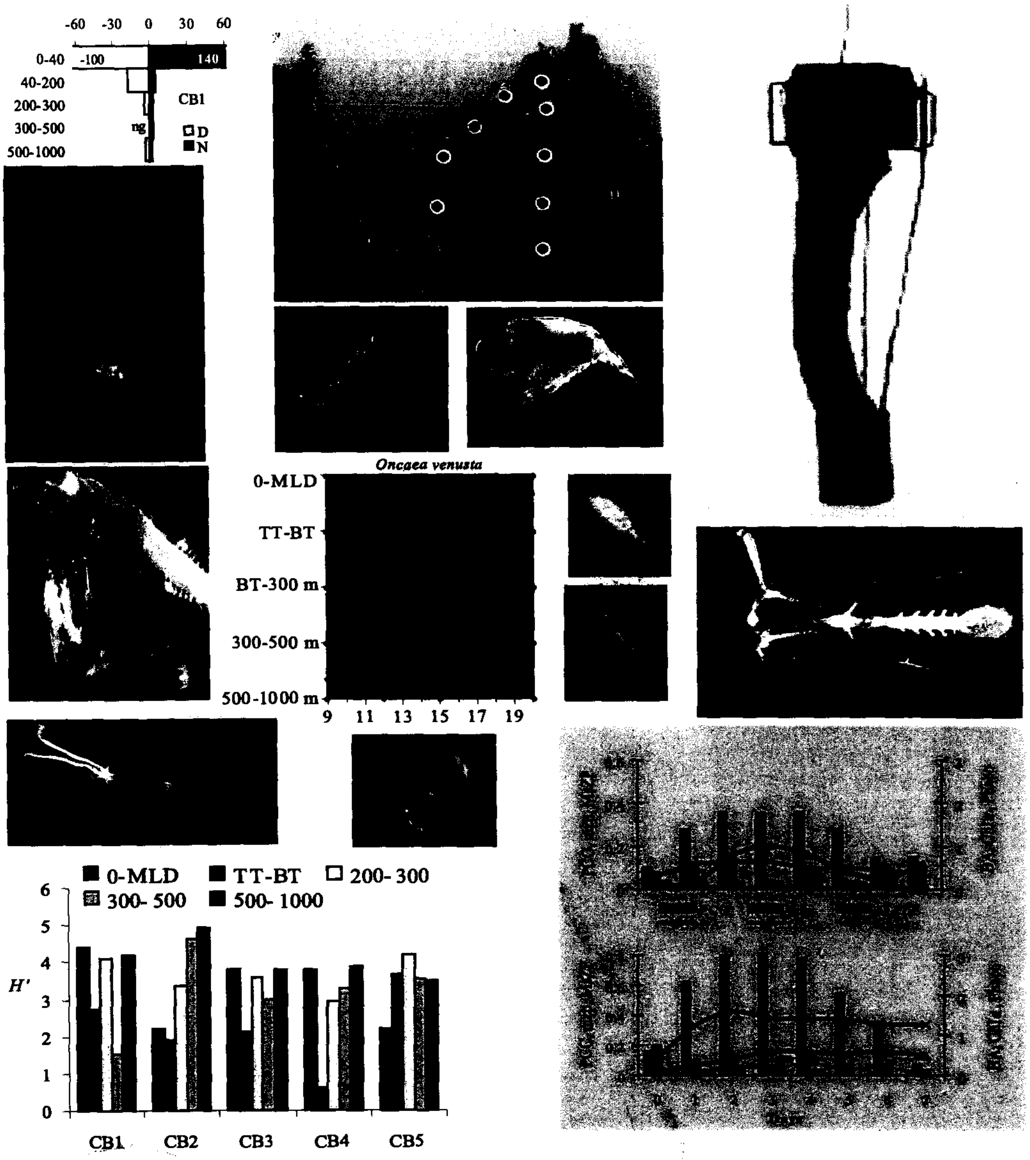
# Mesozooplankton Community Structure: Its Seasonal Shifts, Grazing and Growth Potential in the Bay of Bengal



Thesis submitted to Goa University
for the degree of
Doctor of Philosophy in Marine Sciences

**Veronica Fernandes**

National Institute of Oceanography
Council of Scientific and Industrial Research
Dona Paula, Goa- 403 004, India

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# CERTIFICATE

This is to certify that **Ms. Veronica Fernandes** has duly completed the thesis entitled **'Mesozooplankton community structure: Its seasonal shifts, grazing and growth potential in the Bay of Bengal '** under my supervision for the award of the degree of Doctor of Philosophy.

This thesis being submitted to the Goa University, Taleigao Plateau, Goa for the award of the degree of Doctor of Philosophy in Marine Sciences is based on original studies carried out by her.

The thesis or any part thereof has not been previously submitted for any other degree or diploma in any Universities or Institutions.

N Ramaiah

**N. Ramaiah**
**Research Guide**
**Scientist**
**National Institute of Oceanography**
**Dona Paula, Goa-403 004**

**Date: June 16, 2008**
**Place: Dona Paula**

All suggestions made by examiners have been incorporated

N Ramaiah
(N. RAMAIAH)
Research Guide
May 8, 2009

27/4/09
( B. BERNARD )
External Examiner

# DECLARATION

As required under the University Ordinance 0.19.8 (iv), I hereby declare that the present thesis entitled '**Mesozooplankton community structure: Its seasonal shifts, grazing and growth potential in the Bay of Bengal** ' is my original work carried out in the National Institute of Oceanography, Dona-Paula, Goa and the same has not been submitted in part or in full elsewhere for any other degree or diploma. To the best of my knowledge, the present research is the first comprehensive work of its kind from the area studied.

**Veronica Fernandes**

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**Veronica Fernandes**

*Dedicated To My*
*Beloved Parents*

# Table of Contents

| | |
|---|---|
| Number of Tables | 57 |
| Number of Figures | 64 |
| Number of Plates | 8 |

# Chapter 1

# Chapter 1

## *Introduction*

Ocean biology is complex, profound and, enigmatic. With all its forms known to mankind, life exists from the 'skin' [surface micro-layer] to the deepest zones of the marine domain. Ocean thus is the cradle of wide spectrum of organisms ranging from teeming, tiny autotrophic phytoplankton to heterotrophic bacteria; and from microfauna to fish to macrofauna including the gigantic whales.

Victor Hensen (1887) coined the term "plankton" for all those organisms drifting in the water and those unable to move against the currents. The animal constituent of the plankton is known as zooplankton. Some of these are herbivorous, carnivorous, detritivorous or omnivorous (Metz and Schnack-Schiel 1995). Some foraminiferans, radiolarians and also some metazoans (cnidarians and mollusks) are mixotrophic, the combination of auto- and heterotrophy (Tittel et al. 2003). Some calanoids and cyclopoids are known to be coprophagous, feeding on zooplankton feces (Noji et al. 1991; Gonzales et al.1994).

Depending on the lifetime spent in the planktonic form, zooplankton are either holoplanktonic, spending their entire life in plankton or meroplanktonic, drifting as plankton only for a part of their life before becoming benthic or nektonic (Martin et al. 1996, 1997). Foraminifers, radiolarians, siphonophores, ctenophores, pelagic polychaetes, heteropods, pteropods, ostracods, copepods with few exceptions, hyperiids, euphausiids, most chaetognaths, appendicularians and salps are holoplanktonic. Examples of meroplankton are larvae of cephalopods and fish that become part of nekton when adult. Cladocerans and some copepods produce resting eggs that are part of benthos during unfavorable conditions (Weider et al. 1997; Blumenshine et al. 2000). Hydrozoans and scyphozoans alternate between the planktic medusae during summer and benthic polyp stage during winter (Hartwick 1991). Also, larvae of benthic polychaetes, mollusks, echinoderms, barnacles and decapods are seen in the plankton for a short span of time (Raymont 1983). Animal phyla normally encountered in plankton are listed in Table 1.1.

## 1.1. Significance of Zooplankton

In aquatic ecosystems, zooplankton form an important link between primary and tertiary level in the food chain leading to the production of fishery. About 90% of the world's fisheries occur in rich coastal areas, where dense populations of plankton grow (O'Driscoll 2000). It has been well established that potentials of pelagic fishes *viz.* fin fishes; crustaceans, mollusks and marine mammals either directly or indirectly depend on zooplankton (Arai 1988; Ates 1988; Harbison 1993; Plounevez and Champalbert 2000; Dalpadado et al. 2003; Sabates et al. 2007). The herbivorous zooplankton are efficient grazers of the phytoplankton and have been referred to as living machines transforming plant material into animal tissue. By virtue of sheer abundance and intermediary role between phytoplankton and fish (Hays et al. 2005), they are considered as the chief index of utilization of aquatic biome at the secondary trophic level. The high protein content of plankton covets them to be potential food source for people (Omori 1978).

The shell or tests of protozoan plankton, such as foraminifers, radiolarians and gastropod mollusks contributing to the formation of "globigerina ooze" and "radiolarian ooze" occurring over wide areas of the sea floor is of great economic value. For *e.g.* Radiolarian ooze is utilized as a filler and extender in paint, paper, rubber and in plastics; as an anti-caking agent; thermal insulating material; catalyst carrier; as support in chromatographic columns and polish, abrasive and pesticide extender (Kadey 1983).

Due to their abundance and distribution in oceanic and coastal waters, certain zooplankton species are important indicators of water masses (Webber et al. 1992, 1996). For instance off Plymouth, *Thysanoessa* sp., *Aglantha* sp., *Meganyctiphanes* sp. and *Clione limacina* were found to be the indicator species of Atlantic cold water mass, while the presence of *Agalma elegans* and *Sagitta serratodentata* indicated the arrival of warmer Gulf Stream in the area (Russel 1935; Russel and Yonge 1936). *Doliolum* is also known as an indicator of the North Atlantic warm water current. Mesopelagic species of chaetognaths such as *Sagitta lyra, S. planctonis, S. decipiens* and *Eukrohnia hamata* were observed, ascending to near surface waters by upwelling events off Chile (Alvarino 1965,1992; Ulloa et al.2004) and on the West coast of India (Srinivasan 1976). The association of copepods, in particular *Calanus* species, with rich herring shoals (Kiorboe and Munk 1986) is also worth mentioning. *Euphausia* *superba,* commonly called as krill, forms not only the principal diet of baleen whales but also of seabirds and pinnipeds in the Antarctic (Croxall et al. 1985).

## 1.2. Ecological Adaptations

Physical factors such as light, food, oxygen, temperature and salinity are known to affect zooplankton distributions (Breitburg 1997; Nybakken 2003; Kimmel et al. 2006). Some zooplankton feed at surface during the night, and migrate deeper during the day, forming the 'deep scattering layer' (Kinzer 1969). Such diel vertical migrations are followed possibly to escape the predators that can see and capture them (De Robertis 2002). It could also save them energy by reduced metabolic rate in colder, deeper water (Enright 1977). The neuston of the warmer seas is particularly blue to purple in color due to presence of carotenoid proteins as in *Labidocera* (Herring 1967, 1977). With no surfaces to match or hide behind in the open sea, transparency of tissues provides camouflage. Since phytoplankton is present in the euphotic zone, zooplankton too must avoid sinking out of this zone. In many zooplankton, which are incapable of active movement, buoyancy is achieved by means of morphological adaptations which increase/decrease frictional resistance (Power 1989). The increase in surface body area due to feather like projection or development of long spines or extreme flattening of the body helps them to float passively. In warmer waters, animals are smaller and have more body projections for buoyancy. These projections are adjustable when needed during downward migration.

Tropical zooplankton have more species, grow faster, live shorter and reproduce often (Briggs 1995; Hirst et al. 2003). In the case of medusae, siphonophores, ctenophores, tunicates and fish larvae, flotation is mainly achieved by the inclusion of more fluids and oil droplets in the body, which reduce the specific gravity. With gelatinous watery body, arrow worms and other jellyfishes increase buoyancy by eliminating heavy ions and replacing them with chloride or ammonium ions (Bone et al. 1991). The buoyancy of hydrozoans, such as *Physalia*, *Velella* and *Porpita*, is due to the presence of pneumatophores. Foamy mucous substance secreted by the planktonic gastropod, *Janthina*, facilitates its floatation. The shells of *Janthina* and pteropods are very delicate and fragile that does not allow the animals to sink. Bivalve veliger larvae can swim into the oceanic currents for transport and close their two shells together to sink to the ocean floor. Salps, tunicates, and echinoderm larvae have specialized ciliary structures to propel through the water.

## 1.3. Feeding Ecology

Herbivorous and omnivorous filter feeders like copepods, euphausiids and pelagic tunicates feed on large spectra of food: phytoplankton, detritus as well as on nano- and microzooplankton (Alldredge and Madin 1982). Depending on their feeding habit, zooplankton occupy the second (primary herbivores) or third level (primary carnivores) in the food chain. In feeding techniques, copepods use their highly structured feeding appendages to create a feeding current, the food/phytoplankton caught is then broken by the tooth-like mandibles (Koehl and Strickler 1981). Appendicularians have a fine-meshed funnel net inside their house (Paffenhofer 1976; Alldredge 1981) and thaliaceans, a ciliary mucous net inside their barrel shaped body. Many meroplanktic larvae feed by means of ciliary currents, while the pteropods employ large mucous nets for trapping their prey.

Raptorial predators like cnidarians paralyze their prey by nematocyst on their tentacles. Pelagic polychaetes, heteropods, gymnosome pteropods, cephalopods, hyperiids and fish larvae are active hunters. Chaetognaths however, are ambush predators. Cladocerans, ostracods and mysids occupy an intermediate position between the raptorial and filter feeders. Appendicularians and salps may be important only in some areas, due to their seasonal and non-ubiquitous occurrence. Ctenophores and scyphomedusae may be significant top predators as observed in the Black Sea (Harbison 1993) and Baltic Sea (Behrends and Schneider 1995) respectively.

For an effective functioning of food web, there has to be a balance between the predators and the prey availability. In the pelagic realm, it is essentially a bottom-up control (Dufour and Torreton 1996), where the availability of nutrients in the surface layer determines the primary productivity. Top-down control is marked in a microbial food web where ciliates are the main consumers, whose population is controlled by the mesozooplankton devouring them. Both types of food webs exist in the ocean but their relative importance changes with region and season. While the classical food chain operates in the eutrophic, cold, upwelling systems, the microbial loop (top-down control) operates in the warm, oligotrophic regions and especially during summer stratification.

