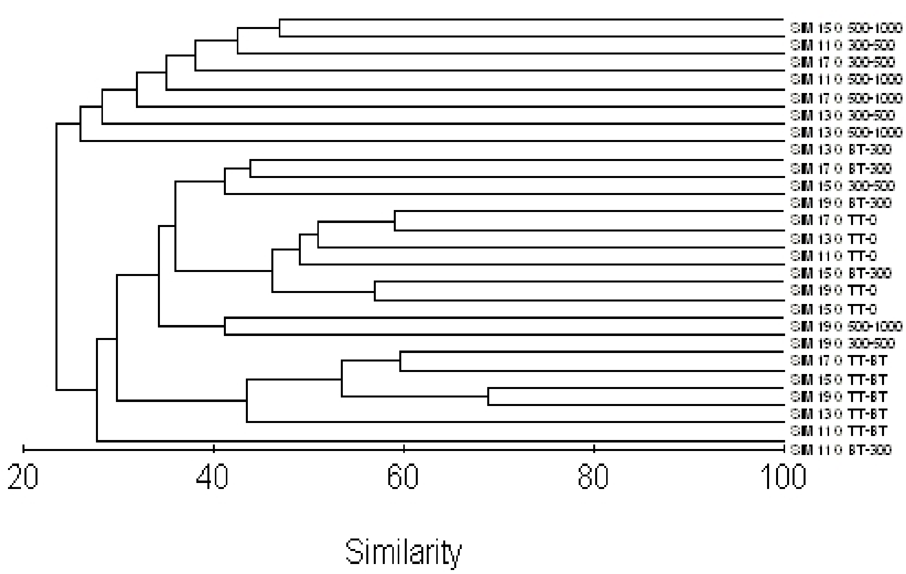

Fig. 7.12. Dendrogram showing the similarity indices in the abundance of copepods in the oceanic stations during SIM

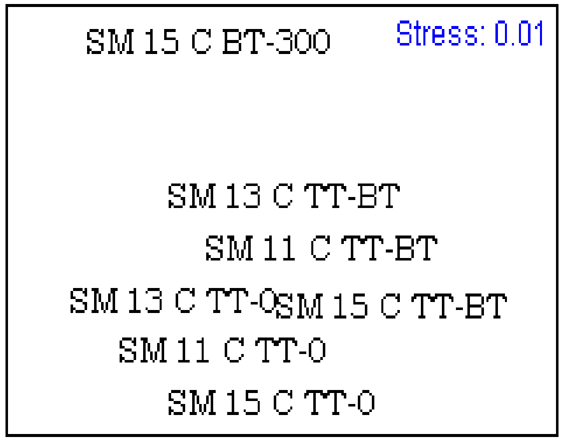

Fig. 7.13. MDS plot for the similarity in the abundance of copepods in the coastal stations of the Bay of Bengal during SM

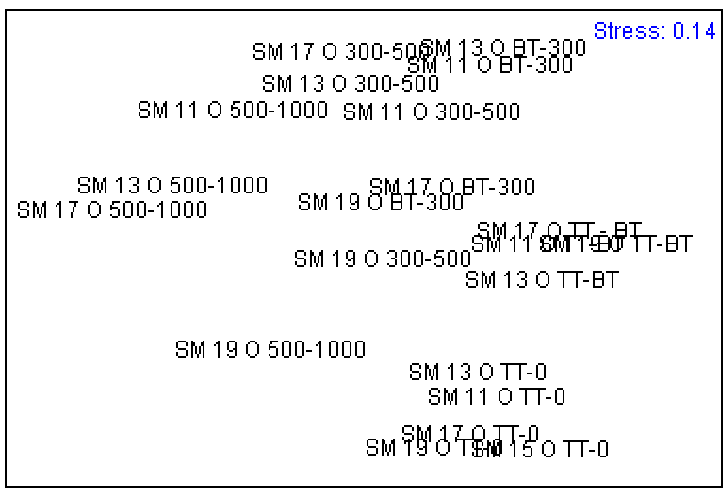

Fig. 7.14. MDS plot for the similarity in abundance of copepods in oceanic stations of the Bay of Bengal during SM

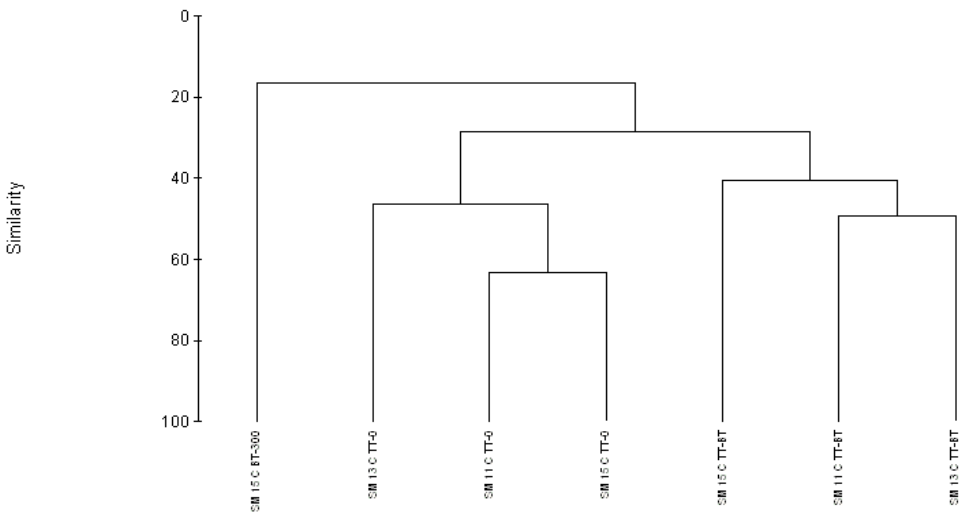

Fig. 7.15. Dendrogram showing the similarity indices in the abundance of copepods in the coastal stations of the Bay of Bengal during SM

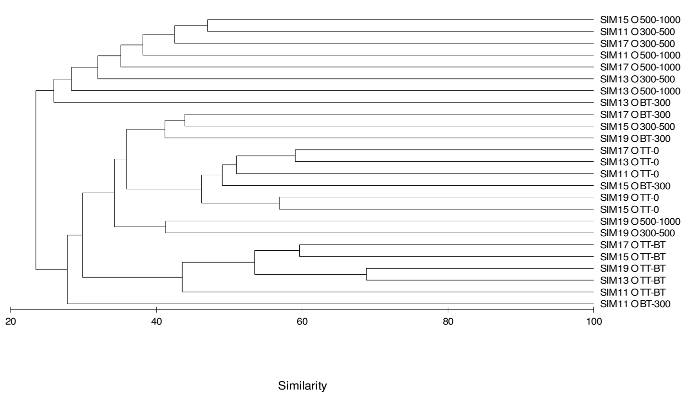

Fig. 7.16. Dendrogram showing the similarity indices in the abundance of copepods in the oceanic stations of the Bay of Bengal during SM

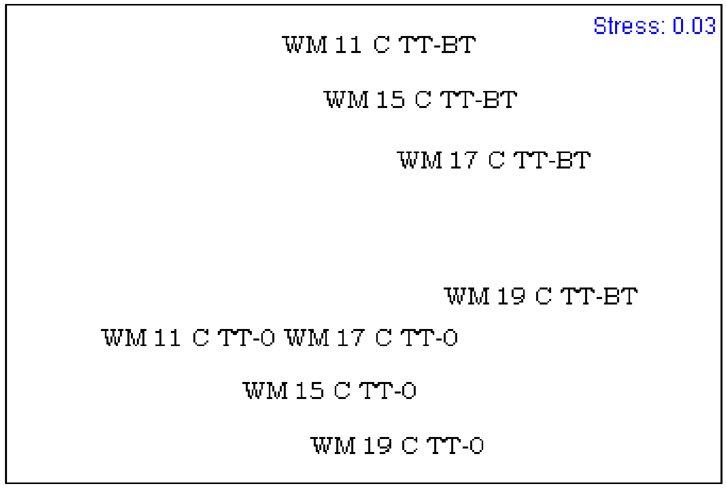

Fig. 7.17. MDS plot for the similarity in the abundance of copepods in the coastal stations of the Bay of Bengal during WM

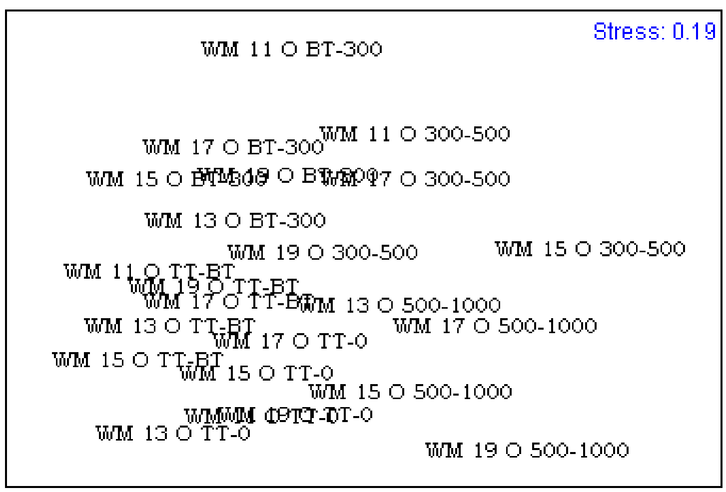

Fig. 7.18. MDS plot for the similarity in the abundance of copepods in the oceanic stations of the Bay of Bengal during WM

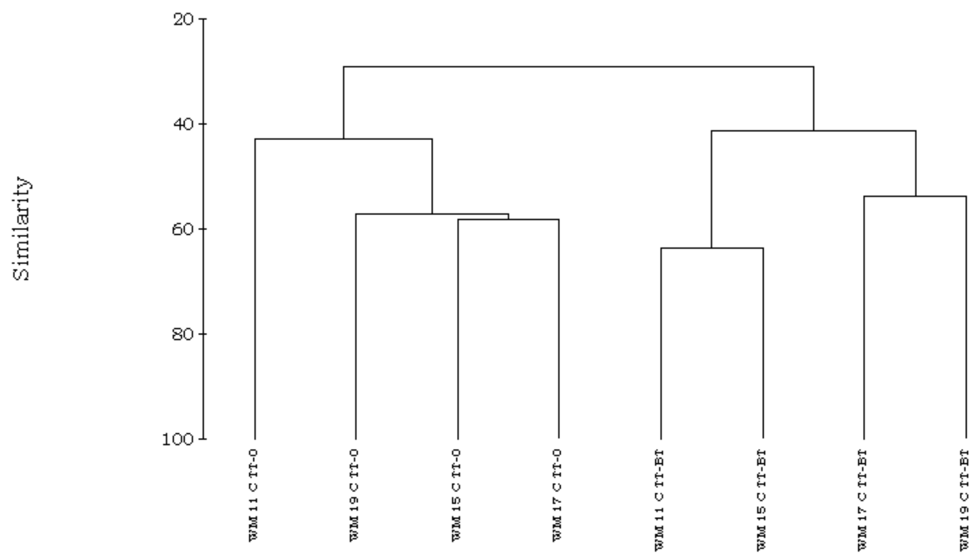

Fig. 7.19. Dendrogram showing the similarity indices in the abundance of copepods in the coastal stations of the Bay of Bengal during WM