## 1.4. Community Structure and Distribution

Communities are defined as associations of different populations co-existing in space and time (Begon et al. 1990). These associations have specific properties, *e.g.* composition, diversity, ratio of rare to common species, indicator species and biomass production. Knowledge of plankton community structure functioning depends on answering which, how much, where and when plankton occurs.

Zooplankton inhabit all the oceans, from surface, down to their greatest depths sampled (Banse 1964, Vinogradov 1962, 1968, 1972). Their distribution is governed by water depth, trophic status of the area and temperature regime. Water depth separates the oceanic from the neritic plankton. Deeper open ocean regions, beyond the 200 m have a higher proportion of holoplankton compared to the coastal regions with relatively low salinities. The epipelagic (0-200 m) and mesopelagic (200-1000 m) zones are the main domains of zooplankton. Below 1000 m, their abundance decreases logarithmically (Vinogradov 1977). However, copepods usually dominate the samples irrespective of the region.

Like all ecological entities, zooplankton exhibit variability of populations or communities over a broad range of spatial and temporal scales (Legendre et al. 1986; Pinel-Alloul 1995; Currie et al. 1998). Several investigations have highlighted environmental processes that generate and maintain the spatial patterns of marine zooplankton. These processes are of two types: i) physical processes mainly generated by climatic and hydrodynamic regimes (Haury et al. 1978; Denman and Powell 1984; Davis et al. 1991; Piontkovski et al. 1995 a, b; Leising and Yen 1997; Noda et al. 1998; Huntley et al. 2000; Roman et al. 2001), and ii) biological processes (Haury and Wiebe 1982; Mackas et al. 1985; Tiselius 1992; Buskey 1998; Folt and Burns 1999; Rollwagen-Bollens and Landry 2000) arising due to varieties of physiological and metabolic as well as due to inter relationships between the organismic component in a given biotope.

Zooplankton associated with tropical environments display ecological features that diverge from associations in temperate areas. In tropical areas, seasons are difficult to predict and are usually less pronounced, compared to temperate zones (Webber and Roff 1995). The smaller biomass in the tropics is offset by higher growth rates (Hopcroft and Roff 1998 b; Hopcroft et al. 1998 a). With the seasonal variations in sea temperature being slight, the seasonal amplitudes of variation of zooplankton biomass and production are low (Hopcroft and Roff 1990; Champbell et al. 1997). However, seasonal cycles in zooplankton biomass have been observed in warm seas such as the Sargasso Sea (Menzel and Ryther 1961; Deevey and Brooks 1971).

The annual fluctuations in biomass in tropics are generally related to the rather variable pattern of rainfall, especially in coastal tropical regions (Yoshioka et al. 1985; Chisholm and Roff 1990). The strong variations in rainfall during the dry and wet seasons influence coastal water flow as well as surface layer salinity (Yoshioka et al. 1985; Webber et al. 1992). Salas-de-Leon et al. (1998) showed that zooplankton biomass is affected by river inputs through nutrient run-off and upwelling. Also, at any latitude, more biomass is observed in neritic regions compared to the ones of open ocean waters. Riley et al. (1949) found zooplankton volume ratios for coastal:slope:oceanic waters as 10:4:1 in the Sargasso Sea. Oceanic plankton also has poor organic content. Vinogradov (1970) has summarized information on the biomass of zooplankton in tropical oceans. Salps occurring in swarms can give exceptionally large biomass. Wickstead (1968) observed that copepod reproduction is seasonal, with a generation time of 3-4 weeks. Their production in coastal tropical waters is equivalent to that of temperate coastal waters (Chisholm and Roff 1990). Some studies have also shown the importance of nauplii and copepodites in terms of abundance and production (Hopcroft et al. 1998 a, b). Not only do nauplii have a central role in secondary production in tropical systems, but also they may be critical intermediaries between the classical (grazing) food web and the microbial loop (Roff et al. 1995). Hydrographical changes are also known to affect the stability of zooplankton communities (Webber et al. 1992, 1996; Rios-Jara 1998).

## 1.5. Size Range and Diversity

Marine zooplankton comprises a large variety of organisms. While tiny flagellates are usually a few micrometers, the giant jellyfish is up to 2 m in diameter, spanning 6 orders of magnitude in size. Schutt (1892) was among the pioneers who began organizing the wide-ranging zooplanktonic animals into some size classes for an easy comprehension of this enormous range of organisms. Later, Sieburth et al. (1978) organised them into nano- (2-20 μm), micro- (20-200 μm), meso- (200 μm -2 cm), macro- (2-20 cm) and mega- (20-200 cm) plankton. Since body size governs the growth rate, the doubling time for zooplankton in the range of 100-1500 µm is ~2-12 days (Sheldon et al. 1972; Steele 1977).

The enormous diversity of animals in the plankton is well recognized. The zooplankton is characterized by having representatives of almost every taxon of the animal kingdom. Marine zooplankton is comprised of ~36000 species (ICES 2000). Only 27% of these are holoplanktonic with the remaining meroplanktonic. Their species diversity is governed by temperature and evolutionary age of the oceans. Their highest diversity is thus found in the tropics. The diversity of copepods is usually higher in warm, oceanic waters. From the wide variety of taxa observed, Copepoda forms the dominant fraction and is therefore justifiable to study them in detail. Several aspects of biology of this Group are described in Chapter 6. Be (1966; 1967) and Be and Toderlund (1971) report 27-30 species of foraminiferans of which 22 are warm water species, living mainly in the upper 100 m (Berger 1969). Similarly, 4500 species of Radiolaria, 900 of Cnidaria, 80 of Ctenophora, 100 of Polychaeta, 10600 of Mollusca, ~9000 of Crustacea, 2000 of Echinodermata, 50 of Chaetognatha, 100 of Tunicata and 3000 species of fish larvae, are estimated to be in the plankton (ICES 2000).

## 1.6. Grazing, Growth and Metabolism

Mesozooplankton grazing is a main factor in removing phytoplankton from the water column (Steele 1974; Banse 1994). Zooplankton grazing and metabolism in the open ocean waters have received growing attention in recent years, particularly in the Pacific within the JGOFS equatorial Pacific study (Dam et al. 1995; Zhang et al. 1995; Le Borgne and Rodier 1997; Roman and Gauzens 1997; Zhang and Dam 1997; Roman et al. 2002 b; Le-Borgne and Landry 2003) and the Atlantic Oceans (Le Borgne 1977, 1981, 1982). A quantitative assessment of the effects of zooplankton grazing and nutrient regeneration on the standing crop and growth of the phytoplankton community is important for an understanding of aquatic ecosystem dynamics. A common, and increasingly popular, approach for the estimation of ingestion rates of herbivores and predators is based on the use of gut contents and estimated gut passage times (Baars and Helling 1985).

Due to the variety in the diet of zooplankton, it is important to carry out experimental analysis in order to understand their feeding ecology. Many experimental studies aiming to understand trophic interactions are available (Calbet and Landry 1999; Landry et al. 2003; Sautour et al. 2000; Stibor et al. 2004). Most of the organic matter originated through primary production in the surface layers is fated to mineralize through *in situ* planktonic respiration (Hernandez-Leon and Ikeda 2005). As a convenient measure of zooplankton metabolism, oxygen consumption rate has often been used. Early investigations on zooplankton respiration were mostly carried out on *Calanus finmarchicus* (Marshall et al.1935; Clarke and Bonnet 1939). A respiration rate determination indicates the amount of carbon being oxidized (Marshall and Orr 1962) and allows the calculation of a first-order approximation to the rate of nutrient recycling (Harris 1959; Satomi and Pomeroy 1965; Martin 1968; Ganf and Blaika 1974).

Growth and metabolism of zooplankton depends on the interaction of a number of external and internal factors. The external factors include food supply, nutritional quality of food, predation, temperature, salinity and oxygen. The internal factors are body size and physiological state. Potential growth rate is possible under ideal conditions, however in reality, it may be limited by one of the above factors as well as top down control. Since metabolic rate is also a function of body size, smaller organisms have a comparatively higher rate and grow faster than the larger ones. In marine copepods, where dominant copepods seldom vary in body size, temperature has been demonstrated as the main factor governing their growth rate (Huntley and Lopez 1992). In warmer waters, it is possible to build up a large population from a low standing stock rather sooner due to the high growth rate. The ratio between production and biomass is an important index of population dynamics indicating turnover rate of organic matter. Under optimal conditions, the highest turnover is observed in the tropics.

## 1.7. Sampling Methods

Most mesozooplankton sampling methods rely on the use of fine mesh nets, originally made of bolting silk, now made of nylon and/or other synthetic material. Mesh size is a critical factor in selecting organisms. The quantity of plankton passing through the net is variable, depending on factors such as elasticity of the net, towing speed, clogging (especially in phytoplankton-rich coastal areas), animal shape and, possession of spines and projecting appendages by animals (Raymont 1983). The use of vertically hauled closing nets has been of great value in plankton sampling in a particular section of water column and its quantification on regional and seasonal scales. One of the chief problems in quantitative sampling is estimation of the water filtered through the net. For this purpose, a number of flow meters have been devised. Avoidance of net by larger organisms such as euphausiids may be in response to visual stimuli (net should not be shiny), pressure changes, acceleration or turbulence or actual contact with the towing apparatus (Brinton 1967). The Hardy Continuous Plankton Recorder (Hardy 1939) conceived in the1920s has proved to be an important tool in sampling large areas of the open ocean and is especially useful in monitoring long-term faunistic changes in surface layers (Reid et al. 2003). Galliene et al. (2001) have shown a good agreement between biovolume using optical plankton counter and carbon content using vertical plankton hauls in the North Atlantic.

There are two main types of quantitative procedures for zooplankton, biomass determination and counting methods. Biomass/biovolume is generally expressed as mass per unit volume of water *i.e.* mg $m^{-3}$, or related to the sea surface as mg $m^{-2}$. There are a variety of methods for biovolume/biomass measurements. However, the volumetric and gravimetric methods are rapid compared to the biochemical methods. In the first one, displacement volume is the most reliable hence, most commonly used. The other, settling volume is less precise when gelatinous organisms and, ones with long appendages of higher buoyancy are present in the mixed plankton sample (Hensen 1887). In the gravimetric method involving wet mass measurement of samples after being preserved by formalin, slight to large loss of biomass is possible. Dry mass and biochemical measurements cause destruction of sample. Measuring abundance, the number of individuals per unit volume/surface of water (individuals $m^{-3}$ or $m^{-2}$) though laborious, demanding experience, allows parallel quantification and species identification. It is generally the most accepted basis of community analysis.

## 1.8. Study Area and Objectives

The Bay of Bengal (BoB) is a unique embayment receiving large river inflow (~1.62 x $10^{12}$ $m^3$ $year^{-1}$) from Godavari, Krishna, Cauvery, Mahanadi, Ganges, Brahmaputra and Irrawaddy. Precipitation (*ca.* 2 m year$^{-1}$) exceeding evaporation (~1 m year$^{-1}$; Han and Webster 2002), low-saline surface waters (28– 33 psu), warmer sea-surface temperatures (SST, 29–30°C) and weak winds (<7 m s$^{-1}$) stratify the upper 30–40 m column of the Bay (Prasannakumar et al. 2002). Further, absence of marked upwelling limits nutrient injection into euphotic layer. Apart from this, the high terrigenous input (*ca.* 1.4 x $10^9$ tons year$^{-1}$, Subramanian 1993) by rivers and prolonged cloud cover cause light limitation leading to low photosynthetic production (Prasannakumar et al. 2002).

In the Bay, quantitative and qualitative surveys examining the seasonal cycle of zooplankton are limited mostly to inshore waters. Using the opportunity of the Bay of Bengal Process Studies (BOBPS) programme, it was planned to decipher the spatio-temporal variability of zooplankton community. This first time study was planned for a comparative analysis from the open-ocean and near-coastal waters from the surface to 1000 m with the main idea of understanding its relation with the physico-chemical parameters.

For this study, the following objectives were planned:

- To measure the vertical distribution of mesozooplankton biomass and population density with the main idea to decipher spatio-temporal variability and to characterize the mesozooplankton community structure as well as to carry out a detailed taxonomic analysis to obtain species identification wherever possible.

  The rationale behind this objective is the following. The surface primary production in the Bay varies with seasonally reversing monsoon currents. It ultimately governs the amount of organic matter produced and transported to deeper depths. This might also be reflected in the biomass and composition of zooplankton species at deeper depths. This set of analyses was to provide answers to the questions as to: a) how the zooplankton biomass responds to low-saline upper waters that make the Bay to be low to moderate in phytoplankton biomass and, b) how their populations in terms of abundance and type vary during different seasons when physical, chemical and chlorophyll characteristics change. As oligotrophic regions are known to harbor larger diversity of organisms, it was pondered over that the zooplankton group/species diversity would be more. In the near-estuarine surface condition of the Bay, there is scarce photosynthetic food and relatively more detrital matter through allochthonous inputs from the rivers. With warmer sea-surface temperature of almost always ≥ 28°C, it was also intended to examine whether there is any predominance of a single or a few species, location-, depth- or season-wise.

- To understand the influences of environmental and biological factors on the mesozooplankton population dynamics through experimental alterations of nutrients, salinity, phytoplankton density, microzooplankton and bacteria. Further, to estimate mesozooplankton ingestion, egestion, grazing, respiration and potential growth rates.

  There have been no experimental studies to realize the grazing potential of mesozooplankton assemblages in the Bay of Bengal. Mesozooplankton with diverse food habits are known to be the major consumers of phytoplankton as well as microzooplankton and bacteria. Since salinity, nutrients and phytoplankton abundance and type vary regionally in the Bay, the rationale was to set up microcosm experiments at different latitudes to get basic information on the environmental effects on zooplankton, potential grazing, predation and omnivory.

  Since strong latitudinal gradients in salinity are observed in the top 50 m in central as well as western Bay, measurements of mesozooplankton gut fluorescence were also carried out at various latitudes to obtain the ingestion and defecation rates. Similarly, respiration rate through dissolved oxygen measurements were also done at these stations to obtain estimations of overall metabolic activity.