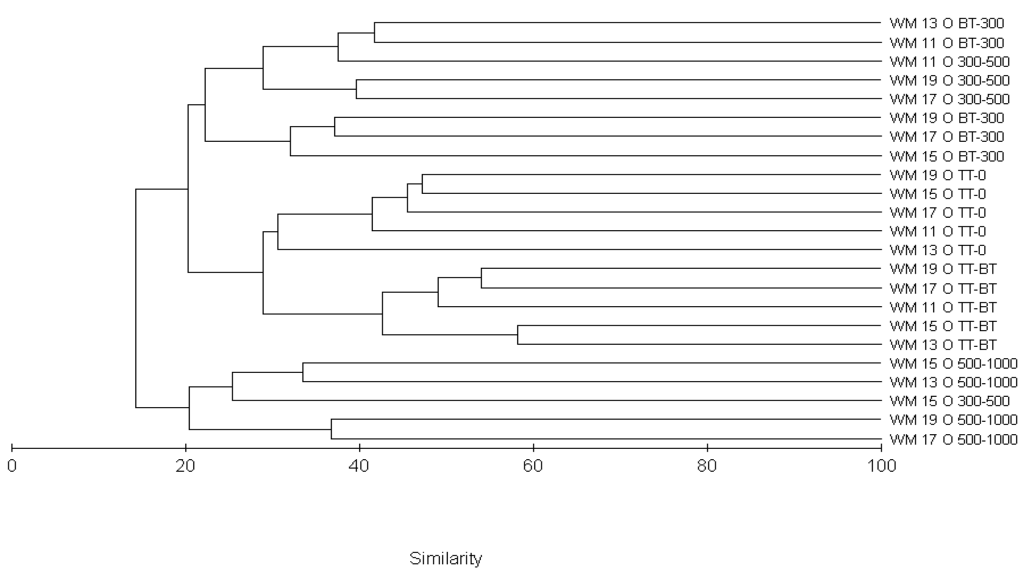

Fig. 7.20. Dendrogram showing the similarity indices in the abundance of copepods in the oceanic stations of the Bay of Bengal during WM

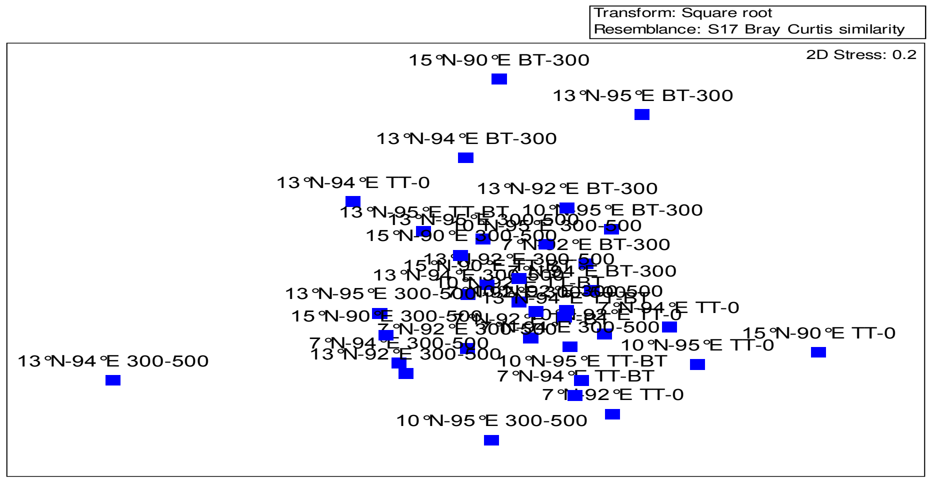

Fig. 7.21. MDS plot for the similarity in the abundance of copepods in the Andaman Sea during intermonsoon fall

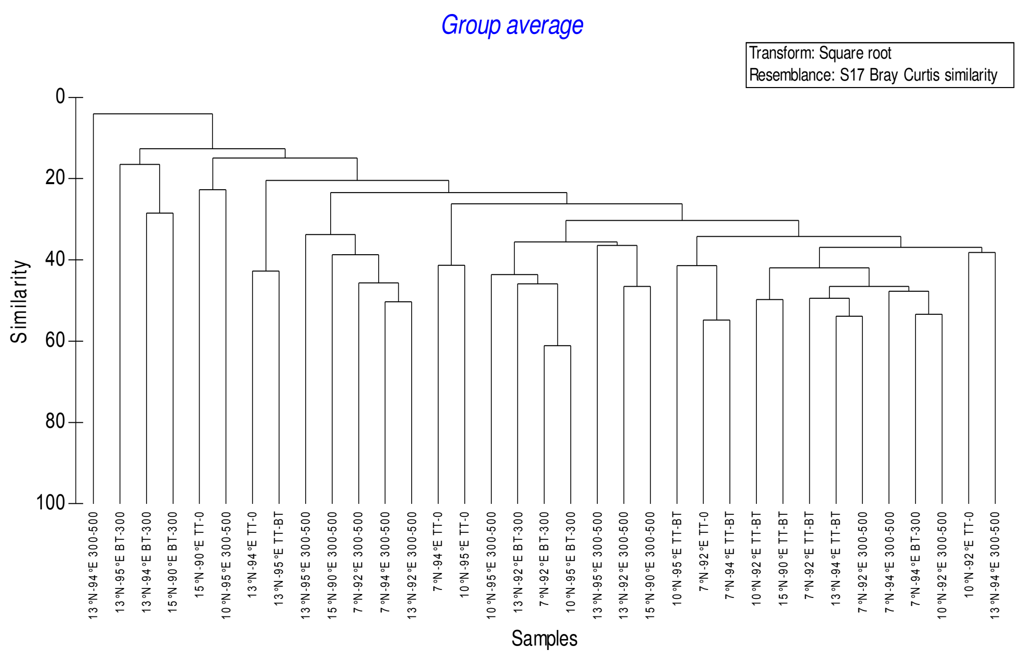

Fig. 7.22. Dendrogram showing the similarity indices in the abundance of copepods in the Andaman sea during intermonsoon fall

Table 7.1. Two Way ANOVA results for the Orders of Copepods (total) at the Bay of Bengal

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Season	17290678.2	2	8645339.1	19.113	0.000
Depth	32459430.3	4	8114857.6	17.940	0.000
Interaction	17053271.3	8	2131658.9	4.713	**0.000**
Error	441025527.8	975	452333.9		
Total	507828907.7	989			

Table 7.2. Two Way ANOVA results for the Orders of Copepods during SIM at the Bay of Bengal

Source of Variation	Sum of Squares	Df	Mean Square	F	Sig.
Depth	1606682.7	4	401670.7	2.952	0.020
Station	5288521.4	9	587613.5	4.319	0.000
Interaction	4110781.1	24	171282.5	1.259	**0.185**
Error	78912440.0	580	136055.9		
Total	89918425.2	617			

Table 7.3. Two Way ANOVA results for the Orders of Copepods during SM at the Bay of Bengal

Source of Variation	Sum of Squares	Df	Mean Square	F	Sig.
Depth	3480416.7	4	870104.2	2.372	0.055
Station	4027696.5	7	575385.2	1.568	0.149
Interaction	5457928.3	16	341120.5	0.930	**0.537**
Error	57970082.9	158	366899.3		
Total	70936124.3	185			

Table 7.4. Two Way ANOVA results for the Orders of Copepods during WM at the Bay of Bengal

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Depth	18791177.8	4	4697794.5	3.259	0.013
Station	34547338.5	8	4318417.3	2.996	0.004
Interaction	26846920.4	18	1491495.6	1.035	**0.425**
Error	223438708.7	155	1441540.1		
Total	303624145.4	185			

Table 7.5. Two Way ANOVA results for the Orders of Copepods during Inter Monsoon Fall at the Andaman Sea

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Depth	1116001.8	4	279000.4	2.318	0.059
Station	3182297.0	7	454613.9	3.777	0.001
Interaction	3913658.7	23	170159.1	1.414	**0.108**
Error	23231906.7	193	120372.6		
Total	31443864.2	227			

Table 7.6. Two Way ANOVA results for the families coming under the Order Calanoida at the Bay of Bengal for all the samples

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Season	987869.0	2	493934.5	12.773	0.000
Depth	1784860.6	4	446215.1	11.539	0.000
Interaction	1195096.8	8	149387.1	3.863	**0.000**
Error	144355339.2	3733	38670.1		
Total	148323165.6	3747			

Table 7.7. Two Way ANOVA results for different families coming under order Calanoida during SIM at the Bay of Bengal

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Depth	149237.0	4	37309.3	4.133	0.002
Station	262624.8	9	29180.5	3.233	0.001
Interaction	219930.7	24	9163.8	1.015	**0.442**
Error	20778979.4	2302	9026.5		
Total	21410772.0	2339			

Table 7.8. Two Way ANOVA results for different families coming under order Calanoida during SM at the Bay of Bengal

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Depth	285678.1	4	71419.5	2.580	0.036
Station	247877.3	7	35411.0	1.279	0.258
Interaction	367527.1	16	22970.4	0.830	**0.652**
Error	18711934.0	676	27680.4		
Total	19613016.5	703			

Table 7.9. Two Way ANOVA results for different families coming under order Calanoida during winter at the Bay of Bengal

Source of Variation	Sum of Squares	Df	Mean Square	F	Sig.
Depth	961160.3	4	240290.1	1.617	0.168
Station	2038327.8	8	254791.0	1.714	0.092
Interaction	1730251.9	18	96125.1	0.647	**0.863**
Error	100035176.9	673	148640.7		
Total	104764916.9	703			

Table 7.10. Two Way ANOVA results for different families coming under Order Calanoida during Inter Monsoon Fall at the Andaman