  Since growth is temperature dependant, standard growth rate equations were used to obtain estimates of mesozooplankton growth potential in the warm pool environment of the Bay.

## Table 1.1. Taxonomic Classification of Marine Zooplankton (Garrison 2004)

**KINGDOM PROTISTA:** Eukaryotic single-celled, colonial, and a few multicellular heterotrophs
# PHYLUM **SARCODINA**: Amoebas and their relatives
Class **Rhizopodea**: Foraminiferans
Class **Actinopodea**: Radiolarians

**KINGDOM ANIMALIA:** Mostly multicellular heterotrophs
# PHYLUM **PORIFERA**: Sponges
# PHYLUM **CNIDARIA**: Jellyfish and their kin; all are equipped with stinging cells
Class **Hydrozoa**: Polyp-like animals that often have a medusa-like stage in their life cycle, such as Portuguese man-of-war (*Physalia physalis*)
Class **Scyphozoa**: Jellyfish with no (or reduced) polyp stage in life cycle
Class **Cubozoa**: Sea wasps; commonly called box jellyfishes (*e.g. Chironex flecke*ri)
Class **Anthozoa**: Sea anemones, coral
# PHYLUM **CTENOPHORA**: "Sea gooseberries/ comb jellies"; round, gelatinous, predatory
# PHYLUM **MOLLUSCA**: Mollusks
Class **Monoplacophora**: Rare, deep-water forms with limpet-like shells
Class **Polyplacophora**: Bearing many plates *e.g.* 8-piece shells in Chitons
Class **Aplacophora**: Shell-less; sand burrowing *e.g. Helicoradomenia, Chaetoderma*
Class **Gastropoda**: Snails, limpets, abalones, sea slugs, pteropods
Class **Bivalvia**: Clams, oysters, scallops, mussels and shipworms
Class **Cephalopoda**: Squid, octopuses, and nautiluses
Class **Scaphopoda**: Tooth shells *e.g. Dentalium pretiosum*
# PHYLUM **ARTHROPODA**: jointed-foot invertebrates
Subphylum **Crustacea**: Copepods, barnacles, krill, isopods, amphipods, shrimp, lobsters, crabs
Subphylum **Chelicerata**: Horseshoe crabs, sea spiders
Subphylum **Uniramia**: Insects, *e.g. Halobates*
# PHYLUM **SIPUNCULA**: Peanut worms; all marine
# PHYLUM **ANNELIDA:** Segmented worms; *e.g.* polychaetes
PHYLUM **ECHINODERMATA**: Radially symmetrical, most with a water-vascular system, spiny-skinned, benthic
Class **Asteroidea**: Sea stars
Class **Ophiuroidea**: Brittle stars, basket stars
Class **Echinoidea**: Sea urchins, sand dollars, and sea biscuits
Class **Holothuroidea**: Sea cucumbers
Class **Crinoidea**: Sea lilies, feather stars
Class **Concentricycloidea**: Sea daisies
# PHYLUM **CHAETOGNATHA**: Arrow worms; stiff-bodied, planktonic and predaceous
# PHYLUM **CHORDATA**: Having at some stage of development a dorsal nerve cord, a notochord, and gill slits
Subphylum **Urochordata**: Sea squirts, tunicates (Appendicularia),Thaliacea (Doliolida, Pyrosomida, Salpida)
Subphylum **Cephalochordata**: Lancelets, *Amphioxus*
Subphylum: **Vertebrata**
Class **Agnatha**: Jawless fishes such as lampreys, hagfishes; cartilaginous skeleton
Class **Chondrichthyes**: Jawed cartilaginous fish with paired fins and nostrils, scales, two-chambered hearts; sharks, skates, rays, chimaeras and sawfish
Class **Osteichthyes**: Bony fishes

# *Chapter 2*

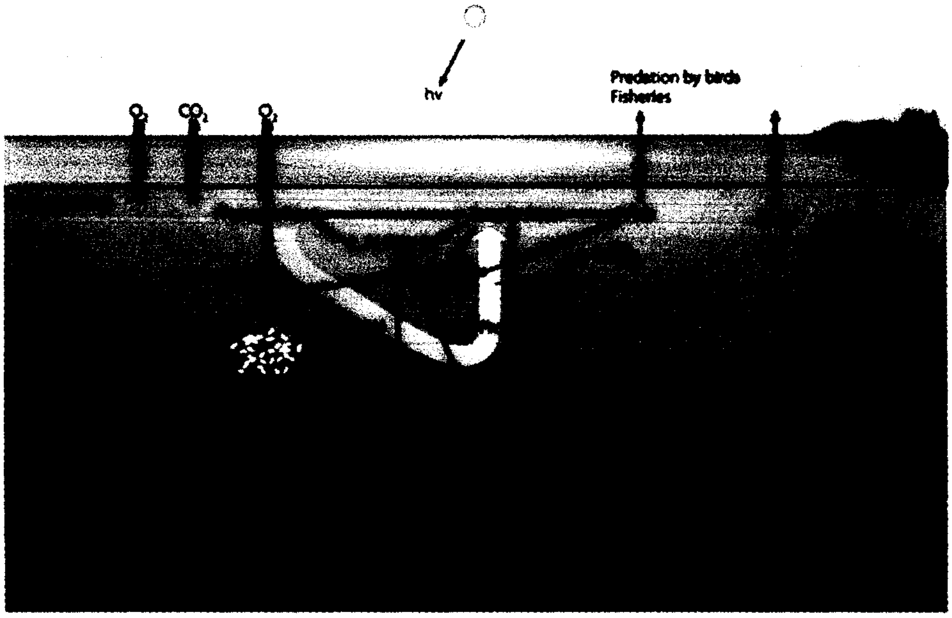
# Chapter 2

## *Review of Literature*

Mesozooplankton are the main link between planktonic primary producers and consumers such as fish. Such a key component in the structure and functioning of marine planktonic food webs (Fig. 2.1) has other roles too. For instance, their role of regeneration of inorganic nutrients, especially ammonia that is ideally suited to promote phytoplankton growth into surface waters is highly recognized (Saiz et al. 2007). Regeneration of nutrients in the photic zone via the "microbial loop" during the low chlorophyll times has also been appreciated (Nybakken 1997; Fig. 2.2). Their diel vertical migration (DVM) in all oceans is a universally known feature (Hays 2003). By the process of DVM, they feed near surface at night, migrate to deeper depth during the day (Fig. 2.3) where they continue to defecate, respire, excrete, and thus export the ingested carbon and nitrogen out of the photic zone (Longhurst and Harrison 1989; Hays et al. 1997; Schnetzer and Steinberg 2002 b). About 20 species of marine zooplankton are commercially utilized as food or feed. These are mainly planktonic crustaceans comprising ~11% of the crustacean fishery in the world (Omori 1978). Due to their large density, shorter life span, drifting nature, high group/species diversity and different tolerance to varying environmental conditions, some of them are also used as indicators of physical, chemical and biological processes in the aquatic ecosystems (Beaugrand 2005).

Approximately 36000 zooplankton species exist in the oceans, out of which ~11500 belong to subclass Copepoda (ICES 2000). Hardy (1970) and Turner (2004) proposed that the copepods are the most numerous metazoan animals in the world, even outnumbering the insects, despite the latter having more species. Well-fed copepods produce larger batches of eggs (Steidinger and Walker 1984). Therefore the successful reproduction of herbivorous zooplankton depends on adequate supply of phytoplankton. Owing to their abundance, their fecal pellets, which are produced at rates of up to150 individual$^{-1}$ day$^{-1}$ (Pinto et al. 2001), represent an ecologically important energy source

Figure 2.1. An un-assorted sample of mesozooplankton



Nature Reviews | Microbiology

Figure 2.2. Schematic presentation of a marine food web (Azam and Malfattti 2007)

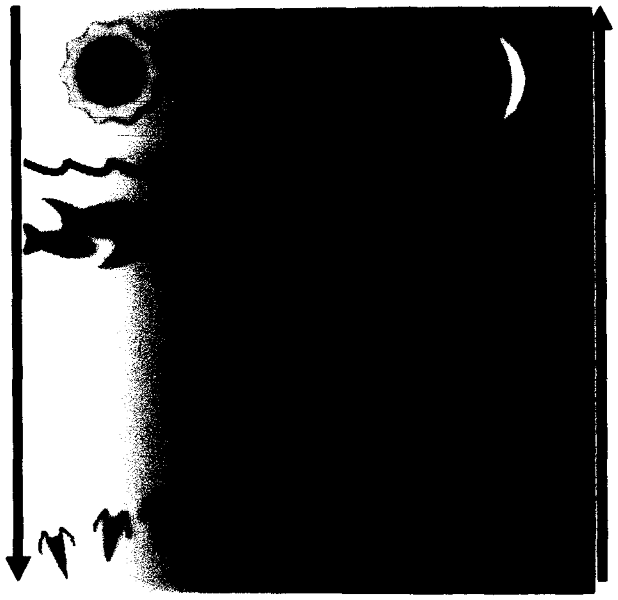


Figure 2.3. Schematic diagram of diel vertical migration in zooplankton. While downward movement (left side arrow) is begun at dawn, the upward movement begins by dusk

for detritus feeders. The flux of fecal pellets ~50-100 m day$^{-1}$ (Suess 1980) to the ocean floor may have a significant impact on nutrient cycling and sedimentation rates.

Ecologically, copepods are important links in the food chain linking the microscopic algal cells to juvenile fish to whales. They constitute the biggest source of protein in the oceans. Most of the economically important fishes depend on copepods and even the whales in the northern hemisphere feed on them. Some copepods like *Branchiura* (commonly referred to as sea lice) are known parasites of fish. Copepod fecal pellets contribute greatly to the marine snow and therefore accelerate the flow of nutrients and minerals from surface waters to the bottom of the seas. The sheer abundance of copepods in marine plankton secures them a vital role in the marine ecosystem.

Several investigators have documented various aspects of mesozooplankton biology (Raymont 1983). For instance, from spatio-temporal studies, it has been evidenced that mesozooplankton populations in the Northeast Pacific have undergone a regime shift possibly following changes in climatic conditions (Batten and Welch 2004). Fernandez-Alamo and Farber-Lorda (2006) have shown that zooplankton spatio-temporal variations coincide with water circulations, water-masses and upwelling. They also found that they were directly related to the regime shifts of commercial fisheries in the eastern tropical Pacific. From a 50- year historic record, these authors have observed a shift from the sardine regime during low zooplankton biomass to anchovy regime during high zooplankton biomass. Similarly, the interannual changes in zooplankton communities were directly linked to the growth of sardine larvae in the Mediterranean Sea (Mercado et al. 2007). High zooplankton production off Saurashtra coast in the Indian Ocean region corresponds to the rich fisheries (Govindan et al. 1982). These physical processes affect primary productivity and, thus play a prominent role in structuring of zooplankton communities, as a consequence, affecting the recruitment of pelagic fisheries.

## 2.1. Spatio-temporal Distribution of Biomass and Abundance

Nutrients and, primary and secondary productivity ultimately determine the sustainable harvest of fish resources (Cushing 1971). A change in phytoplankton production does affect the biomass at the higher trophic levels including fishery yield (Nixon 1988; Gucinski et al.1990). Environmental parameters like salinity, dissolved oxygen and nutrients directly influence the abundance and diversity (Siokou-Frangou et al. 1998) as well as the distribution (Nasser et al. 1998) of zooplankton. However, Irigoien et al. (2004 a) have shown that zooplankton diversity, which is a unimodal function of its biomass, is not related to phytoplankton biomass.

Mixed zooplankton is assumed to contain carbon comprising ~ 35- 45% of the dry weight in the North Pacific (Omori 1969) and ~34% in the Indian Ocean (Madhupratap et al. 1981; Madhupratap and Haridas 1990). Their biomass is reported to be higher in boreal and polar waters, intermediate in equatorial waters and the lowest in subtropical gyres (Hernandez-Leon and Ikeda 2005). Mesozooplankton represent a major, but neglected component of the carbon cycle in the ocean. Also, climate change manifestation in terms of local-scale temperature variations seem to affect and alternate zooplankton life histories (Costello et al. 2006).

### 2.1.1. Depth-wise distribution

Mesozooplankton abundance in the Arabian Sea (AS) is fairly high in the mixed layer depth (MLD) all through the year (Madhupratap et al. 1996 a). Padmavati et al. (1998) found higher standing stocks of zooplankton in the MLD and the lowest in the 500-1000 m (deepest sampled strata) in the central and eastern AS. Higher biomass in the upper 200 m was related to potentially higher food levels in this depth zone (Wishner et al. 1998). Their biovolumes decrease with increasing depth in all seasons in the northern AS (Pieper et al. 2001), in phase with the primary production in the top 150 m (Koppelmann et al. 2003). In the mesopelagic realm (150–1050 m), the seasonal coupling was less clear and there was no such evidence in the bathypelagic zone below 1050 m (Koppelmann et al. 2003). At two sites (one each in the central and western Arabian Sea), zooplankton biomass and abundance that were measured up to 4000 m were elevated in the oxygenated surface waters, decreased sharply in the oxygen minimum zone (OMZ) before decreasing gradually below 1000 m (Koppelmann et al. 2005).

In a study from upper 4440 m in the eastern Mediterranean, maximum abundance of zooplankton was observed at 100 m, where maximum phytoplankton was present (Kimor and Wood 1975). At 1000 m, the biomass was ~ 1% of the surface zooplankton, at 5000 m about 0.1% (Wishner 1979). Effects of differences in surface primary productivity on deep-sea plankton biomass was also much less than the effect of depth

Mesozooplankton samples taken from surface to 4270 m in the eastern Mediterranean revealed inter-annual increase in biomass throughout the column during the sampling period of 1987 and 1993 (Weikert et al. 2001).

Zooplankton biomass was also reported to decrease exponentially with depth in the western North Pacific. Observations of Yamaguchi et al. (2005) revealed very low C, N concentration and high C: N ratio below 3000 m implying dominance of detritus below this depth. Recently, Schulz et al. (2007) demonstrated that hydrography and water masses were important in governing the distinct vertical zonation of zooplankton in the central Baltic.