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Depth	20044.1	4	5011.0	0.926	0.448
Station	103593.3	7	14799.0	2.735	0.008
Interaction	148998.8	23	6478.2	1.197	**0.238**
Error	4506990.4	833	5410.6		
Total	4779626.5	867			

Table 7.11. Two Way ANOVA results of numerical abundance of copepods before Cyclone in the Bay of Bengal

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Station	3303514.4	13	254116.5	3.645	0.000
Error	59959635.1	860	69720.5		
Total	63263149.5	873			

Table 7.12. Two Way ANOVA results of numerical abundance of copepods after Cyclone in the Bay of Bengal

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Station	931061.2	11	84641.9	0.439	0.938
Error	50942783.9	264	192965.1		
Total	51873845.1	275			

Table 7.13. Correlations between Physical parameters and Families of Copepods during SIM in the Bay of Bengal

		SST	Sigma-T	Salinity
Calanidae	Pearson Correlation	.067	-.133	.087
	P-value	.500	.179	.384
Megacalanus	Pearson Correlation	.(a)	.(a)	.(a)
	P-value	.	.	.
Paracalanidae	Pearson Correlation	-.056	**-.206**(*)	-.064
	P-value	.574	.036	.518
Mecynoceridae	Pearson Correlation	.129	-.019	-.138
	P-value	.196	.846	.163
Eucalanidae	Pearson Correlation	-.040	-.039	.041
	P-value	.691	.698	.678
Clausocalanidae	Pearson Correlation	-.049	-.001	.053
	P-value	.626	.990	.593
Pseudocalanidae	Pearson Correlation	-.144	-.016	-.125
	P-value	.147	.869	.207
Aetideidae	Pearson Correlation	.059	-.138	.043
	P-value	.552	.164	.668
Euchaetidae	Pearson Correlation	-.001	-.090	.000
	P-value	.994	.364	.998
Phaennidae	Pearson Correlation	-.019	.006	.047
	P-value	.852	.949	.635
Scolecithricidae	Pearson Correlation	.008	.019	.089
	P-value	.935	.848	.370
Centropagidae	Pearson Correlation	.079	-.106	-.107
	P-value	.426	.287	.283
	Pearson	(a)	(a)	(a)

* Correlation is significant at the 0.05 level.

** Correlation is significant at the 0.01 level.

a Cannot be computed because at least one of the variables is constant.

Table 7.14. Correlations between Physical parameters and Families of Copepods in the Bay of Bengal during SM

		SST	Sigma-T	Salinity
Calanidae	Pearson Correlation	.095	.087	.154
	P-value	.610	.643	.407
Megacalanus	Pearson Correlation	.(a)	.(a)	.(a)
	P-value	.	.	.
Paracalanidae	Pearson Correlation	-.272	-.477(**)	-.329
	P-value	.138	.007	.071
Mecynoceridae	Pearson Correlation	.145	-.296	-.431(*)
	P-value	.436	.106	.015
Eucalanidae	Pearson Correlation	-.325	-.111	.069
	P-value	.075	.553	.712
Clausocalanidae	Pearson Correlation	.111	.150	.219
	P-value	.552	.421	.237
Pseudocalanidae	Pearson Correlation	.159	.163	.196
	P-value	.394	.380	.292
Aetideidae	Pearson Correlation	.102	.278	.298
	P-value	.584	.130	.103
Euchaetidae	Pearson Correlation	-.522(**)	-.179	-.002
	P-value	.003	.336	.993
Phaennidae	Pearson Correlation	.076	-.332	-.580(**)
	P-value	.686	.068	.001
Scolecithricidae	Pearson Correlation	.399(*)	.161	.087
	P-value	.026	.386	.641

Centropagidae	Pearson Correlation	-.239	-.307	-.358(*)
	P-value	.196	.092	.048
Diaptomidae	Pearson Correlation	.067	-.242	-.223
	P-value	.720	.190	.228
Temoridae	Pearson Correlation	-.471(**)	-.401(*)	-.246
	P-value	.008	.025	.182
Metridiidae	Pearson Correlation	-.298	.284	.379(*)
	P-value	.104	.122	.035
Lucicutiidae	Pearson Correlation	-.301	.125	.213
	P-value	.100	.501	.250
Heterorhabdidae	Pearson Correlation	.168	.103	-.219
	P-value	.368	.583	.236
Augaptilidae	Pearson Correlation	.195	.049	-.003
	P-value	.292	.792	.989
Arietellidae	Pearson Correlation	.067	.206	.115
	P-value	.720	.266	.537
Candaciidae	Pearson Correlation	.362(*)	-.447(*)	-.387(*)
	P-value	.045	.012	.031
Pontellidae	Pearson Correlation	-.050	-.441(*)	-.419(*)
	P-value	.790	.013	.019
Tortanidae	Pearson Correlation	.(a)	.(a)	.(a)
	P-value	.	.	.
Acartiidae	Pearson Correlation	.160	-.299	-.296
	P-value	.391	.102	.106

* Correlation is significant at the 0.05 level.

** Correlation is significant at the 0.01 level.

a Cannot be computed because at least one of the variables is constant.

Table 7.15. Correlations between Physical parameters and Families of Copepods during WM in the Bay of Bengal

		SST	Sigma-T	Salinity
Calanidae	Pearson Correlation	-.277	.044	.179
	P-value	.132	.813	.336
Megacalanus	Pearson Correlation	.(a)	.(a)	.(a)
	P-value	.	.	.
Paracalanidae	Pearson Correlation	-.129	-.537(**)	-.571(**)
	P-value	.489	.002	.001
Mecynoceridae	Pearson Correlation	.021	.089	.145
	P-value	.911	.633	.436
Eucalanidae	Pearson Correlation	-.147	-.056	.077
	P-value	.430	.765	.681
Clausocalanidae	Pearson Correlation	-.201	-.043	.008
	P-value	.277	.818	.965
Pseudocalanidae	Pearson Correlation	-.005	.203	.107
	P-value	.978	.274	.566
Aetideidae	Pearson Correlation	-.260	.080	.137
	P-value	.158	.669	.461
Euchaetidae	Pearson Correlation	-.131	-.459(**)	-.373(*)
	P-value	.484	.009	.039
Phaennidae	Pearson Correlation	-.187	-.100	.006
	P-value	.313	.594	.973
Scolecithricidae	Pearson Correlation	-.392(*)	-.223	-.184
	P-value	.029	.228	.321
Centropagidae	Pearson Correlation	-.426(*)	-.167	-.131
	P-value	.017	.368	.482
Diaptomidae	Pearson Correlation	.(a)	.(a)	.(a)
	P-value	.	.	.
Temoridae	Pearson Correlation	.020	-.315	-.383(*)
	P-value	.916	.084	.034
Metridiidae	Pearson Correlation	-.163	-.180	-.092

	P-value	.382	.332	.623
Lucicutiidae	Pearson Correlation	-.111	.017	-.090
	P-value	.553	.930	.631
Heterorhabdidae	Pearson Correlation	-.150	.585(**)	.415(*)
	P-value	.422	.001	.020
Augaptilidae	Pearson Correlation	-.166	.268	.174
	P-value	.371	.144	.349
Arietellidae	Pearson Correlation	-.203	.176	.121
	P-value	.274	.345	.515
Candaciidae	Pearson Correlation	.105	-.551(**)	-.404(*)
	P-value	.574	.001	.024
Pontellidae	Pearson Correlation	-.014	-.364(*)	-.359(*)
	P-value	.942	.044	.048
Tortanidae	Pearson Correlation	.(a)	.(a)	.(a)
	P-value	.	.	.
Acartiidae	Pearson Correlation	.264	-.227	-.242
	P-value	.152	.219	.190

* Correlation is significant at the 0.05 level.

** Correlation is significant at the 0.01 level.

a Cannot be computed because at least one of the variables is constant.

Table 7.16. Correlations between Physical parameters and Families of copepods in the Andaman Sea

		SST	Sigma-T	Salinity
Calanidae	Pearson Correlation	.002	.088	.166
	P-value	.993	.600	.320
Megacalanus	Pearson Correlation	-.091	.181	.108
	P-value	.587	.277	.519
Paracalanidae	Pearson Correlation	-.263	-.492(**)	-.369(*)
	P-value	.110	.002	.023

Mecynoceridae	Pearson Correlation	-.108	.128	.074
	P-value	.520	.444	.658
Eucalanidae	Pearson Correlation	-.348(*)	-.243	-.145
	P-value	.032	.142	.386
Clausocalanidae	Pearson Correlation	-.108	.099	.098
	P-value	.520	.552	.557
Pseudocalanidae	Pearson Correlation	-.095	.229	.145
	P-value	.572	.166	.386
Aetideidae	Pearson Correlation	-.233	-.039	.024
	P-value	.159	.816	.888
Euchaetidae	Pearson Correlation	-.265	-.296	-.151
	P-value	.108	.071	.367
Phaennidae	Pearson Correlation	-.276	-.027	.028
	P-value	.094	.873	.866
Scolecithricidae	Pearson Correlation	.084	.190	.156
	P-value	.616	.254	.349
Centropagidae	Pearson Correlation	.(a)	.(a)	.(a)
	P-value	.	.	.
Diaptomidae	Pearson Correlation	.(a)	.(a)	.(a)
	P-value	.	.	.
Temoridae	Pearson Correlation	.(a)	.(a)	.(a)
	P-value	.	.	.
Metridiidae	Pearson Correlation	-.106	.072	.169
	P-value	.525	.667	.310
Lucicutiidae	Pearson Correlation	.350(*)	.209	.182
	P-value	.031	.209	.275
Heterorhabdidae	Pearson Correlation	-.001	.148	.097
	P-value	.995	.376	.564
Augaptilidae	Pearson Correlation	-.145	-.141	-.056
	P-value	.386	.397	.738
Arietellidae	Pearson Correlation	-.031	-.178	-.203

	P-value	.852	.284	.221
Candaciidae	Pearson Correlation	-.141	-.479(**)	-.440(**)
	P-value	.398	.002	.006
Pontellidae	Pearson Correlation	.224	-.426(**)	-.483(**)
	P-value	.177	.008	.002
Tortanidae	Pearson Correlation	.(a)	.(a)	.(a)
	P-value	.	.	.
Acartiidae	Pearson Correlation	.291	.076	.100
	P-value	.077	.650	.550

* Correlation is significant at the 0.05 level.

** Correlation is significant at the 0.01 level.

a Cannot be computed because at least one of the variables is constant.