### 2.1.2. Diel vertical migration

Smith et al. (1998) recognized that zooplankton biomass exhibit diel variability in the inshore and offshore waters of the AS. Goswami et al. (2000) also noticed high zooplankton biomass in the night samples on the West coast of India. Similar observations were made in the northwestern AS (Jayalakshmy 2000). The OMZ restricts vertical migration of most copepods except *Pleuromamma indica* in the Arabian Sea (Saraswathy and Iyer 1986). Couwelaar (1997) also found that vertical migration of some zooplankton was not hampered by the OMZ (0.1 ml $l^{-1}$; 4.5 μM) in the AS. Surface abundances at night and deep scattering layers at 150 to 450 m in the day time have been reported from the Arabian Sea during the intermonsoon (Koppelmann and Weikert 1997). At least two groups of zooplankton, one that stays in the upper mixed layer and another that makes daily excursions, exist in the AS. Morrison et al. (1999) state that a subsurface peak of non- migrating zooplankton is also typically present in the lower OMZ (near the lower 4.5 μM oxycline) in the AS. The diel vertical migration (DVM) of zooplankton contribute significantly to dissolved carbon and nutrient export by respiring and excreting surface-ingested particulate organic matter below the mixed layer (Schnetzer and Steinberg 2002 b). Vertical gradients in dissolved oxygen (DO) and temperature were related to DVM of zooplankton in the Arabian Sea (Luo et al. 2000).

Saltzman and Wishner (1997) studied vertical distribution of copepods in the upper 1230 m, in relation to the OMZ in the eastern tropical Pacific. Diel variations were also observed in zooplankton biomass at the Bermuda Atlantic time-series (BATS) site in the North Atlantic (Madin et al. 2001). The average biomass at night within the upper 200 m exceeded that at day by 3.5 times in the Angola Benguela coastal upwelling zone and the OMZ (0.2 ml $l^{-1}$) was no barrier to migrating zooplankon (Postel et al. 2007). While some chaetognaths and species of copepods were found to perform DVM, over 60% of the zooplankton did not perform significant DVM in the Irish Sea (Irigoien at al. 2004 b). In the near-shore areas where DO reduction to< 1.0 ml $l^{-1}$ may be sudden, widespread, or unpredictable, the patterns of reduced copepod abundance in bottom waters may primarily be due to mortality rather than avoidance (Stalder and Marcus 1997).

### 2.1.3. Seasonal and latitudinal variability

Copepod distribution was found to vary seasonally in the Tapong Bay off Taiwan (Lo et al. 2004 a). Kang et al. (2004) attributed zooplankton distribution patterns to the spatial variations in chlorophyll (chl) *a*. Yamaguchi et al. (2005) found that diversity increased offshore. Spatial variability of zooplankton species richness, abundance and biomass was ascribed to salinity gradient in estuarine waters of China (Li et al. 2006).

Ramfos et al. (2006) found strong seasonal changes in dominant copepods in the surface layer in the eastern Mediterranean Sea, where strong variations in hydrography was evident with biomass and abundance decreasing offshore. In a monthly sampling at the BATS, zooplankton biomass showed seasonal variations (Madin et al. 2001). Salinity was found to control the spatio- temporal changes in mesozooplankton community structure in the Seine Estuary (Mauny and Dauvin 2002), Bristol Channel and Severn Estuary (Collins and Williams 1981). Seasonal and spatial variation in mesozooplankton biomass correlating positively with chlorophyll, primary production and organic particulate matter and, negatively with temperature and salinity was observed in the Northwest Mediterranean (Gaudy et al. 2003). Abundance of zooplankton increased with increasing temperature, salinity and chlorophyll *a* values in a temperate estuary in western Portugal (Vieira et al. 2003). Uncoupling between phytoplankton and zooplankton consumers was observed in the Waquoit Bay (Lawrence et al. 2004).

Temperature, salinity and suspended matter seem to regulate the seasonal and annual variability of zooplankton density in the turbid Gironde Estuary (David et al. 2005). Vidjak et al. (2006) observed high mesozooplankton abundance and low diversity in the eastern Adriatic Sea during the warmer part of the year. On the contrary, a 10- year survey in the western Mediterranean revealed seasonal and interannual changes in zooplankton biomass and assemblages, with the warmer years having lesser biomass compared to the cooler years (De-Puelles et al. 2007). Alcaraz et al. (2007) found that the deep chl *a* maxima during summer stratification allows the formation of deep zooplankton maxima in the Mediterranean.

The eastern Arabian Sea is rich in zooplankton production (Menon and George 1977) mainly due to coastal upwelling. Along the West coast of India, accelerated zooplankton production was documented during periods of high salinity (Madhupratap 1986; Tiwari and Nair 1993). The phytoplankton to zooplankton carbon ratio has been higher during the periods of low salinity in Cochin backwaters (Madhu et al. 2007). Zooplankton diversity that was inversely related to abundance showed variability between the monsoons in the western Indian Ocean (Mwaluma et al. 2003). Changes observed in zooplankton biomass using an Acoustic Doppler Current Profiler were associated with monsoonal oscillations in the AS (Ashjian et al. 2002). Madhupratap and Haridas (1975) noticed that zooplankton displacement volumes were higher at those stations where swarms of hydromedusae and ctenophores occurred. Zooplankton biovolumes varied seasonally, with the lowest biovolumes during the summer monsoon (SUM), intermediate during the fall intermonsoon (FIM) and the highest during the winter (Northeast) monsoon (WM) in the northern AS (Pieper et al. 2001). High biomass was observed off Oman, the upwelling zone during SUM (Hitchcock et al. 2002). They also observed high biomass of zooplankton coinciding with the large phytoplankton blooms in the Red Sea and Gulf of Aden during WM, and in the Somali Current and northern Somali Basin coinciding with the high primary production during SUM. Smith and Madhupratap (2005) found high standing stocks of zooplankton in the AS being sustained during low chlorophyll period *i.e.* the WM by the microbial loop. They also reported that by the end of SUM, at least one abundant epipelagic copepod species goes through diapause in the subsurface. However, Padmavati et al. (1998) did not find much variation between coastal and offshore standing stocks of zooplankton in the AS. However, Smith et al. (1998) and Stelfox et al. (1999) found that zooplankton differed in the inshore and offshore waters with the seasonally reversing monsoons in the AS.

In a study carried out in the neritic and estuarine waters off Coromandel Coast, Bay of Bengal (BoB), during the period from January 1960 to December 1967, a steady-increasing trend in plankton production was evident from months of March to October, correlating with the salinity and rainfall (Subbaraju and Krishnamurthy 1972). Higher zooplankton standing stocks were reported in the upwelling area in the western Bay of Bengal (Nair et al.1981). Piontkovski et al. (1995 b) stated that zooplankton abundance-spectra change with hydrodynamic regimes of water in the Indian Ocean. In a study from the western Bay of Bengal during January and May, Rakhesh et al. (2006), recorded 58 copepod species dominating the zooplankton sample collections in the top layers. Basin-scale and mesoscale processes such as warm-core eddies, cold-core eddies and upwelling areas influence the abundance and spatial heterogeneity of plankton populations across a wide spatial scale in the BoB (Muraleedharan et al. 2007). Spatial differences in zooplankton were also found in the Malacca Strait (Rezai et al. 2004).

## 2.2. Composition

Achuthankutty and Selvakumar (1979) observed high abundance of *Acetes* larvae during pre- and post monsoon in the estuarine systems of Goa. Nair and Paulinose (1980) recorded elevated abundance of decapod larvae near to the coast, decreasing gradually towards the open ocean. Copepods dominate the marine zooplankton community and often contribute over 80-90% of the total zooplankton in near-shore and estuarine habitats (Ramaiah and Nair 1993). Most herbivores in the AS are either small filter feeders like copepods or large mucous filters feeders like tunicates that are able to feed on very small particles (Nair et al. 1999). Kidwai and Amjad (2000) reported 38 taxonomic groups from the samples collected during SUM and WM in the Arabian Sea. Copepoda was the most dominant group, followed by chaetognaths and siphonophores in their collection.

The size structure of zooplankton was related to the spatio- temporal variation in size spectra of dominant phytoplankton (Stelfox et al. 1999). Increased abundances of *Calanoides carinatus* were observed off Oman, the upwelling zone during SUM

(Hitchcock et al. 2002). Among the preponderant Calanoida, the members of families Clausocalanidae and Paracalanidae were the most abundant among copepods in the Gulf of Aqaba. As Cornils et al. (2007) propose, this abundance is strongly linked to the annual temperature cycle.

Zooplankton composition was homogenous and diversity low irrespective of season in the subtropical Inland Sea of Japan (Madhupratap and Onbe 1986). Vertical distribution of zooplankton community was closely linked with the hydrographic structure in East Japan Sea (Ashjian et al. 2005). Across the continental margin of the Northeast Pacific, zooplankton show a typical gradient in community composition from near-shore to oceanic. This gradient is usually the steepest near the continental shelf break (Mackas and Coyle 2005). Numerical abundance of copepod fraction in the smaller size-range of 100-300 µm was seven times greater than the larger size fraction of >330 µm in Tapong Bay (Lo et al. 2004 a). *Oithona*, the most ubiquitous and abundant copepod in the world's oceans increased in abundance during the FIM and WM in the AS (Smith and Madhupratap 2005). According to Bottger-Schnack (1994), Calanoida, Cyclopoida (*Oithon*a and *Paroithona*) and Poecilostomatoida (mainly *Oncaea*) are the three most abundant copepod orders in the eastern Mediterranean, Arabian Sea and Red Sea. In the epipelagic zone (0-100 m), these orders are reported to occur at similar abundance levels, whereas in the meso- and bathypelagic zones, *Oncaea* dominates numerically (60-80%). Nakata et al. (2004) suggest that an increase in temperature and decrease in primary production (PP) would reduce the reproduction of the oncaeids in the surface layer. Among the 178 copepod-species identified off northern Taiwan, western North Pacific during spring, *Paracalanus aculeatus, Oncaea venusta* and *Clausocalanus furcatus* were the three dominant species (Lo et al. 2004 b). These three species contributed 43% of the total copepod numbers during their study. The deep-dwelling detritivorous copepod, *Lucicutia grandis* was found in high numbers at the lower interface of the OMZ (400-1100 m) at one station in the Arabian Sea during spring intermonsoon and summer monsoon (Gowing and Wishner 1998). Nishikawa et al. (2007) recorded dominance of Eucalanidae, Metridinidae and Lucicutiidae in the OMZ of the Sulu Sea. Ramfos et al. (2006) found strong seasonal changes in the dominant copepods in surface layer of the eastern Mediterranean.

Siphonophora are the major and regular constituents of the marine zooplankton, which occupy fourth or fifth place in the order of abundance in the tropical community (Yamazi 1971). However, unlike other zooplankton, it is very difficult to obtain an accurate estimation of siphonophore population in an area because of its structure, complexities and fragile nature (Rengarajan 1983). Hydromedusae represent an important and exclusive carnivorous zooplankton group in the coastal zones of India (Santhakumari 1977). Factors such as salinity, temperature, currents, food availability and seasons regulate the distribution of medusae (Santhakumari and Nair 1999). The abundance of fish larvae and salinity showed a significant negative correlation ($p<0.001$) indicating that the fish larval abundance decreased as salinity increased (Devi 1977). Occurrence of fish eggs and larvae during summer indicates the spawning periods of various fishes of the inshore waters of the Tuticorin (Marychamy et al. 1985).

The protozoan Acantharia, containing zooxanthellae and chl *a*, was recorded as deep as 4000 m and below for the first time in the eastern Mediterranean (Kimor and Wood 1975). Batistic et al. (2003) found that chaetognath abundance was high in the upper 100 m and decreased with increasing depth. From the Southern Ocean, Hempel (1985) described three very different large-scale subsystems, the ice-free West Wind Drift dominated by copepods, the seasonal pack-ice zone with the krill *Euphausia superba* as the main component, and the permanent pack-ice zone where copepods and the ice-krill *Euphausia crystallorophias* are the major plankton-elements. Both copepods and larvaceans are sources of fluorescent- and chromophoric dissolved organic matter in marine coastal systems (Urban-Rich et al. 2006).

Higher concentrations of pteropods were observed in the center of a cold-core eddy compared to the ambient water in the northeastern Atlantic, with large sized specimens occurring in 100-400 m depth than in the surface (Beckmann et al. 1987). The high abundance of filter-feeders (ostracods, cladocerans, doliolids and salps) was ascribed to elevated chlorophyll concentrations in the cyclonic eddy in the southwestern Mediterranean Sea, during summer (Riandey et al. 2005). Data from continuous plankton recorder (CPR) surveys demonstrate that zooplankton communities have undergone geographical as well as size shifts off the Northwest European shelf (Pitois and Fox 2006).

In the northern Indian Ocean, plankton communities differed in zones of intensive divergence, poor divergence and stratified waters in terms of their biomass, species diversity, and trophic group ratios (Timonin 1976). The disproportionately high abundance of very few species of mesozooplankton in the epipelagic zone of the Red Sea than the bathypelagic zone was related to high temperature (≥21.5°C) and salinity (≥ 40 psu; Weikert 1982) in the later zone. A faunistic change was also observed in the bathy- to abysso- pelagic zone in the eastern Mediterranean (Weikert et al. 2001). The mesozooplankton composition is noted to vary with space and season in the Indian Ocean sector of the Southern Ocean (Mayzaud et al. 2002 a).

## 2.3. Grazing- and Growth- Rates

The small sized mesozooplankton (200-500 μm) contributing >50% to the total grazing rates by mesozooplankton showed latitudinal differences in central tropical Pacific (Zhang et al. 1995). Their rates of ingestion, egestion and production in the equatorial Pacific 140°W and 180° are maximal in the high-nutrient low-chlorophyll (HNLC) zone associated with equatorial upwelling (5°S–5°N) as compared to the more oligotrophic regions to the north and south of it (Roman et al. 2002 b). In the equatorial upwelling region of the Atlantic, high primary production rates and low phytoplankton biomass were suggestive of a strong top-down control of primary producers by zooplankton (Perez et al. 2005). Sautour et al. (2000) found that 26% of the total PP was grazed by mesozooplankton in the Gironde Estuary. Their average grazing rates varying from 19 to 92 mg C $m^{-2}$ $d^{-1}$ in the AS during September-December resulted in the removal of 4-12% of daily PP (Edwards et al. 1999). Hernandez-Leon et al. (2002) observed high gut fluorescence in zooplankton along an upwelling filament extending from Northwest African coast to offshore. Grazing was also estimated by using $^{14}$C- radiolabeled natural (*i.e.*, mixed) phytoplankton populations (Griffiths and Caperon 1979). However, the reliability of the results is better when the experimental time is short enough to prevent recycling of the isotope, and growth of the phytoplankton substrate.