7.17. Correlations between Physical parameters and Families of Copepods during the Cyclone 175

		Sigma-T	Salinity
Calanidae	Pearson Correlation	.132	.140
	P-value	.626	.606
Megacalanus	Pearson Correlation	.(a)	.(a)
	P-value	.	.
Paracalanidae	Pearson Correlation	.212	.222
	P-value	.430	.408
Mecynoceridae	Pearson Correlation	.093	.102
	P-value	.733	.708

Eucalanidae	Pearson Correlation	.159	.158
	P-value	.557	.559
Clausocalanidae	Pearson Correlation	.101	.090
	P-value	.709	.742
Pseudocalanidae	Pearson Correlation	.(a)	.(a)
	P-value	.	.
Aetideidae	Pearson Correlation	-.001	-.008
	P-value	.998	.978
Euchaetidae	Pearson Correlation	.066	.065
	P-value	.807	.811
Phaennidae	Pearson Correlation	.(a)	.(a)
	P-value	.	.
Scolecithricidae	Pearson Correlation	-.107	-.105
	P-value	.693	.699
Centropagidae	Pearson Correlation	.111	.110
	P-value	.682	.685
Diaptomidae	Pearson Correlation	.096	.097
	P-value	.724	.721
Temoridae	Pearson Correlation	.(a)	.(a)
	P-value	.000	.000
Metridiidae	Pearson Correlation	.082	.070
	P-value	.763	.797
Lucicutiidae	Pearson Correlation	.114	.101
	P-value	.675	.709
Heterorhabdidae	Pearson Correlation	.(a)	.(a)
	P-value	.000	.000
Augaptilidae	Pearson Correlation	.(a)	.(a)
	P-value	.	.
Arietellidae	Pearson Correlation	.(a)	.(a)
	P-value	.	.

Candaciidae	Pearson Correlation	.007	.018
	P-value	.980	.948
Pontellidae	Pearson Correlation	.015	.018
	P-value	.955	.947
Tortanidae	Pearson Correlation	.(a)	.(a)
	P-value	.	.
Acartiidae	Pearson Correlation	.093	.102
	P-value	.733	.708

** Correlation is significant at the 0.01 level.

* Correlation is significant at the 0.05 level.

a Cannot be computed because at least one of the variables is constant.

7.18. Correlations between Physical parameters and Families of Copepods during Cyclone 178

		SST	**Salinity**
Calanidae	Pearson Correlation	-.364	-.332
	P-value	.375	.422
Megacalanus	Pearson Correlation	.(a)	.(a)
	P-value	.	.

Paracalanidae	Pearson Correlation	.049	-.458
	P-value	.908	.253
Mecynoceridae	Pearson Correlation	.(a)	.(a)
	P-value	.000	.000
Eucalanidae	Pearson Correlation	.202	.483
	P-value	.632	.226
Clausocalanidae	Pearson Correlation	-.181	-.072
	P-value	.669	.865
Pseudocalanidae	Pearson Correlation	.(a)	.(a)
	P-value	.	.
Aetideidae	Pearson Correlation	-.324	-.159
	P-value	.433	.708
Euchaetidae	Pearson Correlation	-.573	-.150
	P-value	.138	.722
Phaennidae	Pearson Correlation	.(a)	.(a)
	P-value	.	.
Scolecithricidae	Pearson Correlation	-.022	.236
	P-value	.959	.574
Centropagidae	Pearson Correlation	-.579	-.223
	P-value	.133	.596
Diaptomidae	Pearson Correlation	.(a)	.(a)
	P-value	.	.
Temoridae	Pearson Correlation	-.147	-.070
	P-value	.728	.868
Metridiidae	Pearson Correlation	.298	.551
	P-value	.473	.157
Lucicutiidae	Pearson Correlation	-.561	-.110
	P-value	.148	.795

Heterorhabdidae	Pearson Correlation	-.035	.294
	P-value	.934	.479
Augaptilidae	Pearson Correlation	.150	.391
	P-value	.723	.338
Arietellidae	Pearson Correlation	.(a)	.(a)
	P-value	.	.
Candaciidae	Pearson Correlation	-.668	-.281
	P-value	.070	.501
Pontellidae	Pearson Correlation	.053	-.413
	P-value	.900	.309
Tortanidae	Pearson Correlation	.(a)	.(a)
	P-value	.	.
Acartiidae	Pearson Correlation	.(a)	.(a)
	P-value	.000	.000

* Correlation is significant at the 0.05 level.

** Correlation is significant at the 0.01 level.

a Cannot be computed because at least one of the variables is constant.

Table 7.19. Diversity indices in the Andaman Sea during Fall Intermonsoon

Sample	S	N	d	J'	H'(log2)	Lambda'
7°N-92°E TT-0	25	5211	2.804	0.585	2.718	0.197
7°N-94°E TT-0	13	1785	1.603	0.721	2.668	0.198
10°N-95°E TT-0	12	828	1.637	0.535	1.918	0.427
10°N-92°E TT-0	39	2192	4.940	0.726	3.839	0.112
13°N-94°E TT-0	10	154	1.787	0.749	2.489	0.239
15°N-90°E TT-0	12	1239	1.544	0.806	2.888	0.183
7°N-92°E TT-BT	25	1539	3.270	0.648	3.007	0.173
7°N-94°E TT-BT	18	4673	2.012	0.605	2.524	0.274
10°N-95°E TT-BT	30	3874	3.510	0.684	3.354	0.150

10°N-92°E TT-BT	20	1552	2.586	0.732	3.163	0.158
13°N-94°E TT-BT	22	1600	2.846	0.698	3.111	0.174
13°N-95°E TT-BT	13	125	2.485	0.907	3.356	0.102
15°N-90°E TT-BT	20	380	3.199	0.747	3.229	0.135
7°N-92°E BT-300	26	1529	3.410	0.706	3.32	0.124
7°N-94°E BT-300	7	1160	0.850	0.650	1.824	0.371
10°N-95°E BT-300	23	1280	3.075	0.600	2.716	0.202
13°N-92°E BT-300	12	458	1.795	0.672	2.408	0.260
13°N-94°E BT-300	14	117	2.730	0.842	3.205	0.126
13°N-95°E BT-300	17	25	4.971	0.972	3.974	0.030
15°N-90°E BT-300	8	188	1.337	0.896	2.689	0.190
7°N-92°E 300-500	36	1478	4.796	0.563	2.911	0.234
7°N-94°E 300-500	10	792	1.348	0.806	2.677	0.196
10°N-95°E 300-500	41	624	6.215	0.645	3.457	0.150
10°N-92°E 300-500	28	1663	3.641	0.428	2.057	0.338
13°N-95°E 300-500	34	263	5.922	0.733	3.727	0.140
13°N-94°E 300-500	34	429	5.444	0.756	3.844	0.117
13°N-92°E 300-500	25	578	3.774	0.745	3.458	0.138
15°N-90°E 300-500	33	651	4.939	0.778	3.924	0.091
7°N-92°E 500-1000	30	1388	4.008	0.575	2.823	0.189
7°N-94°E 500-1000	23	685	3.369	0.839	3.794	0.101
10°N-95°E 500-1000	59	1230	8.152	0.701	4.122	0.103
13°N-95°E 500-1000	39	480	6.155	0.710	3.751	0.128
13°N-94°E 500-1000	8	46	1.828	0.891	2.672	0.164
13°N-92°E 500-1000	24	687	3.521	0.696	3.191	0.167
15°N-90°E 500-1000	23	875	3.248	0.719	3.253	0.193

Chapter VIII

DISCUSSION

There is growing evidence of strong physical – biological linkages in plankton communities of marine ecosystems (Stephen, 1984, Le Fevre, 1986; Fortier, *et.al.*, 1992; Nielsen et al.,1957; 1992; Prasanna Kumar *et al.*, 2004). But most of the available information on plankton dynamics and physical-biological linkages originates from studies in temperate waters, which are characterized by strong winter or summer seasonality in heat influx and water stratification, while fewer studies have been carried out in tropical waters, where hydrographical conditions are different (Munk Peter, 2004). Literature available on different biological aspects of the BoB and the Andaman Sea are limited. The present investigation gives detailed information on the distribution and diversity of the Bay of Bengal and the Andaman Sea (Northeastern Indian Ocean).

8.1. Physico-chemical Environment

The Bay of Bengal water is characterized by surface layer with freshwater component having salinity range from 28.0 to 35.0 psu and temperature range 25-29°C. The BoB is located in the monsoon belt, but it comes under the influence of semiannual seasonality of the Asian monsoon (Ramage, 1971) because of the differential heating and cooling of the Sea. During monsoon seasons, the river runoff from the Indian rivers to the BoB plays a critical role in the process of monsoon intensification by creating and sustaining low salinity layer on top of BoB (Rajamani, 2005). The sediment load associated with riverine input appears to scavenge biogenic material from the surface layer into the depth with higher sinking fluxes at BoB (Nair *et al.*, 1989; Ittekot *et al.*, 1991; Hake *et al.,* 1993; Ramaswami *et al.*, 1994 and Unger *et al.*, 2003). A vivid picture on the environment and productivity of the EEZ of India and adjoining areas including the island system, both vertically and horizontally is governed by K.K.C. Nair,2010 in an Atlas published by ministry of Earth Science.

In contrast to the Arabian Sea, one of the well studied regions of Indian Ocean, the BoB is considered to be less productive. This is because of the low phytoplankton biomass and primary productivity recorded from the BoB resulted from the low availability of nutrient in the upper layer due to stratification and heavy cloud coverage (Prasannakumar *et al.,* 2002; Madhupratap *et al.*, 2003). Another reason for this condition is the rapid sinking rate of particles and subsequent unavailability of nutrients to the biotic community (Radhakrishna *et al.*, 1978; Bauer, *et al.*, 1991; Brock *et al.*, 1991; Prasannakumar *et al.*, 2001a, 2002; Prasannakumar *et al.*, 2003). The field observations were further supported by the satellite data (Sea WiFS) which showed very low Chlorophyll -*a* values (Gomes *et al*., 2000; Prasannakumar *et al.,* 2002). During the present observations, influence of fresh water influx from rivers could be seen in the northern region where they form a fresh water lens over high saline sea water at the time of summer monsoon. The thermocline layer depth ranged between 32 to 142m and the average depth, obtained were 88m. The coastal station of 15°N recorded for minimum thermocline layer depth where as the oceanic layer of 11°N experienced for maximum thermocline layer depth. During the present study, a lens of nitrate (1µM), phosphate (0.2 to 0.4µM) and silicate (1 to 6 µM) was recorded from the surface layers. In the northern most region (20.5°N) of inshore waters during summer monsoon period, this feature was much closer to the coast in the northern BoB and did not initiate the upward pumping of nutrients. But along offshore waters, nutrient enrichments were absent in the upper layers confirming the previous works even though enormous quantity of freshwater was discharged into the Bay from the rivers. This was in accordance with the previous studies that rivers flowing into the Bay might not contribute much to the inorganic nutrient pool (Rajendran *et al*., 1980; de Souza *et al*., 1981; Rao *et al.*, 1994).