Using the gut fluorescence (GF) technique, Pakhomov and Froneman (2004) showed that copepods were the most conspicuous grazers in the upper 200 m. Along an eastern transect of the southern Atlantic Ocean, GF accounted for ~40% of total zooplankton grazing. The grazing impact of the copepods (>73 % of total zooplankton) changed seasonally and spatially in the Pearl River Estuary and, varied between <0.3% and 75% of the chlorophyll standing stock, and up to 21-104% of the daily phytoplankton production (Tan et al. 2004). In the Atlantic (Huskin et al. 2001 a), copepod gut evacuation rate averaged 0.03 min $^{-1}$ irrespective of latitude or body size. Their grazing impact averaged ~6% of the integrated chlorophyll (chl) *a* concentration and 22% of the primary production in the subtropical Atlantic during spring (Huskin et al. 2001 b) with higher gut content during night.

Paffenhofer (2002) has revealed that many species of diatoms in bloom concentrations can negatively affect the nauplii of many calanoid copepods. Exudates and transparent exopolymer particles from *Phaeocystis globosa* are known to drastically reduce the microalgal feeding rates of naupliar stages of copepods (Dutz et al. 2005). Gut content analysis of the copepods *Pleuromamma xiphias* (Giesbrecht), *Euchirella messinensis* (Claus) and of the euphausiid *Thysanopoda aequalis* (Hansen) indicated that all three species fed on a wide variety of phytoplankton, zooplankton, and detrital material. Diet changes generally reflected seasonal trends in phytoplankton community structure. However, species-specific feeding preferences and differences in feeding selectivity among the three species, all with distinct mouthpart morphology, were evident (Schnetzer and Steinberg 2002 a).

Wu et al. (2004) studied the gut contents of the poecilostomatoids, *Oncaea venusta*, *O. mediterranea*, and *O. conifera* from the southern Taiwan Strait. Copepod gut contents comprising diatoms (*Chaetoceros* sp. and *Thalassiothrix* sp.), radiolaria and, microzooplanktonic- and copepod debris suggests the kind of food components available in the study area. Such analyses are useful in suggesting non-selectively and diversity in feeding habits. As copepods feeding on coccolithophores are known to egest only 27-50% of the ingested coccolith calcite, there are strong possibilities of its acid digestion in their guts (Harris 1994). *Oncaea venusta* is known to attack and feed on chaetognaths (Go et al. 1998). From the fatty acid and alcohol composition of oncaeids and oithoniids, it has been concluded that feeding behaviour of all their species is omnivorous and/or carnivorous (Kattner et al. 2003). Copepods are also known to be highly adept at consuming their own fecal pellets, a process called coprohexy (coprophagy), by removing the peritrophic membrane with its attached bacterial flora leaving behind "ghost" pellets, consisting of only a membrane with little or no apparent solid content (Lampitt et al. 1990).

The preponderant ~2µm sized phytoplankton in warm oligotrophic open oceans are too small for direct consumption efficiently by mesozooplankton (Calbet and Landry 1999). Food chain analysis suggests that a significant fraction of the microzooplankton is probably consumed by mesozooplankton (Dam et al. 1995; Calbet and Landry 1999). An estimated 28% of the carbon demand of mesozooplankton is met by ciliates and heterotrophic dinoflagellates in coastal waters off Zanzibar during May-June (Lugomela et al. 2001). Schnetzer and Caron (2005) observed that the copepods were responsible for removing 5-36 % of the microzooplankton standing stocks in the San Pedro Channel, California resulting in increased abundance of nanozooplankton. Umani et al. (2005) demonstrated that mesozooplankton consume ~76% of the daily PP in the mesotrophic northern Adriatic Sea. Further, microzooplankton also formed substantial portion in their diet.

In the Arabian Sea, mesozooplankton were mostly omnivorous consuming detritus and protozoa (Richardson et al. 2006). However, they mainly grazed upon large phytoplankton whenever they prevailed. Heterotrophic prey constitutes a relevant fraction of zooplankton diet, as an alternative to the scarce phytoplankton in the Northwest Mediterranean Sea (Saiz et al. 2007). Seasonal and inter-annual variations in mesozooplankton grazing were observed in the upwelling region, off northern California (Slaughter et al. 2006). Zooplankton grazing on bacterioplankton populations was found to be insignificant in some studies (Boak and Goalder 1983). However, from the experimental addition of nutrients in the eastern Mediterranean (Pasternak et al. 2005), gut fullness of herbivores suggested the rapid utilization of the enhanced stocks of bacterio-and phyto-plankton.

While planktivorous fish are known to be important predators of fish eggs and larvae (Steidinger and Walker 1984), some zooplankton are known to be predators on ichtyoplankton (Brewer at al. 1984). Scyphomedusae are known to consume a variety of zooplankton such as larvaceans, cladocerans, fish eggs and hydromedusae (Fancett 1988). Terazaki (1996) inferred that the diet of *Sagitta enflata* consists of ~52% copepods and a small percentage each of foraminiferans, chaetognaths, pteropods, ostracods, crustacean and fish larvae, corresponding to a daily feeding rate of ~ 8% of the secondary production in the central equatorial Pacific. Though copepods were the main diet of chaetognaths, cannibalism was common in the South Adriatic (Batistic et al. 2003). Salps have a fine-mesh filter, on which they can retain even the smallest phytoplankton. In contrast, pteropods ingest mostly larger phytoplankton and the fecal pellets of both these epipelagic herbivores, large in size are source of food for the deeper living animals.

Zooplankton growth rate averaging 0.12 $d^{-1}$, varying only slightly with seasons in the northern AS was the highest in inshore waters (Roman et al. 2000). The higher mesozooplankton biomass and derived growth-rate parameters at stations of Hawaiian ocean time-series (HOT) than those of BATS were attributed to episodic nutrient inputs at BATS and mismatches between phytoplankton production and the grazing/production response by mesozooplankton in addition to periodic salp swarms (Roman et al. 2002 a). Mean instantaneous growth rates (*g*) ranged from as high as 0.90 $d^{-1}$ for *Parvocalanus crassirostris* to as low as 0.41 $d^{-1}$ for *Corycaeus* spp. (Hopcroft and Roff 1998 b). Cyclopoids were found to grow more slowly compared to calanoids of the same size (Hopcroft et al. 1998 a). Growth rate in *Sagitta elegans* was observed to be of the order of 2-3 mm per month (Brodeur and Terazaki 1999).

## 2.4. Mesozooplankton Respiration Rates

The average values of zooplankton respiration rates obtained in the morning hours oscillated between 0.015 and 0.016 mg $O_2$ mg dry weight$^{-1}$ (DW) $hr^{-1}$ (light and dark incubations). At night, these rates were higher probably due to increased swimming speeds and filtration rates and ranged from 0.020 to 0.035 mg $O_2$ mg $DW^{-1}$ $hr^{-1}$ (Macedo and Pinto-Coelho 2000). They also opine that increase in zooplankton biomass and, longer incubation produce lower respiration rates. The average mesozooplankton respiration rate in open oceans amounts to 3 Gt C $yr^{-1}$ (Del Giorgio and Duarte 2002). Respiration rates measured for 13 species of copepods varied from 0.5–0.6 ml $O_2$ $ind^{-1}$ $day^{-1}$ for smaller species to 20–62 ml $O_2$ $ind^{-1}$ $day^{-1}$ for the larger ones in the Indian sector of the Antarctic Ocean (Mayzaud et al. 2002 b). Assuming a respiratory quotient of 0.8 and digestion efficiency of 0.7, the carbon requirement for respiration of *Oithona similis* was calculated to be 125–143 ng C animal$^{-1}$ day$^{-1}$ off Massachusetts (Nakamura and Turner 1997). According to Hernandez-Leon and Ikeda (2005), specific respiration rates were the highest in equatorial waters and rapidly decreased pole ward. The global community respiration estimate for mesozooplankton in the upper 200 m of the oceans integrated over all the latitudes is 10.4 ± 3.7($n$ = 838), 2.2 ± 0.4 ($n$ = 57) and 0.40 ± 0.2 ($n$ = 12) Gt C yr$^{-1}$ in the epipelagic (top 200 m), mesopelagic (200–1000 m) and bathypelagic (below 1000 m) zones respectively. Global depth-integrated mesozooplankton respiration (13.0 ± 4.2 Gt C yr$^{-1}$) was 17–32% of global primary production. Body weight, temperature and the extent of motion will affect energy expenditures and thus, the respiration rates of zooplankton. Ikeda (1985) revealed that 84 - 96% of variation in metabolic rates of marine epipelagic zooplankton is due to body mass and habitat temperature. Owing to relatively low organic matter content in the gelatinous forms, it was found that there was no significant difference in the dry weight-specific respiration rates of gelatinous- (cnidarians, ctenophores and salps) and non-gelatinous zooplankton. The spatial distribution of zooplankton metabolic rates appears to be closely related to hydrographic features as demonstrated by Alcaraz et al. (2007) in the Mediterranean regions.

## 2.5. Zooplankton Studies in the Bay of Bengal

The general hydrography and circulation of the Bay of Bengal have been well studied (Shetye et al. 1991, 1996; Varkey et al. 1996; Shankar et al. 2002). These studies highlight the low sea surface salinities, particularly in the northern region of the BoB as a result of the heavy monsoonal precipitation that exceeds evaporation by over 70 cm annually (Gill 1982) and large freshwater influxes (1.6 × 10$^{12}$ m$^{3}$ yr$^{-1}$; UNESCO 1988) from the Ganges, Brahmaputra and Irawaddy rivers. The voluminous freshwater in the Bay (Prasad 1997) generates highly stable stratification in the upper layers of the northern BoB (Prasannakumar et al. 2002, 2004). The stratification forms a strong 'barrier layer' to the re-supply of nutrients from deeper waters (Lukas and Lindstrom 1991; Sprintall and Tomczak 1992; Prasannakumar et al. 2002; Vinayachandran et al. 2002). This barrier persists throughout the late summer and post monsoon periods, and the associated hydrographic characteristics have a profound influence on the biological productivity.

The BoB is generally considered to have a lower biological productivity than the Arabian Sea. Nutrients brought in by the rivers are thought to be removed to the deeper waters because of the narrow shelf (Qasim 1977; Sengupta et al. 1977). The poor solar irradiance during the summer monsoon because of the heavy cloud cover leads to poorer primary productivity. It is evident from the literature that most of the studies on zooplankton distribution and related hydrography are available from the Atlantic and the Pacific Oceans. In the Indian Ocean, they are mainly from the Arabian Sea. Little was known of the oceanography of the Indian Ocean including the Bay of Bengal before the International Indian Ocean Expedition (IIOE). With participation from 20 nations and 40 research vessels; physical, chemical, biological as well as geological studies were carried out during the IIOE (1960-65; Zeitzschel 1973).

Studies are available on the hydrography (La Fond 1957; Varadachari et al. 1967; Rao and Jayraman 1968; Rao et al. 1986; Murty et al. 1992; Shetye et al. 1996; Varkey et al. 1996; Schott and McCreary 2001; Prasannakumar et al. 2002; Shankar et al. 2002) and a few on the nutrient distributions (Sengupta et al. 1977; De Sousa et al. 1981; Rao et al. 1994; Sarma et al. 1994; Naqvi 2001; Madhupratap et al. 2003; Sardessai et al. 2007) in the Bay. Spatio-temporal variations in chlorophyll *a*, primary- and bacterial productivity are also available from the BoB (Radhakrishna et al. 1978, 1982; Bhattathiri et al. 1980; Devassy et al. 1983; Sarma and Kumar 1991; Madhupratap et al. 2003; Prasannakumar et al. 2002, 2004, 2007; Paul et al. 2007; Fernandes et al. 2008). However, most zooplankton studies are from the upper 200 m; confining mostly to the coastal areas.

Pioneering research in zooplankton from the East coast of India is from the Madras University (Menon 1930, 1931; Aiyar et al. 1936). Menon (1930, 1932) gave a brief account of scyphomedusae and hydromedusae off Madras coast. Panikkar (1936) gave a general account of anthozoan larvae. John (1933, 1937) described seasonal variations of *Sagitta*. Alikunhi (1949, 1951, 1967) described stomatopod and phyllosoma larvae; Krishnaswamy (1953, 1957), the copepods; Nayar (1959) the amphipods and Nair (1946, 1952), fish eggs and larvae. Nair and Aiyar (1943) studied theThaliacea off Madras. At the Andhra University, Waltair, Professor Ganapati and colleagues made quantitative study of plankton in Lawson's Bay (Ganapati and Rao 1954, 1958). Distribution of *Physalia* (Ganapati and Rao 1962), polychaetes (Ganapati and Radhakrishna 1958), pelagic tunicates (Ganapati and Bhavanarayana 1958), fish eggs and larvae (Ganapati and Raju 1961, 1963) and copepods (Chandramohan and Rao 1969), and feeding habits of *Janthina* (Ganapati and Rao 1959) have been reported. Seasonal study of zooplankton was carried out in the Bahuda Estuary, off South Orissa coast (Mishra and Panigrahy 1998). Ecological aspects of zooplankton have also been studied from the neritic and estuarine waters of Porto Novo (Krishnamurthy 1967; Subbaraju and Krishnamurthy 1972). In the Gulf of Mannar too, some studies on zooplankton are available (Prasad 1954, 1956, 1969). However, data on abundance and composition of mesozooplankton in the open waters of the Bay after -and even during- IIOE (Panikkar and Rao 1973; Pati 1980; Nair et al. 1981; Achuthankutty et al. 1980; Madhupratap et al. 2003; Rakhesh et al. 2006) is relatively scarce.