The vertical thermal structure showed distinct thermal inversion. Relatively cold surface waters were lying over the warm subsurface waters particularly in the north. i.e., the amplitude of the thermal inversions increased northward while small scale inversions were noticed in the southern regions. The occurrence of thermal inversion was earlier reported by Varkey *et al*. (1996) in the northern BoB and the Andaman Sea. Vertical structure of SSS in the upper 50m showed frontal pattern towards the coast indicating the freshwater influx from the continent. In general, along the coastal region, very low saline waters spread in the upper 30m of the entire east coast. But in the oceanic region, the low saline waters were restricted to the north and high saline waters restricted to the south. Isopycnals in the upper 50m have the same result as that of isohaline pattern, below which the temperature dominated over salinity in the density field. The density structure have a pattern resembling that of salinity in the upper 10m only, indicating the dominance of salinity field over temperature on density. The entire coastal region was reported to have the density greater than 20, but in the oceanic region, low density restricted only to the north and the strong gradients were observed from north to south.

Maximum SSS observed were at the oceanic station of 11°N and minimum at the coastal regions of 15°N because of the Krishna river influx. The warm and low saline waters in the oceanic region provided stratified surface layer which resulted in thin mixed layer (~15 m) at 15°N at the oceanic region.

Vertical distribution of temperature during spring inter monsoon showed an isothermal layer of about 25m, below which the isotherms showed stratification. An up sloping of isotherms towards north was observed in the upper 150m thermal structure. The near shore values of SST were relatively lower than that of the oceanic values. The vertical salinity distribution showed the presence of low saline waters in the northern BoB than the southern region in which an intrusion of high saline waters below 100m can be seen. The vertical density structure of density showed patterns to salinity and the denser water was observed near the shore. Isopycnals of the sigma-t showed dominance of salinity over the temperature in the upper 50m, below which temperature dominated the density field.

During SIM, the anti cyclonic circulation pattern with the pole ward flowing EICC (East India Coastal Current) was observed at the western Bay. This confirmed the earlier observations (Shetye *et al*., 1993; Murty *et al*., 1993;

Sunilkumar *et al*., 1997) as well as satellite observations (Legeckis, 1987) and was successfully simulated in modeling studies too (McCreary *et al.,* 1993; Vinayachandran *et al*., 1996; Shankar *et al*., 1996).

During WM unlike the Arabian Sea, winter cooling did not lead to convective mixing. Enrichment of upper layers was not effective to intense stratification of the waters, caused by low saline water of the upper layer especially in the north even though the SST was found low.

The present study at the Andaman Sea was carried out during inter monsoon fall (Oct-Nov.), which was the transition period between the withdrawal of SW Monsoon and the onset of NE Monsoon around the Andaman - Nicobar Islands. A tongue of Arabian Sea high salinity water penetrating into the central BoB and extending northwards was responsible for warmer and more saline subsurface waters of the BoB side of the Islands. This might be the reason for more productivity at the BoB side of the Andaman Sea compared to its north western side during present study.

8.2. Biological Environment

In any attempt to evaluate the primary production in the BoB, findings during IIOE comes foremost (Krey,1973). One of the basic aims of the expedition was to accumulate data on primary productivity and the environmental phenomena that regulate it. Vertical and horizontal distribution of primary productivity in the BoB during different seasons showed similarity to the observations made by many earlier researchers (Gomes *et.al.* 2000; Madhupratap *et.al.*, 2001). The range of surface primary productivity reported during the *Galathea Expedition* was 0.01–2.16 mgC $m^{-3}day^{-1}$ and that of the column reported by *Anton Brunn* during 1976 was 129.99–329.45 mgC $m^{-2}day^{-1}$. Column primary productivity of 180 to 2200 mgC m^{-2} day^{-1} was reported by Bhattathiri *et.al* (1980) from the BoB. During the present study period, maximum primary productivity was recorded at the coastal stations than oceanic stations. The coastal station at 15ºN Lat. during SM was characterized by highest primary productivity and the oceanic station at 13ºN Lat. with lowest rate. Comparing the average primary productivity, the coastal stations were found more productive than oceanic stations during SM and WM. But during SIM, the oceanic stations recorded more production than coastal stations except at 13ºN Lat. The enhanced primary productivity in this area was due to the presence of an Eddy like structure which brought detectable amount of nitrate up to 25m. Sen Gupta *et al* (1977) recorded nitrate depleted upper layers in the BoB during SIM. The BoB was a cyclone prone region, where cyclone induced upwelling and subsequent nutrient enrichment are likely to churn-up the area, injecting nutrients to the shallow euphotic zone (shallow due to cloud cover and turbidity arising from sediment influx) and thereby enhancing production in the upper layers. Although the riverine flux may bring in nutrients to the BoB, they were thought to be lost to the deep because of its narrow shelf (Qasim, 1977; Sen Gupta *et.al.,* 1977; Radhakrishna *et.al.,* 1978). Comparatively heavier cloud cover might be another reason for prohibiting photo-illumination and resultant inhibition of photosynthesis at BoB (Madhupratap *et.al*., 2003).

Primary productivity data from the Andaman Sea during inter monsoon fall season agreed with the data collected from earlier works (Rangarajan *et.al*., 1972; Devassy *et.al*., 1981, Madhu *et.al*., 2002). Zernova and Ivanov (1964) found that the Andaman Sea was a region of highest production of phytoplankton in the northern Indian Ocean. Prasad (1966) also reported a moderately high plankton production in the Andaman Sea. High primary productivity during colder months and low primary productivity during high temperature and high salinity associated seasons were the result of observations on PP from the Andaman Sea. During the present study, primary productivity varied from 0.1 t0.24 mgCm-^{3} day^{-1} at the Andaman Sea during Inter monsoon fall season (high SST and SSS were observed during this period) and confirmed the oligotrophic nature of the Andaman Sea.

Distribution of phytoplankton and Chl-*a* around little the Andaman were studied by Devassy *et.al* (1981) and established the dionoflagellates as the important constituent of plankton community of the Andaman Sea unlike the Arabian Sea and coastal waters of the BoB.

Long term variation of meso zooplankton biomass in various seas were closely linked to climate change (Brodeur and Ware, 1992; Kaoru-Nakata and

Nakata-Koyama (2003). At the BoB, the vertical biomass variation during different seasons revealed that, the mixed layer supports nearly 5 to10 fold of zooplankton biomass than at the 500-1000 m depth. Less variation was observed during spring while summer monsoon account for maximum zooplankton variation at different depths. During summer monsoon, in the mixed layer maximum amount of zooplankton was observed while the 500-1000 m depth strata had maximum zooplankton abundance during winter monsoon.

The average biomass for the BoB considering all the seasons and depth strata was 270 ml/1000m^3 which was more than double when compared with earlier observations of the shelf waters of the north east (105.5 ml/1000m^3) and more than three fold what recorded for south east (87.3ml/1000m^3) by Mathew *et.al.* (1996a). The narrow continental shelf characterized by limited mixing, prevalence of stable stratification (Mathew *et.al* 1990) and low primary productivity (Nair and Pillai, 1972) might have caused the low zooplankton production in the ambient waters of the BoB. Sreekumaran *et.al* (1996 a) observed an average biomass of 33.2 ml/1000m^3 in the BoB. Maximum biomass was found in the southern region and that could be due to the relatively higher primary productivity and Chl-*a,* existing in that region of the BoB. Occurrence of high average zooplankton biomass observed in the coastal stations along the southern region might be due to the river water plume as suggested by Madhupratap *et.al* (1993). The observation of low zooplankton biomass during SIM could be explained by the hypothesis by Cushing (1989) and subsequently supported by Yentch and Phinney (1989, 1995) based on the observations on seasonal variations in cell size of phytoplankton from the tropical regions. They stated that, in strongly stratified water column, phytoplankton with smaller cell size were the dominant component of the standing stock and was important in tropical regions including the northern Arabian Sea (Yentch and Phinne, 1995). This hypothesis has particular significance in the BoB due to the oligotrophic nature all around the year as a result of stratification, which was maximum during SIM. Majority of phytoplankton in the BoB during SIM could be contributed by small sized phytoplankton (Jyothibabu, 2004). This was obviously indicated in the vertical distribution of physical and chemical parameters during the present study.

Biomass of zooplankton collected from different depth strata from the Andaman Sea revealed their abundance in the mixed layer. The highest biomass obtained was 233 ml/1000m^3. Previous studies revealed that, the biomass of the zooplankton in the Andaman Sea was found to be poor and the average value remained around 5.6 ml/100m3 (Madhupratap *et.al.*, 1981; Nair *et.al.,* 1981). The zooplankton from the Andaman Sea consisted of a mixture of neritic and oceanic species with euryhaline marine forms dominating the zooplankton. The diversity was uniformly high in the Andaman waters. Thirteen species of Chaetognaths were reported from the area by Nair *et.al.* (1981); and 48 species of copepods and 160 species of ostracods was reported by Madhupratap *et.al* (1981a). Vertical distribution of meso zooplankton biomass in relation to oxygen minimum layer in the Andaman Sea was reported by Madhu *et.al* (2003). They observed that biomass and group wise diversity was maximum in the mixed layer (average 5ml/100 m^3) and sometimes in the thermocline layer (4.4 ml/100m^3) also. They concluded that the minimum average biomass values were confined to the depth strata of 300-BT (0.09ml/100m^3), where the oxygen minimum layer was more pronounced. In the present observations, the amount of dissolved oxygen was reduced to 0.2 ml/liter at the 300-BTdepth strata, but not reached the critical oxygen minimum level of 0.1 ml/liter level. That might be the reason for occurrence of least average biomass at 300-500 layer and not at the BT-300m depth strata. An average biomass of 62 ml/100m^3 was obtained at BT-300m layer whereas only 22.2 ml/100m^3 was observed at 300-500 m layer. Overall, the Andaman Sea was poorly investigated in spite of the fact that it supported rich and varied resources of living and non living organism (Pai, 2003).

Copepods

The importance of Indo-Pacific region maintaining species diversity had been dealt with Mauchline. J (1998) who reported this region as cardinal in the diversity of species. Species composition and dominance of Copepod fauna of the Indian Ocean were first studied by Sewell in 1947 who listed 229 species of copepods up to a depth of 3000m. Grice and Hulsemann (1966) listed 310 species of copepods from the western Indian Ocean. Epipelagic calanoid copepods of the northern Indian Ocean were tabulated by Madhupratap and Haridas (1986). They listed out 198 species from the upper 200m of Northern Indian Ocean excluding Pseudodiaptomidae and Acartiidae. A recent study on the mesozooplankton community in the BoB, during the summer monsoon period of 2001 listed 163 species of copepods of which 132 represented by the Order Calanoida (Veronica and Ramaiah, 2009).

During the present study, a total of 318 Copepod species (belong to 35 families and 89 genera) were recorded from the Exclusive Economic Zone of East Coast of India, of which 200 copepods were identified during Inter monsoon fall season from the Andaman Sea and 277 were from the Bay of Bengal during Summer monsoon (169 species which include 146 Calanoids), winter monsoon (183 species of which includes 158 calanoids) and Inter monsoon spring (240 species of which was 211 calanoids).

Among the total number of copepods (2,55,566) analyzed from the Bay of Bengal nearly 50% were concentrated in the thermocline layer (ie;1,23,963). *Corycacus* and *Oncea venusta* formed the bulk of concentration, 13 and 13.6% respectively.

The analysis of temporal variations of the orders of Copepoda at five depths strata of the BoB clearly reflected the dominance of order Calanoida over other orders. They constituted a major component at BT-300m layer and at the thermocline layer their percentage composition was less. Summer monsoon accounted for the maximum calanoid concentration at all depths strata except at the lowermost(500-1000) in which, winter monsoon had the maximum concentration of calanoids.

In the surface layer, the families, Calanidae, Paracalanidae, Candaciidae, Pontellidae and Arietellidae were found to occur more among different layers of the water column of the BoB. Madhupratap et.al., 1996, reported the presence of fine filter feeders such as salps and appendicularians, along with small copepods (<2 mm) of the genera *Paracalanus, Acrocalanus, Clausocalanus, Calanus minor, Cosmocalanus and Undinula* in the upper mixed layer of Arabian sea in both productive (winter) and oligotrophic (inter monsoon seasons)period.

Phaennidae and Aetididae were highest in the TT-BT layer, whereas Metriidae recorded its highest percentage in the BT-300 layer. Clausocalanidae and Lucicutiidae showed its dominance in the 300-500m layer. Highest percentage of occurrence of the families Megacalanidae, Mecynoceridae, Eucalanidae, Pseudocalanidae, Aetididae, Euchaetidae, Scolecithricidae, Heterorhabdidae and Augaptilidae were recorded in the 500-1000m layer.

The cyclonic and post cyclonic Copepod species were compared and the data recorded from species in the mixed layer showed the occurrence of the meso-bathypelagic species such as, *e.g. Gaussia sewelli, Pleuromamma xiphias, Augaptilus longicaudatus and Heterostylites longicornis.* Stephen and Rashiba (2005) which that the BoB and the Andaman Sea (rich in species diversity especially below 300mhad reported). This could be attributed to the influence of Pacific water intrusion through the Malacca strait. Since the BoB and the Andaman Sea experienced sporadic cyclones, some of the bathypelagic species got lifted to the mixed layer. Though the density of copepods was less compared to the Arabian Sea, in general the BoB showed a rich and diverse copepod community in the upper 1000m.

The vertical distribution of copepods in the Bay of Bengal revealed the presence of the following species *Acartia danae, Calanopia minor, C.aurivilli, Candacia columbiae, Centropages calaninus, Pontellopsis scotti, P.securifer, Pseudodiaptomus auriveilli, Eucheata tenuis, Isias tropica, Pseudoamallothrix indica* and *Xanthocalanus cornifer* at the mixed layer only. These species were highly restricted the salinity of the water column of the upper layers of the BoB.

Species which were recorded only at the thermocline layer of the BoB include, *Aetidiopsis acutus, Aetidiopsis brady, Candacia curta, Centropages orisini, Chirundina indica, Eucheata flava, E.indica, E.minuta, Euchirella galeata, Gaidius minutus, Hemirhabdus grimaldi* and *Pontellopsis macronyx.*

The species which was found only at the BT-300m depth strata of BoB during the study period include a single species named *Clytemnestra scutellata.* The species observed only at the 300-500m depth strata were *Gaetanus latifrons, Heterorhabdus tenuis,H. vipera, Lophothrix humilifrons, Lucicutia macrocera, L.*

magna, Metis pachyptilus, Pareuchaeta scotti, Colecithricella tenuiserrata, Scottocalanus magnus, S. setosus, S. terranovae.

Augaptilus anceps, A. longicaudatus, Cephalophanes frigidus, Disseta palaumboi, D. scopularis, Euaugaptilus angustus, E. bullifer, E. digitatus, E. indicus, E. laticeps, E. longimanus, E. mixtus, E. nudus, E. squamatus, Eucheata spinosa, Euchirella bella, E. curta, Gaidius brevispinus, Hemirhabdus spp.,Nullosetigera impar, P. muticus, Scolecithricells denteta, S.tropica, Scottocalanus farrani, S. longispinus, S. persecans, , Spinocalanus magnus and Xanthocalanus amabilis were recorded only at the lower depth strata of the BoB. Most of these species particularly *Euaugaptilus* and *Augaptilus* were endemic to Indian Ocean.

Spatial distribution of copepods at mixed layer revealed that species diversity was more at the southern BoB compared to northern region(Tab.5.4). Stations at the 13° and 15°N latitudes of the BoB maximum species diversity was recorded. The important species of copepods noticed at the southern region of BoB include*, Xanthocalanus cornifer, Lucicutia challengeri, Gaetanus kruppi, Chirundina streetsi, Chirudinella magna, Augaptilus glacialis, Haloptilus ornatus, Pareucheata simplex and some species belongs to Eucheatidae* and *Scolecithricidae,* where as the northern BoB was characterized by the presence of *Euchirella rostrata, Pontellopsis scotti, P. securifer, Scolecithricella nicobarica, Heterostylites longicornis, Clytemnestra and Aegisthus mucronatus.*

At the thermocline layer, a gradual decrease could be observed in the number of restricted species. The 11°N latitude had maximum copepod species confined to that area at the thermocline layer(Table.5.5). They include *Aetidiopsis acutus, A. brady, Candacia pacifica, Centropages orsini, Eucheata media, Gaetanus kruppi, G.miles, G.minor, Haloptilus acutifrons, H. spiniceps, hemirhabdus grimaldi and Mesorhabdus brevicaudatus.* The 17ºN and 19º N latitude of the BoB was noticed for the presence of *Eucalanus sewelli, Gaidius minutus and Candacia truncata.*

At the BT-300m depth strata, the 15°N Latitude i.e., the central bay were noticed for a good number of species which were confined to this layer only. Where as the southern and northern regions had only few species confined to that area(Tab.5.6). *Metridia princeps* and *M. okotensis* were the important species recorded from the central bay where as *Pareuchaeta simplex and Haloptilus ornatus* from the southern bay and the *Eucalanus inermis,* and *Paracandacia simplex* from the northern Bay of Bengal(Tab. 5.6).

The 300-500m depth strata of the BoB ,maximum number of restricted copepods at the 13°N Lat(Tab.5.7). Presence of *Chridius gracilis, Drepanopsis orbus, Metis* sp.*, Heterorhabdus tanneri* and *H. robustus* at the northern region and *Mesorhabdus angustus, Pareucheata scotti, Phaenna spinifera, Scolecithricella marginata, Scottocalanus terranovae, Subeucalanus subtenuis, Pareucheata barbata, Pleuromamma borealis* and *Euaugaptilus oblongus* at the southern region was remarkable.

The 1000-500m depth strata was noted for its enormous species diversity at the northern most end of the BoB. Although a gradual reduction in the number of restricted species at the lowermost strata was observed from south to north, at 19°N Lat(Tab.5.8) the number of species confined to that area showed an increase. *Scolecithricella tenuipus, Scolecithricella tropica, Scolecithricella vittatta,Scottocalanus australis* and *Scaphocalanus elongates* were the species represented that area.

From the north eastern Andaman Sea in the mixed layer, species diversity as well as the numerical abundance for the family Metrididae was observed high. Four species were identified of which *Pleuromamma piseki* was the dominant group. Order Calanoida was represented with 40 species out of 154 species obtained from the mixed layer waters of the Andaman sea(Tab.6.3). The bio composition ratio for the Order Harpacticoida, Cyclopoida and Poecilostomatoida were 15:5:74.

In the thermocline layer out of 125 specimens obtained, 67 belonged to the order Calanoida. Dominance of Family Metrididae at this layer was obvious(Tab.6.4). *Heterorhabdus pappiligear, Lucicutia flavicornis, Scottocalanus helena* and *Subeucalanus pileatus* contributed much to the richness of copepod community at this layer. *Cosmocalanus darvini, Eucalanus attaenuatus, Subeucasslanus subcarsses, Aetidiopsis giesbrechti, Gaetanus miles, Euchirella amonea, Valdiella oligarthra, Eucheata rimana, E. wolfeni, Phaenna* *spinifera, Scolecithrix brady, Heterorhabdus abyssalis* and *Haloptilus setuliger* were also reported from this region.

At BT-300m layer, *Subeucalanus mucrontus, Gaetanus miles, Euchirella pulchera, Pareucheata malayencis, Phaenna spinifera, Scolechithricella lophophora, S. propinqua* and *Haloptilus setuliger* were observed(Tab.6.5). Different species of *Pleuromamma* were found abundantly distributed in the water column.

The 500-300m layer of the north eastern Andaman sea noted for the presence of the following species *Megacalanus princeps, Clausocalanus arcuicornis, C. farrani, Spinocalanus magnus, S. spinosus, Gaetanus kruppi, G. minutus, Euchirella areata, E. pulchera, E. messinensis, E. indica, E. venusta, Chirundina sewelli, Valdiviella oligarthra, Pareucheata barbatta, P. malayensis, Phaenna spinifera, Scottocalanus daughlishi, S. helenae, S. securifrons, Scolecithricella emarginata, S. propinqua, Lucicutia ovalis, Dissetta palaumboi, Dissetta scopularis, Heterorhadbus abyssalis, H. longicornis, H. pappiliger, H. subspinifrons, Euaugaptilus magnus, Haloptilus longicornis, H. longiceps,Nullosetigera bidentatus, Candacia aethiopica* (Tab.6.6). Family Metrididae which formed the dominant component of the Order Calanoida, in this stratum was represented by five species.