For instance, as is inferable from Rao (1973), the data on mesozooplankton during the IIOE was from a very few locations and not consistent to obtain a seasonal picture. Zooplankton, comprising of a large number of foraminiferans, radiolarians and sponge larvae have been reported off Barren Islands, Andamans (Eashwar et al. 2001). Studies of Madhupratap et al. (1981), Madhu et al. (2003), Munk et al. (2004), Satapoomin et al. (2004) and Ik (2007) describe the zooplankton from the Andaman Sea. From the Malacca Strait, Rezai et al. (2005) reported spatio-temporal variability in calanoid copepods. From all these studies, it is clearly suggestive that there are no investigations on seasonal variability of zooplankton from surface to1000 m in the BoB. Also, detailed analyses of copepod species, grazing and metabolic rates from the open ocean have not been carried out earlier.

# *Chapter 3*

# Chapter 3

## *General Hydrography and Distribution of Chlorophyll a*

It is well known that physical processes that make the nutrients available to the upper layers control biological production in warm tropical waters. The hydrography and circulation of the Bay of Bengal is complex due to the interplay of semi-annually reversing monsoon winds and perennial warm and fresh water pool (Vinayachandran and Shetye 1991). Inflow of warm high saline waters of the Arabian Sea, the Persian Gulf and of the Red Sea origin (Jensen 2001) may affect the zooplankton biomass and assemblages in the Bay. In addition, a number of cyclonic disturbances during both pre-monsoon (May) and post-monsoon (October) also bear an influence on zooplankton.

Physical oceanographic studies following the International Indian Ocean Expedition (IIOE 1960-65) have gathered considerable amount of information on hydrographic characteristics and general circulation of the Bay (Shetye et al. 1991, 1996; Varkey et al. 1996; Schott and McCreary 2001; Shankar et al. 2002). These studies have described in detail the monsoon circulation of the Bay of Bengal and to an extent, the mixed layer dynamics and stratification. During the summer monsoon, the current (Summer Monsoon Current) flows eastward as a continuous current from the western Arabian Sea to the Bay of Bengal; during the winter monsoon, it (Winter Monsoon Current) flows westward, from the western Bay to the western Arabian Sea (Shankar et al. 2002). It is these currents, which transfer water masses between the two highly dissimilar arms of the North Indian Ocean, the Bay of Bengal and the Arabian Sea. With a positive net heat flux from the atmosphere (Murty et al. 2000), sea surface temperatures are mostly warmer *i.e.* ≥28°C except during winter. Surface winds are generally weak ($<10$ m $s^{-1}$) and variable with seasons. The stratification due to low salinity (ranging from 24-34 psu) in the upper 100 m, a consequence of water debouched by rivers ($1.6 \times 10^{12}$ $m^3$ $yr^{-1}$; Subramanian 1993; from Ganges, Brahmaputra, Irrawady, Mahanadi, Godavari, Krishna, Cauvery and Pennar) and precipitation in excess of evaporation (2 m $yr^{-1}$; Prasad 1997) is the most interesting feature about the hydrography of the Bay of Bengal (Shetye et al. 1996).

Chemical properties (Sengupta et al. 1977; De Sousa et al. 1981; Rao et al. 1994; Sardessai et al. 2007) and distribution of chlorophyll *a* (chl *a*) and primary production (PP) in the Bay (Radhakrishna et al. 1978, 1982; Devassy et al. 1983; Sarma and Kumar 1991; Prasannakumar et al. 2002, 2004, 2007; Madhupratap et al. 2003) are also reported. The mean concentrations of nitrate were 1.2±0.55µg at $l^{-1}$ and that of phosphate was 2.80±2.46 µg at $l^{-1}$ during summer monsoon (Bhattathiri et al. 1980). Sardessai et al. (2007) have shown that the top 20 m is mostly devoid of nitrate except in regions of cold-core eddies. Bhattathiri et al. (1980) reported that chl *a* varied from 0.02 to 0.93 mg $m^{-3}$ at inshore stations and, from 0.01 to1.01 mg $m^{-3}$ at the offshore stations during summer monsoon. Similarly, primary production (PP) ranges are from 120 to 310 mg C $m^{-2}$ $d^{-1}$ in the open ocean, and 10-2160 mg C $m^{-2}$ $d^{-1}$ from the shelf region (Qasim 1979). Though there is a general understanding about the general circulation, hydrography, biogeochemistry and primary productivity characteristics in the Bay, their role in governing the zooplankton biomass and abundance on spatial and seasonal scale is yet to be understood.

## 3.1. Materials and Methods

As a part of the Bay of Bengal Process Studies (BOBPS) programme to understand the biogeochemistry associated with the seasonal variability of the upper ocean, *in situ* measurements were carried out onboard ORV Sagar Kanya along two transects—in the central Bay (CB) and along the western Bay (WB; Fig. 3.1) during summer monsoon (SUM; July 10-August 10, 2001), fall intermonsoon (FIM; September 14-October 12, 2002), spring intermonsoon (SpIM; April 12-May 7, 2003) and winter monsoon (WM; November 26, 2005 - January 7, 2006). Due to narrow shelf and sudden sloping in the WB, depths varied between 150 and ~1200 m at the sampled stations.

Data on temperature, salinity, dissolved oxygen and nutrients at all the nine stations were collected by the physical and chemical oceanographers. They are duly acknowledged for, and these data are used to understand the effect they bear on biological parameters detailed in the thesis. A Sea-Bird conductivity–temperature–depth (CTD) having a rosette sampler fitted with 10/30-l Go-Flo bottles was used to obtain profiles of temperature and salinity in the upper 1000 m. CTD salinity was calibrated

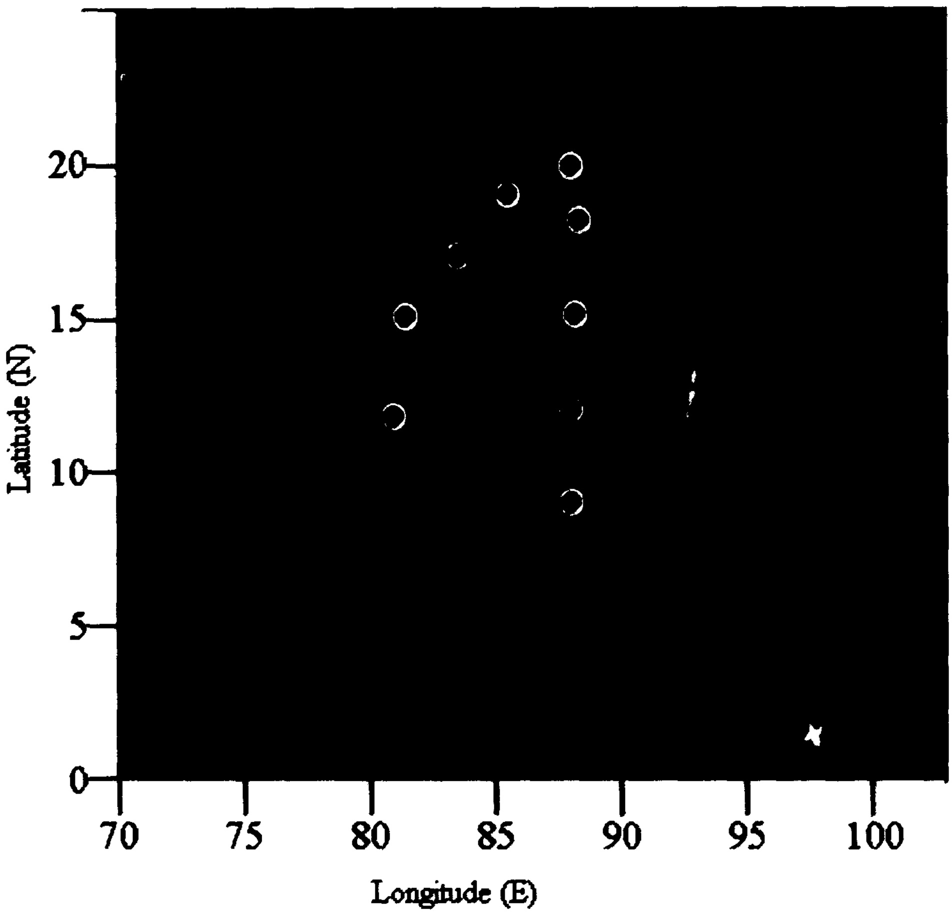


Fig. 3.1: Map showing the sampling locations in the central (along 88°E) and western Bay of Bengal. The data on physical and many chemical parameters presented in the thesis are also from stations in between the locations in this drawing. The biological parameters described in the thesis are from the locations shown here.

against water samples collected simultaneously and analyzed with a Guideline 8400 Autosal. Water samples from various depths were collected in glass bottles and analyzed for dissolved oxygen by Winkler method. Similarly, water samples for nutrients collected in glass and plastic bottles were estimated by autoanalyser (Skalar) as well as standard manual methods (Grasshoff et al. 1983).

For chlorophyll *a* (chl *a*) measurements, one-litre sub-samples of water collected from 8 discrete depths (near-surface, 10, 20, 40, 60, 80, 100 and 120 m) were filtered through 47mm GF/F filters (Whatman, UK, 0.7 µm pore size). Filters were taken individually into 20 ml polycarbonate vials and 10 ml 90% acetone (v/v) was added to extract chl *a* in the dark for 24 h in refrigerator. Chl *a* concentration was measured using a fluorometer (AU 10 Turner Designs, USA) following the JGOFS Protocols (UNESCO 1994). A factor of 50 was used to convert chl *a* to carbon biomass (Banse 1988).

Statistical analyses such as one-way and two-way ANOVA (Excel software program) was carried out for various hydrographical parameters in order to decipher the spatio-temporal variability.

## 3.2. Results

### 3.2.1. Temperature

*Central Bay*

The sea surface temperature (SST) along the open ocean transect (88°E) during SUM was 29°C between CB1 (9°N) and CB3 (15°N) that decreased to 28°C between CB4 (18°N) and CB5 (20°N; Fig. 3.2). The mixed layer depth (MLD) calculated using density criteria (Levitus 1982) was about 15 m at CB1; was in excess of 50 m at CB2 (12°N), but shoaled gradually under the influence of increased freshening to <4 m at 20°N (Table 3.1). Along the CB, thermocline oscillated in the upper 300 m. An upheaval of isotherms was noticed at CB1 where the 28°C isotherm shoaled from ~50 m to 20 m. This was clearly a signature of a subsurface cold-core eddy seen below 15 m, which depressed the ambient temperature at 60 m (27°C) by about 5°C. Similar changes were observed at the northern cold-core eddy at CB5. Below 300 m, the thermal structure did not show any special feature.

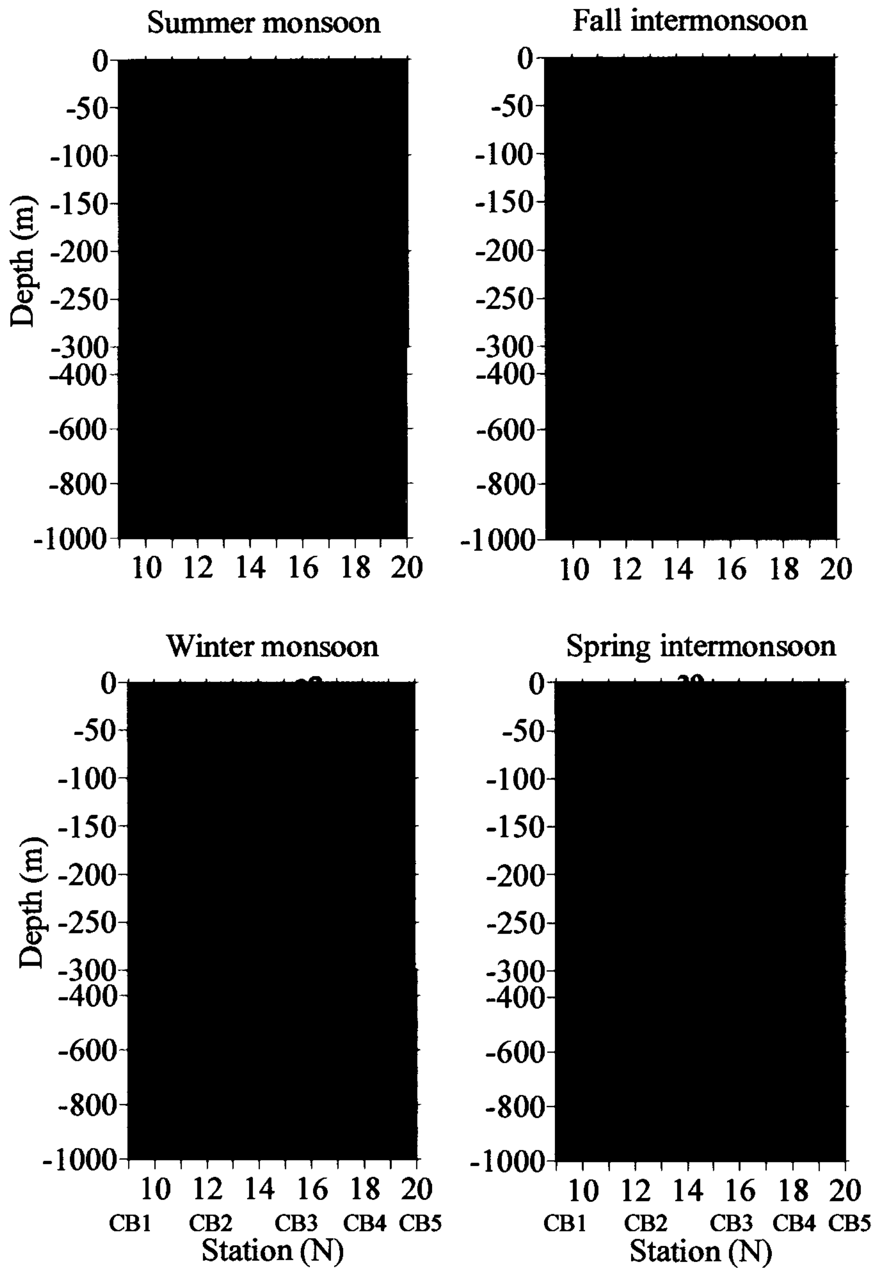


Fig 3.2: Spatio-vertical sections of temperature (°C) in the upper 1000 m of the central Bay during different seasons

Table 3.1.Variations in mixed layer depth (MLD) during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM) along central and western Bay of Bengal

Central Bay

| **Sampling Station** | **Mixed layer depth (m)** | | | |
|---|---|---|---|---|
| | **SUM** | **FIM** | **WM** | **SpIM** |
| CB1 | 15 | 25 | 40 | 40 |
| CB2 | 51 | 60 | 40 | 30 |
| CB3 | 29 | 26 | 40 | 15 |
| CB4 | 13 | 3 | 30 | 40 |
| CB5 | 4 | 5 | 10 | 30 |

Western Bay

| **Sampling Station** | **Mixed layer depth (m)** | | | |
|---|---|---|---|---|
| | **SUM** | **FIM** | **WM** | **SpIM** |
| WB1 | 29 | 30 | 40 | 36 |
| WB2 | 30 | 6 | 20 | 44 |
| WB3 | 14 | 5 | 52 | 17 |
| WB4 | 2 | 7 | 30 | 26 |

During FIM, the SST was ~28°C between CB1 and CB5. The MLD was about 25 m at CB1; deepened to 60 m at CB2, and then shoaled to <5 m at CB5. Thermocline oscillations were present within the upper 300 m and signatures of cold-core eddies were implicit at CB1 and CB5.