At the lowest depth strata of 500-1000m, presence of *Bradycalanus typicus* was noticed together with *Megacalanus prinicpes* and *M. longicornis*. Other important species obtained from this region were *Mecynocera clausi, Monacilla typica, Cephalophanes frigidus, Aetidiopsis griesbrechti, Gaetanus armiger, G. pileatus, G. minor, Gaidius minutus, Euchirella amoena, E. rostrata, Pseudochirella obesa, Chirundina streetsi, C. sewelli, Pareucheata barbata, P. scotti, Uneucheata major, Onchocalanus affinis, Scottocalanus dauglishi, S. magnus, Lophothrix frontalis, Scolecithrix* sp. like *S. brady,* and *S. nicobarica* and *Amallothrix paravalida* (Tab.6.7). Night samples from this region were dominated by different species of Metrididae and Lucicutiidae. Species of *Heterorhadbus* were obtained from night samples whereas the day sample was devoid of the *Heterorhadbus* species and only a few numbers of Lucicutidae and Metrididae obtained from there.

North western region of the Andaman Sea was inhabited by species like, *Eucalanus elongatus, Rhincalanus rostrifrons, Aetidiopsis brady, Gaetanus miles, Scottocalanus* sp., *Gaetanus pileatus, G. armiger, G. miles, G. minor, G. pileatus, Euchirella amoena, E. bitumida, E. messinensis, E. pulchera, E. venusta, Labidocera biocornuta, Valdiviella oligarthra, Lucicutia challengeri, L. macrocera, L. magna, L. maxima, Heterorhadbus compactus, H. abyssalis, H. fistulosus, Heterostylites major, Haloptilus acutifrons, Gaussia princeps, Chirundina streetsi, Xanthocalanus amabilis, Dissetta palaumboi, Euaugaptilus hulsmannae, E. magnus, A. longicaudatus, H. longicornis, Megacalanus princeps, Clausocalanus arcuicornis, C. ferrani, Cephalophen frigidus, Aetideus bradyi, Eucheata rimana, P. malayensis, Scottocalanus investigatoris, S. tongispinus, S. securifrons,* and *Metridia princeps*.

From the ANOVA analysis, it was clear that the orders of the copepods significantly varied with seasons and depths(Tab.7.1) . Seasonally, the interaction was significant during SIM(Tab.7.2), but during SM(Tab.7.3), copepod community exhibited no significant difference depth wise or station wise. During WM(Tab.7.4), significant variations were observed between the orders of copepods.

The families of the Order Calanoida varied significantly both depth wise and station wise during SIM and WM, but no significant variation was observed spatially during SM.

In the Andaman Sea, during Inter Monsoon fall, spatial variation was significant. While it was not significant depth wise in the case of the orders of copepods(Tab.7.5). In the case of the families of the Order Calanoida , the variation was significant between stations only. In the case of cyclonic events, pre-cyclonic period showed significant variations at $p<0.05$ level. The correlation between physical parameters and the copepod families showed that correlations were more significant during SM(Tab.7.14). The SIM showed less correlation(Tab.7.13). It may be due to the stratified conditions for want of mixing of the water column during this period. Family Paracalanidae, Temoridae and Candaciidae correlated with the density of water column during SIM, whereas the families Temoridae and Pontellidae correlated with salinity during

SIM. During SM, the families such as Paracalanidae, Temoridae, Candacidae and Pontellidae directly correlated with density of the water column, whereas Euchaetidae, Scolecithricidae, Temoridae and Candacidae were found to related with surface temperature of the water column. Families like Mecynoceridae, Phaennidae, Centropagidae, Metridiidae, Candacidae and Pontellidae were limited by the sea surface salinity.

During WM, the following families showed significant correlation with density(Tab.7.16), Paracalanidae, Euchaetidae, Heterorhabdidae, Pontellidae, where as Scolecithricidae and Centropagidae were directly correlated with SST. SSS was found directly correlated with families such as Paracalanidae, Euchaetidae, Temoridae, Heterorhabdidae, Candacidae and Pontellidae.

Among the copepod families which were present at the Andaman Sea, direct correlation of SST was observed with Eucalanidae and Lucicutiidae. Density of the water column was the limiting factor for the distribution of Paracalanidae, Candaciidae and Pontellidae. Sea Surface Salinity showed direct correlation with Paracalanidae, Candaciidae and Pontellidae.

The analysis showed that most of the families of the Order Calanidae preferred deeper layers of water column. Paracalanidae was found to be present in all the depths and so was the family Metrididae. In the BoB, among the coastal stations, highest species richness (6.27) and diversity (4.56) were observed during the SIM period in the mixed layer of 11°N and 13°N stations. Evenness was highest (0.85) in the depth range of BT-300m in the 15°N station during SM. Highest dominance value of 0.22 was observed in the mixed layer of the coastal station at 19°N.

Among oceanic stations, species richness were maximum at 11°N station in the depth range of 500-1000m during SIM(Tab.7.5) . Evenness did not vary among the stations and seasons. During SIM , In the station at 11°N and in the depth range of 500-1000m, highest species diversity was recorded(Tab.7.6 &(Tab.7.7)) . Dominance was highest during SM and WM seasons at 500-1000m depth and the thermocline layer respectively(Tab.7.8) . In general, it was clear that the mixed layer of the coastal stations and deeper layers of the oceanic stations showed higher species diversity of copepods. MDS tables showed a comparatively less stress value (<2) which denots the more correlated nature of the data sets of copepod abundance(Tab.7.9). In the Bray-Curtis Similarity analysis as represented in the Dendrogram, almost all the combinations during different seasons showed a similarity of ~60% in all the depth strata(Tab.7.19to Tab.7.21).

Most of the studies in the EEZ of Andaman Sea were based on the abundance and spatial distribution of biomass of zooplankton (Goswami and Rao, 1981; Madhupratap, 1981). There were no previous studies on the species diversity of copepods in the Andaman Sea. In the present observations, it was found that highest species diversity of 4.12 was in the station at 10°N and 95°E at 300-500m depth strata, correspondingly highest species richness was recorded from this station. This station was in the eastern side of the island arc at the 10° Channel, through which the eastern and western parts of the Andaman Sea is connected. Lowest diversity of 1.82 was obtained from the station at 7°N – 94°E at BT-300m layer (av. 3.39±1.68). Dominance was highest in the mixed layer of the 10°N and 95°E station. This indicated the aggregation of a few epipelagic species in the surface layer.

The MDS and Bray-Curtis Similarity indices showed a moderate range of similarity coefficients(Tab.7.22). This might be due to the insufficient data sets for the analysis, since only one season was considered for the study.

Sewell (1947) observed a gradual decrease in the number of deep water copepods in the northern part of the Indian Ocean with a minimum number of species in the Bay of Bengal and this might be due to the lesser influence of Atlantic water in the northern region of the Indian Ocean. De Decker and Mombeck (1964) also noticed the paucity of bathypelagic copepods towards the north and north east. But Grice and Hulsemann (1966) suggested that bathypelagic species could be extremely widespread. In the study of the Genus *Gaussia* Saraswathy, 1973b found that two species of the genus, *G. sewelli* was restricted to the Northern Indian Ocean where as *G. scotti* was present in the southern Indian Ocean as well as in the Pacific and Atlantic Ocean. The tendency of bathy- and mesopalagic species to occupy deeper strata in the tropical part of the ocean and their emergence in the upper layers in subtropical region was noticed for other planktonic organisms like chaetograths (Nair, 1978), Arietellidae (Stephen *et.al*, 1980), Saraladevi *et.al* (1979). In the present study, many mesopelagic and bathypelagic species were recorded from the mixed layer of BoB, such as *Bradycalanus typicus*, *Dissetta palumboi, D. scopularis, Gaussia princeps* and *G. sewelli*.

Euaugaptilus nudus recorded from the deeper collections of the BoB (150-500m) for the first time by Stephen *et.al* (1984), was well represented during the present study also. Sewell (1947), Vinogrdov (1968) and Haq &Ali Khan had segregated copepod population into different vertical groups based on the temperature discontinuity and oxygen deficit conditions which separated the upper warm surface layer from deep waters. This discontinuity layer inhibited the downward extension of the surface population (Stephen, 1984). But during the present study the BT-300m layer acted as the barrier layer which separated the upper two layers from the lower two layers. Minimum number of copepods was concentrated at this layer. Only 3% of total copepod analyzed was obtained from this layer.

Tertiary Production

Mesozooplankton assemblages contribute food for many of the pelagic shoaling fish. The size of the plankton is the major factor that determines the availability of fish in an area as well as the selectivity by the fish predators (Frost, 1972; Reeve and Walter, 1978). The biomass as well as the size composition of zooplankton will influence the growth (Flinkman *et al.*, 1998), recruits (Funakoshi, 1990) and production of fish (Parsons and Lalli, 1988). The copepods which contribute major portion (70-90%) of zooplankton (Stephen, 1999) form the first vital link in the food chain that leads from the minute algal cells to the large fishes and mammals. In the present study, zooplankton contribution of copepods ranged from 56 -91%. Because of their unmitigated abundance, copepods form the chief index in utilization of biotope at secondary level. Thus the copepod bio-composition as well as spatial, vertical and temporal variations would influence the fish production and distribution.

The annual fish production data from the BoB also matched well with the high copepod production. During the course of the study maximum copepod abundance was observed from the south eastern part of the BoB and the southern part of the BoB, especially the region off Chennai. A large dolphin shoal of about 250 dolphins observed during WM at the upper layer of 11°N 80°E was an indication of high primary and secondary production there. It was reported (*CMFRI Spl.Publ*., No.89) from the same area, a total landing of 3,50,709 tones of fish/year which is more than 50% of fish landings from remaining parts of the BoB. Another centre of high copepod production was observed to exist at the head of the bay. Although the numerical abundance was less than the southern region this area was found to support a variety of species of copepods. The fish landing data during the study period from the BoB(*CMFRI Spl.Publ*., No.89) reflected the fact that 19ºN Lat. was more productive than 17ºN Lat. in the case of tertiary production.

Chapter IX

Summary and Conclusion

A study on the copepods from the EEZ of the Bay of Bengal and the Andaman sea was carried out as a part of Marine Research – Living Resources (MR-LR) assessment (Secondary production in Exclusive Economic Zone of India) programme (1997-2002) funded by Ministry of Earth Science, Govt. of India, New Delhi. This programme contemplates comprehensive assessment of Marine Living Resources of the Indian EEZ and studies on the influence of the marine environment including the physico-chemical aspects on these resources. The spatio-temporal variations of the physico-chemical parameters were considerably strong in the Northern part of the Indian Ocean because of the influence of the reversing monsoon systems and its land locked geographic nature at northern side. The Bay of Bengal and the Andaman Sea though located in the same latitudinal belt, exhibited distinct oceanographic features. The presence of the Andaman and Nicobar Islands separate the Andaman Sea from the Bay of Bengal. The various phyto and zooplankton in the water column can be used as indicators of water masses, marine currents and climate modifications. Copepods are the most abundant mesozooplankton but not much information was available from the Bay of Bengal and the Andaman Sea and hence the relevance of this study. The results generated from this investigation would be the first of its kind as the data collected and analyzed were comprehensive and systematic. Extensively collected and investigated data on copepods would serve as baseline information for tracing copepod community structure and ecological assessment. These results may form one of the key factors for fresh assessment of tertiary productivity of the study area, which were not yet fully estimated and exploited.

In this thesis, the qualitative, quantitative and spatio-temporal variations of copepod community in the East Coast of EEZ of India were discussed. Studies on species composition and distribution of copepod fauna of the Indian Ocean subsequent to Sewell`s observation reveals in-depth intricacies in regional and seasonal distribution. Previous studies stated that the Andaman Sea was less productive than the Bay of Bengal.

A total of 22 stations from the Bay of Bengal and 8 stations from the Andaman Sea were selected for this study. Of the 3,83,807 copepods identified from the BoB during the study period 2,55,566 copepods were collected during three different seasons: Spring Inter Monsoon (SIM) of 2001, Summer Monsoon (SM) of 2002 and Winter Monsoon (WM) of 2002 and from 5 different depths strata: (0-TT/Mixed layer/Surface layer, TT-BT/Thermocline layer, BT-300m, 300-500m and 500-1000m). A total of 44,110 copepods from the Andaman Sea were collected, identified and studied during the study period. Copepods from the mixed layer collected during SM of 1999 consist of 79,155 copepods and that collected during the WM of same year consists of 49,086 copepods. These mixed layer samples were analyzed to study the influence of a super cyclone that hit the east coast of India in October, 1999. Major zooplankton taxa namely Foraminifera, Ostracoda, Copepoda, Amphipoda and fish eggs and Fish larvae were markedly higher after the cyclone. Mesopelagic and bathypelagic species namely *Pleuromamma xiphias, Gaussia sewelli, Lucicutia Maxima, L.wolfendeni, L.clausi, Augaptilus longicaudatus, Euchirella pulchera, Heterostylites longicornis* were recorded from the mixed layer extending upto 55m depth which indicate the presence of deep waters in the surface layers.

From the total of 310 copepod species recorded from the study area, 200 were from the Andaman Sea and 277 were from BoB. They belongs to 29 Families and 86 Genera. Calanoids dominated the population numerically (54.3%) and taxonomically (90.5%). Copepod species richness was higher during Spring Inter monsoon period in the Bay of Bengal (240 species which constitute 211 species from Order calanoida) than Winter Monsoon (183 of which 158 species belongs to the Order calanoida) and Summer Monsoon (169 species of which 146 belonged to the Order calanoida).

A total of 23 families and 75 genera of the Order calanoida was encountered of which 19 were recorded from the Andaman Sea and 22 were recorded from the BoB. Family Megacalanidae was recorded from the Andaman Sea alone, while family Centropagidae, Diaptomidae, Temoridae and Tortamidae were recorded from the BoB only. South eastern part of the Andaman Sea is found to be richer than other regions.

The Indo-Pacific region, especially seas adjacent to Malaysian archipelago was the area of greatest diversity in the oceanic realm. Transport of species of Indo-Pacific origin to this area also helped to maintain high diversity. Most of the species, which were new in this area, were reported earlier from the Pacific. The species recorded as first report from the study area were *Bradycalanus typicus, Eucalanus bungii, Eucalanus inermis, Drepanopsis orbus, Xanthocalanus amabilis, Bradyidius angustus, Gaidius minutus, Gaidius brevispinus, Euchirella areata, Chirudinella magna, Uneucheata bispinosa, Pareucheata simplex, Scottocalanus australis, S. terranovae, Scaphocalanus impar, Scolecithricella modia, S. arcuata, S. lophophora, S. lamellifer, Xanthocalanus cornifer, Metridia pacifica, Heterorhabdus pacificus, H. setuligear* and *Euaugaptilus squamatus.*

Bradycalanus typicus, a deep water form obtained from 500-1000m depth strata of the Andaman Sea was a new record for the Indian Ocean. Some rare species of copepods obtained during the study include, *Onchocalanus affinis, Cephalophanes frigidus, Euchirella venusta,* *E.maxima, Pareucheata scotti, Scottocalanus investigatoris, Scolecithricella propinqua, Metridia pacifica, Lucicutia macrocera, L.lucida, Heterorhabdus pacificus, Mesorhabdus angustus, M. brevicauda, Dissetta palumbii, D.scopularis, Euaugaptilus facilis,Nullosetigera helgae* and *Aritellus giesbrechti.*

The endemic species obtained during the study period include, *Centropages tenuiremis, Acartia minor, A.sewelli, Scottocalanus daughlishi, Pontellopsis scotti* and *Pontella investigatoris.*

To check the influence of season and depth on copepod community, two way ANOVA was conducted and it was observed that in the BoB copepod distribution was varying significantly with both season and depth. During WM in the BoB and during inter monsoon fall in the Andaman Sea, they vary significantly at 0.05 level of significance. Salinity forms the limiting factor for the distribution of families such as Temoridae and Pontellidae. They were found more at the surface waters of coastal region of the BoB where the influence of fresh water river runoff was more pronounced. The family Paracalanidae was limited by the density of water column together with family Euchaetidae and Candaciidae during Winter monsoon, Temoridae and Candaciidae during Spring and Candaciidae and Pontellidae during inter monsoon fall and alone during SM . They found more at the region, where the density of water column was found less. Among the 23 families encountered during the study, only Lucicutiidae significantly correlated with the sea surface temperature positively while Euchaetidae and Temoridae were found less, where with high SST. During winter monsoon Family Heterorhabdidae was found more at the stations where there was high density and salinity i.e., positive correlation.

Generally, copepod diversity decreased towards the open sea relative to costal locations with a concomitant decrease in abundance. Based on multivariate analysis, it was possible to distinguish the uniqueness of the Andaman Sea from the rest of the Bay of Bengal.

Species richness, evenness and dominance were found maximum at the Andaman Sea than Bay of Bengal. The South-east station at the Andaman Sea (10°N and 95°E) was noted for the highest richness (8.152) at its 300-500m depth strata as 59 species were identified from a sample of 1230 copepods. Species in copepod community structure across water bodies associated with differing salinity were also noticed. The coastal station at 17°N, at the BoB during Spring inter monsoon from the mixed layer depth accounted for 8.03 richness (58 species from 1209 copepod specimens) which outnumbered the richness of several oceanic stations. Salinity was relatively minimum at this coastal station. Highest species richness for oceanic samples at the BoB (6.92) observed at the lowest depth strata of 11°N during SIM in which 118 copepods were grouped under into 34 taxa.

The average numerical abundance of copepod at the mixed layer of the BoB during the summer seasons of `99 and 2002 (2083 and 2023 copepod specimens respectively) when compared with winter seasons of the same years (4090 and 6508 copepod specimens respectively) and with spring intermonsoon (only 755 copepod specimens) revealed that during Winter monsoon the numerical abundance of copepod at the mixed layer of the BoB were more. Presence of a large dolphin shoal, consisting of 250 dolphins noticed at the surface layer of 11° N 80°E (Southern most coastal station) during the WM of 2002 supported this statement. Primary productivity, Zooplankton abundance and the number of fish larvae obtained from that area were more during the study period when compared to other regions. That may increase the presence of pelagic fishes, the food of dolphins in that area and subsequently dolphins were recorded in a large shoal . Although the numerical abundance of copepods remained almost the same during the SM seasons and increased during the winter monsoon of 2002 than the WM of 1999, their species diversity seemed to have reduced from the 1999 data. The species richness ratio for two consecutive summer season and winter season were 96:80 and 112:87 respectively.

The copepod population in the study area was mostly even at the BT-300m depth strata of 13°N 95° E (Andaman Sea). Seventeen species of copepods were evenly distributed there to form a community of 25 individuals. The dominance of copepod in the Andaman Sea was more at south eastern end (0.427) where as minimum (0.30) at the BT-300m depth strata of 13°N 95°E. The dominance of copepods in the Bay of Bengal was more pronounced during winter monsoon than other seasons. Their diversity did not vary much during three different seasons though it was more during SIM.

Species diversity was measured by both the richness and evenness of the population. The earlier approach to diversity was that when there was more diversity, then it would be considered as a more stable ecosystem. Nowadays it is used to measure and track changes in an ecosystem. During the present study maximum species diversity observed was at the oceanic stations of the BoB and the Andaman sea(4.573) than it's coastal stations (4.56 for the BoB and: 4.12 for the Andaman sea). The BT-300m depth stratum of the Andaman Sea at 7°N 94°E was noted for its least diversity. It was assumed that the copepod community of this area was represented by only seven species and this reduction in the species richness might be related to the avoidance of oxygen minimum layer.

In conclusion, the northeastern Indian Ocean has a pivotal role in preserving the richness of the ocean life because of the high species diversity encountered. The IUCN RED LIST `2008 mentioned 106 copepode species near to extinction. Out of this 106 species , 71 are coming under order Calanoida. But none of the copepods from the Indian Ocean are referred in the red list. It is high time that taxonomist should be able to identify endemic and endangered copepods of Indian seas. The immediate step to be taken could be the preparation of an inventory of marine biodiversity of copepods along with a checklist of the existing species. The present study would serve this purpose to a great extent.

This is an intensive study made over a specified area compared to the extensive observation as done during IIOE. Prior to the present study not much was known on the spatio-temporal distribution and diversity of copepods at the BoB and the Andaman Sea. The present study provides authentic database for future studies on copepods and related fishery oceanographic studies in the EEZ of east coast of India.

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