During WM, the SST was 28°C south of CB3 and, decreased north of it. The vertical thermal structure showed signature of cold-core eddies and thermocline oscillation within the upper 300m. Similar to the observations during SUM and FIM, isotherms shoaled at CB1 and CB5, indicating the persistence of cold-core eddies in CB. MLD was ~40 m between CB1 and CB3, which decreased to 10 m at CB5.

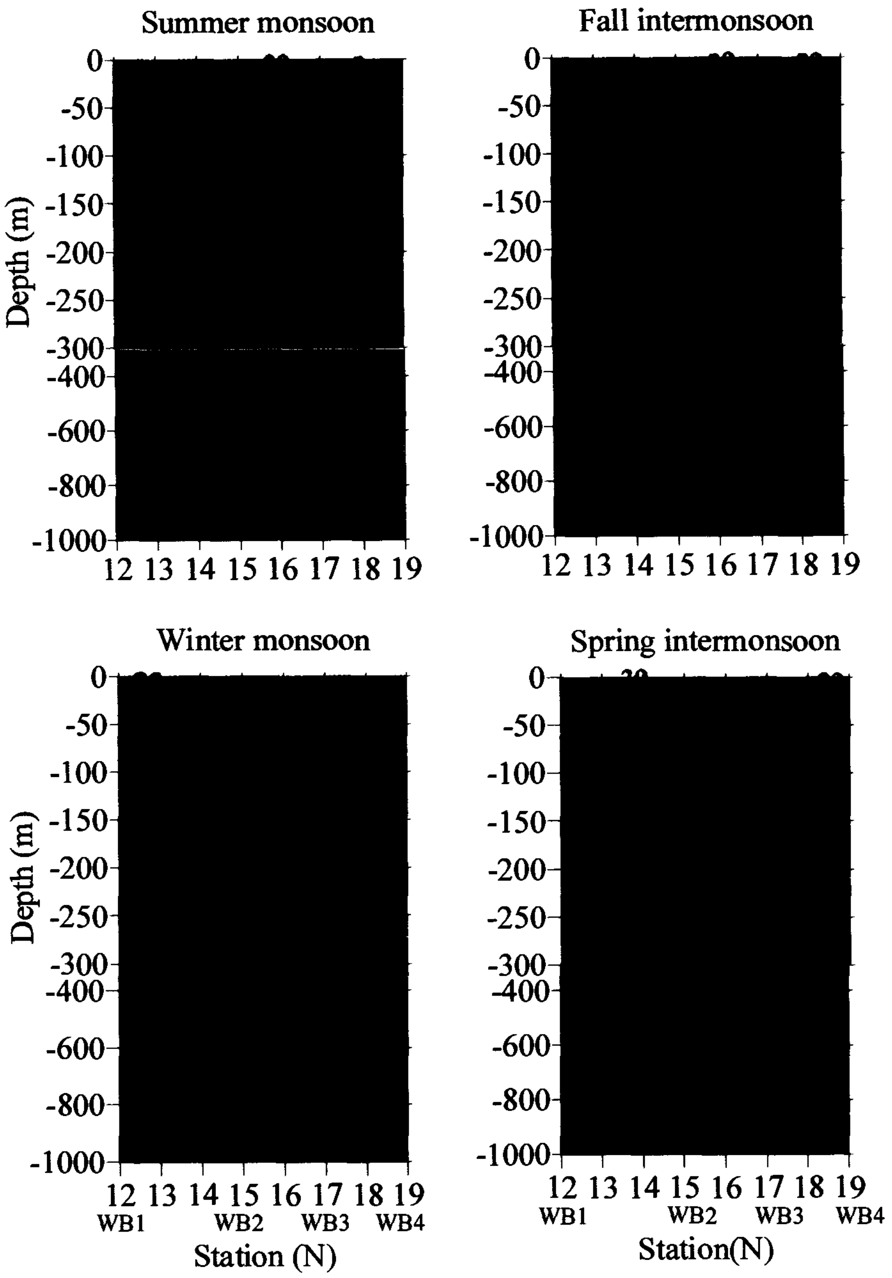
During SpIM, the uppermost 10 m thick isothermal layer showed temperature in excess of 30°C between CB1 and CB3 and was a couple of degrees colder (28°C) between CB4 and CB5. MLD was about 40 m at CB1, was variable at the different stations before becoming shallow once again at CB5. Thermocline oscillations were not very pronounced along the track.

*Western Bay*

In the WB, the SSTs varied between 29° and 30°C during SUM and, were higher than those in the central transect (Fig. 3.3). MLD was 25 m at WB1 and almost non-existent in the northernmost location (Table 3.1). The thermal structure in the upper 300 m also exhibited oscillations within the thermocline as was the case with the open ocean transect. A noteworthy feature was, uplifting of isotherms centered near WB3. The 28°C isotherm shoaled from 60 m to 10 m. This vertical displacement of about 50 m in the upper thermocline depressed the ambient temperature by about 5°C.

During FIM, SST was on an average 30°C (range, 29.2-30.5°C). MLD decreased from about 30 m in the south to <5 m in the north. Cold-core eddy signature could be inferred with its center near WB3, where the 27°C isotherm shoaled from 60 m to ~15 m depressing the ambient temperature by ~3°C.

Averaging 26°C, SST was 2-3°C cooler in the WM compared to that in the other three seasons. Thermal structure showed the presence of oscillations. A cold-core eddy near WB1 could be discerned.


Summer monsoon

Fall intermonsoon

Winter monsoon

Spring intermonsoon

Fig 3.3: Spatio-vertical sections of temperature (°C) in the upper 1000 m of the western Bay during different seasons

Varying between 30.5°C and 29°C, SST showed a decreasing trend from south to north during SpIM. The MLD shoaled from 36 m in south to 26 m in the north. Signatures of cold-core eddies were observed around WB2 and WB3.

### 3.2.2. Salinity

*Central Bay*

Sea surface salinity (SSS) in the CB was about 33.5 psu (practical salinity unit) between CB1 and CB3 during SUM (Fig. 3.4) but reduced rapidly towards north reaching a low of 28 psu at CB5. The salinity gradient in the upper 50m at CB1 was about 1.5 psu while that at CB5 was about 7 psu. Between 50 and 200 m, salinity was close to 34.99 psu.

During FIM, surface salinity showed a slow and steady decrease from ~34.0 psu at CB1 to 32.0 psu at CB3. From CB3, the salinity dropped to 28 psu at CB5. The salinity gradient in the upper 50m was about 1 psu in the south (CB1) and 7 psu in the north. Water mass of 34.99 psu, which existed from surface to 280 m depth at CB2, reduced to a narrow band of 80-200 m at CB5.

SSS ranged between 33.5 in the south (CB1) and 30 psu in the north (CB5) during WM. Salinity gradient was 0.5 psu in the top 50 m in the south, which increased to 3 psu in the north. The halocline was located between 40 and 100 m.

Surface salinity during SpIM (32.7 psu) was higher than in the other three seasons. Salinity gradient of 1 psu in the top 50 m was observed throughout the CB.

In all four seasons in the CB, high salinity water mass of 35.01 psu was observed between 250 and 600 m, below which, water mass of <35 psu existed till 1000 m.

*Western Bay*

Surface salinity varied from 34 psu at WB1 to 24 psu at WB4 during SUM. Strong salinity gradient was observed in the top 50m especially at WB4 (10 psu) compared to south of WB2 (0.5 psu). Below 50 m, homogeneous waters with 34.99 psu were seen till 200 m (Fig 3.5).

Salinity distribution during FIM was similar but the vertical stratification towards north was much stronger than during SUM.

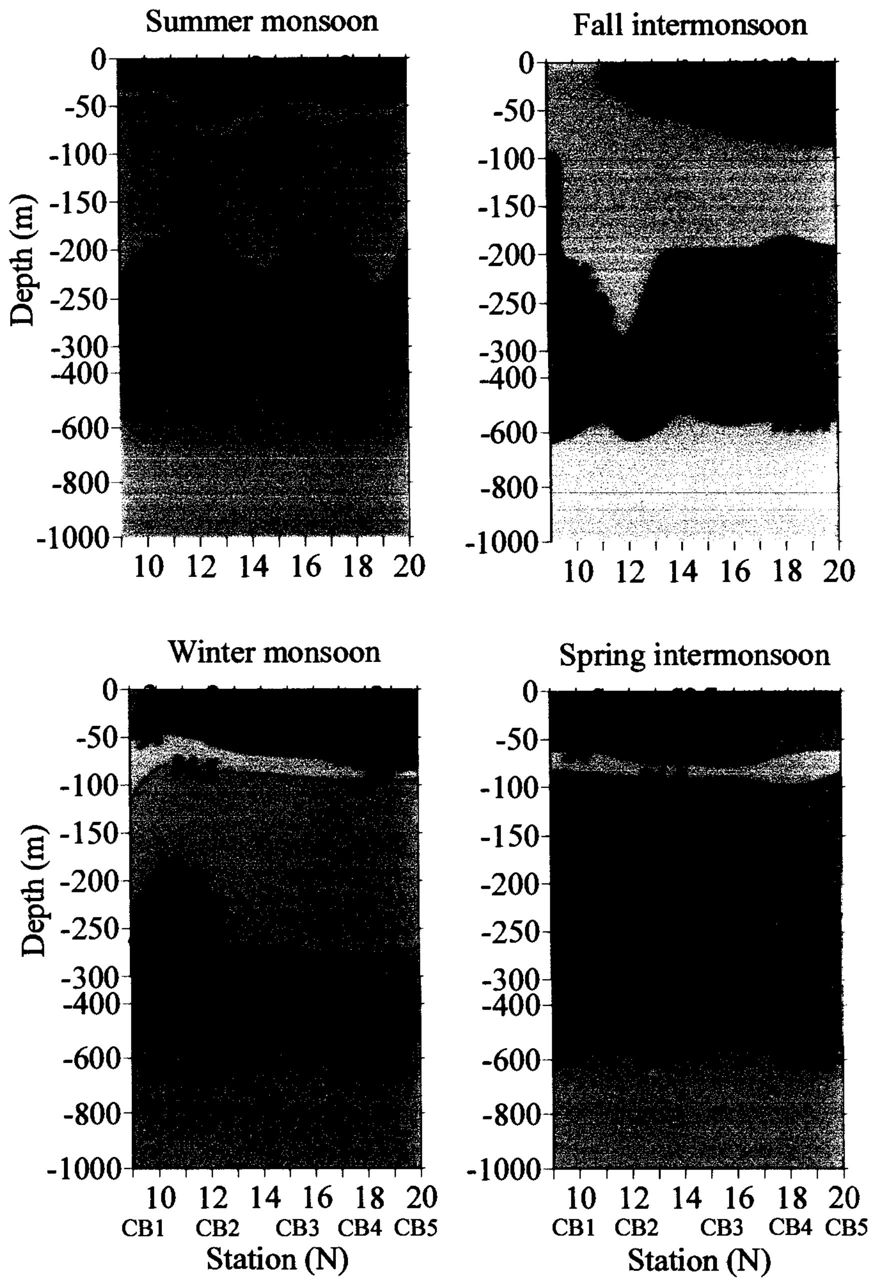


Fig 3.4 Distribution pattern of salinity (psu) in the upper 1000 m of the central Bay during different seasons

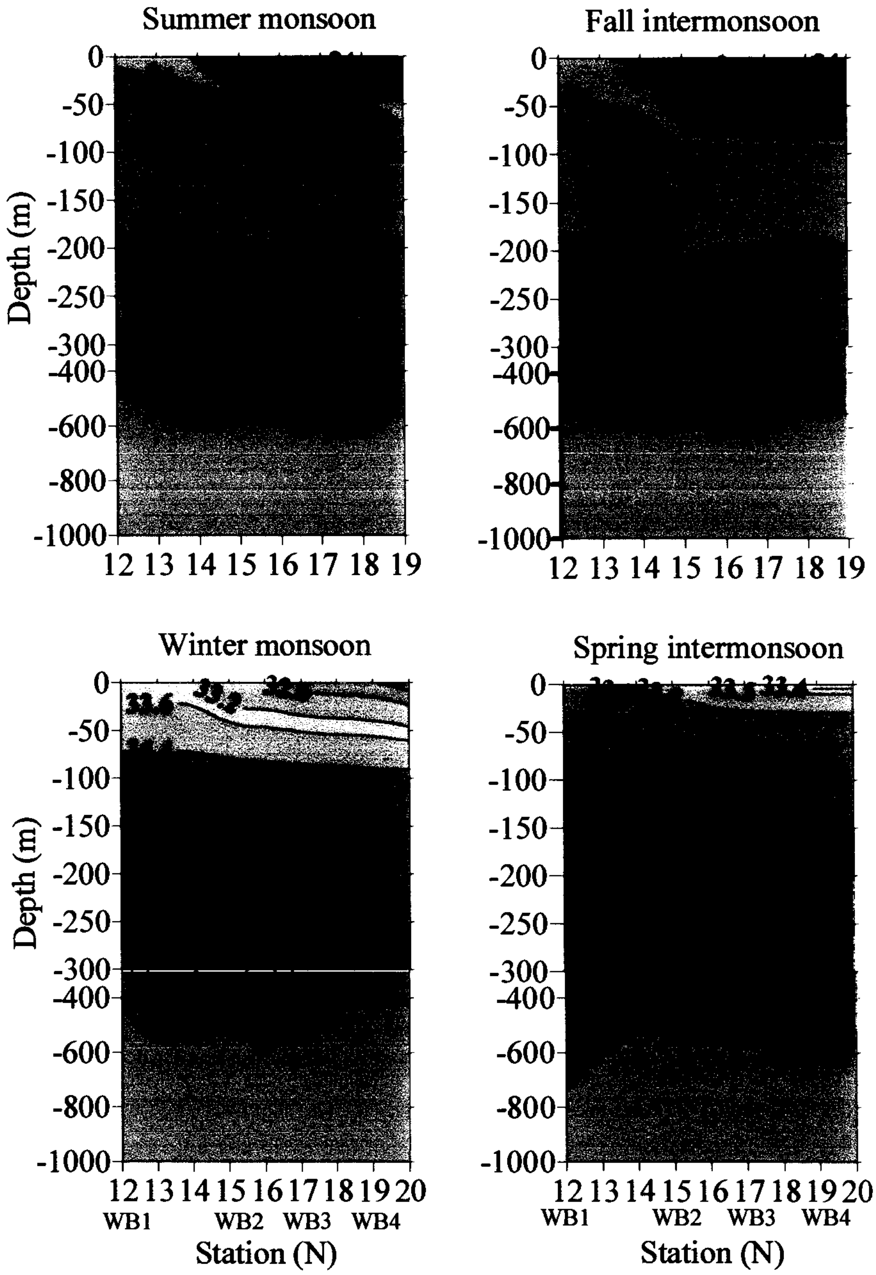


Fig 3.5: Distribution pattern of salinity (psu) in the upper 1000 m of the western Bay during different seasons

During WM, it varied from 33.2 psu in the south to 31.8 in the north. The vertical gradient in salinity in the top 50 m was 1.5 psu at WB1 and, 3 psu at WB4.

Surface salinity was the highest during SpIM without much variation between sampling locations. It decreased by 0.5 psu from south (33.9 psu at WB1) to north (33.4 psu at WB4). Accordingly, the vertical gradient of salinity in the upper 50 m was only 0.4 psu in the south and 0.9 psu in the north. Consistent with thermal structure, salinity distribution also showed prominent isohaline displacements centered near WB1 and WB3.

The water mass of 34.99 psu was observed between 50 and 180 m during SUM and FIM; between 100 and 200 m during WM and SpIM. During all the four seasons, high salinities of 35.01-35.03 psu persisted at depths of 200- 600 m, below which were the low salinity layers of <35 psu till 1000 m.

### 3.2.3. Dissolved oxygen

*Central Bay*

During SUM, dissolved oxygen (DO) concentration in the surface varied from 180 μM (180/44.6 ≡ 4 ml $l^{-1}$) at CB1 to 200 μM at CB5. An intense oxygen minimum zone (OMZ) with ≤10 μM DO extended from ~100-150 m to ~700 m mostly between CB2 and CB5. Suboxic/low oxygen waters (5 μM) were observed between 100 and 200 m from CB3 to CB5. Intrusion of waters with relatively higher oxygen concentrations of 15-35 μM was observed at depth of 350-700 m between CB1 and CB2. Below 700 m, the DO gradually increased to register 35 μM at 1000 m (Fig. 3.6).

During FIM, surface oxygen hardly varied from south to north ranging narrowly from 200 μM at CB1 to 195 μM at CB5. The oxygen minimum layer of 10 μM was seen at depths of 100-600 m between CB2 and CB5 (Fig 3.6). The suboxic zone was also seen at similar between CB3 and CB5. The intermediate waters between 400 and 600 m had DO in the range of 5-20 μM whereas the deeper waters had relatively higher oxygen content (20-25 μM).

During winter season, DO concentration varied from 215 μM (4.8 ml $l^{-1}$) at the surface, which gradually decreased to 30 μM by 200 m. Lowest concentration of 25 μM

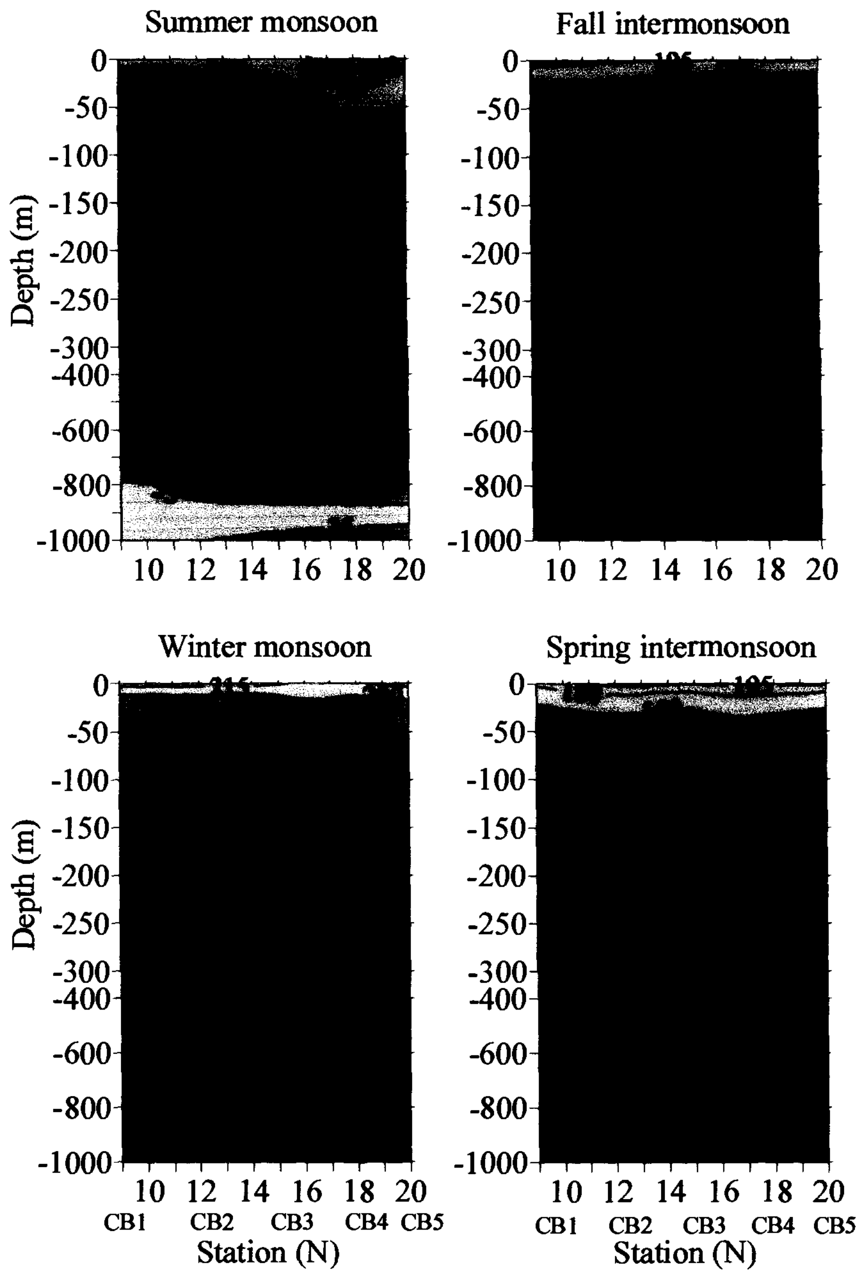


Fig 3.6: Distribution of dissolved oxygen (μM) in the upper 1000 m of the central Bay during different seasons

was observed between CB1 and CB3 in the depth range of 270 to 500 m. There was a gradual increase in oxygen levels below this depth to 50 µM by 1000 m.

During spring intermonsoon, surface oxygen concentration of 195 µM decreased to 50 µM at 80 m. At CB4 and CB5, the dissolved oxygen was significantly lower due to the upheaval of the subsurface water mass in this region. The oxygen minimum layer was mostly confined to 100-500 m between CB3 and CB5. A narrow band of near-suboxic waters was seen from 200 to 400 m at the same latitudes. Intermediate waters between 400 and 600 m had oxygen content in the range of 5-20 µM, which increased in the deep water to 20-40 µM.

*Western Bay*

The up-sloping of the low oxygen waters along the western margin (Fig. 3.7) was observed at WB3 in all the seasons except WM. During SUM, the DO of 190 µM in the surface decreased to 10 µM at 100m. Suboxic water was observed between 150-400 m throughout the WB. Between 400 and 600 m, the DO concentration was 10 µM. In the deeper waters, it increased gradually from 10 to 50 µM.

During FIM, surface oxygen concentration increased from 200µM at WB1 to 205 µM at WB4. The narrow band of suboxic waters was seen at shallower depths of 200 and 400 m at WB1, was between 300 and 400 m until WB3, and was between 100 and 400 m at WB3-WB4. Between 400 and 600 m, the oxygen concentration was in the range of 10-25 µm. Below 600 m, the DO increased gradually to 45 µM.

In WM, the surface oxygen with decreasing concentration from south to north (230-200 µM) was higher than in any other season. Sinking of the water mass with relatively higher oxygen was observed between WB3 and WB4. Oxygen minimum zone (10 µM) was observed between 100 and 150 m. Suboxic waters were not observed in this season.

Oxygen concentration decreased from 195 µM in the south to 190 µM in the north during SpIM. The oxygen minimum layer extended from 170 to 500 m between WB3 and WB4. Suboxic waters, prominently seen during SUM and FIM, were absent during SpIM. Below 600 m, the DO increased from 25-50 µM by 1000 m.

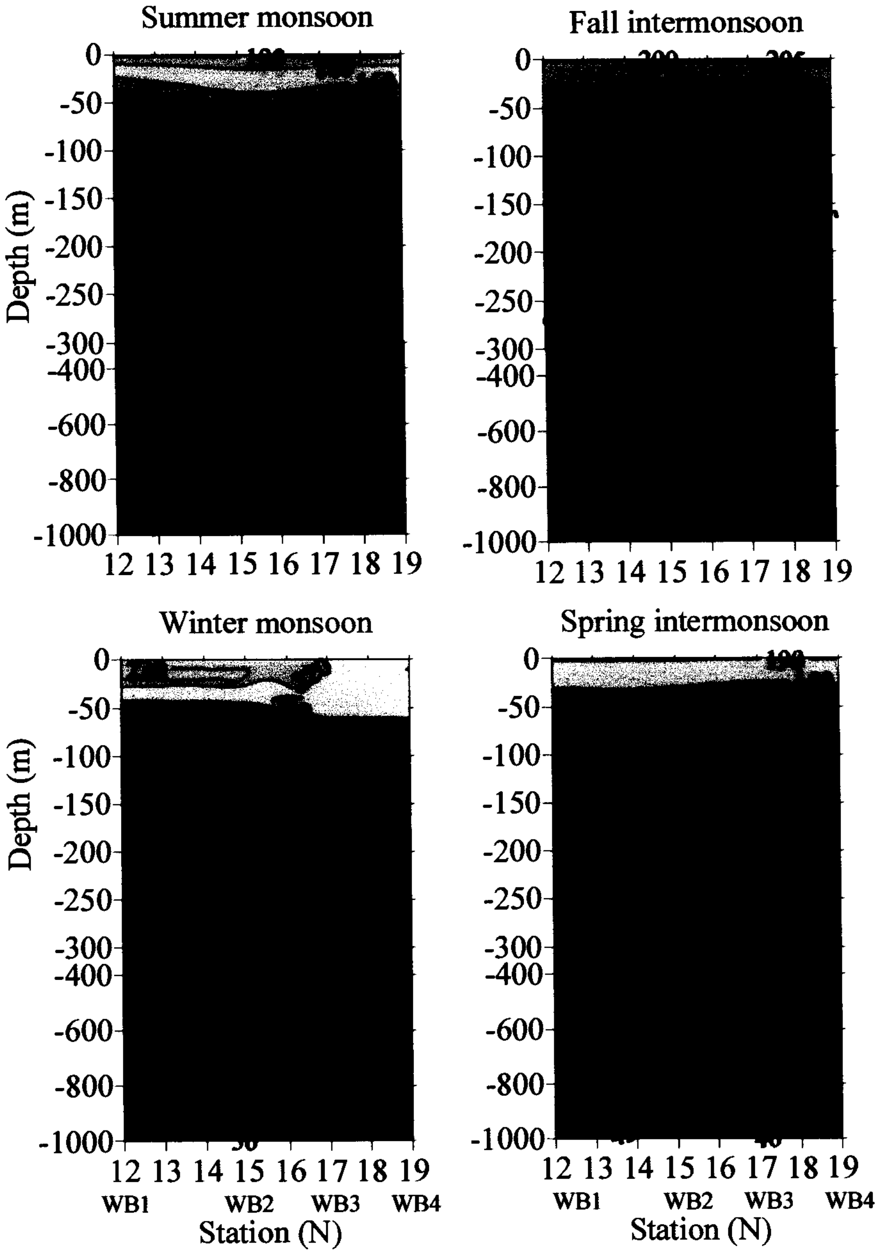


Fig 3.7: Variation of dissolved oxygen (μM) in the upper 1000 m of the western Bay during different seasons

### 3.2.4. Nutrients

*Central Bay*

During SUM, the nitrate ($NO_3$) concentration in the top 40 m was below detection limit (≡0) to 9.0 μM at CB1, was below detection limit from CB2 to CB4, and was 0-2.8 μM at CB5. It was generally higher in the deeper layers. Phosphate ($PO_4$) was not detectable in the top 120 m at CB1. It was observed only below 60 m from CB2 to CB4. Its concentration was 0-0.3 μM in the top 40 m at CB5. Silicate ($SiO_3$) was higher in the top 40 m at CB1 (1-3.8 μM) and CB5 (0.6-2.9 μM) and, increased in the deeper layer (Table 3.2).

Unlike during SUM, all the three nutrients were observed in greater concentrations in the upper 40 m at all stations during FIM, especially at CB1 ($NO_3$: 0.2-9.6 μM; $PO_4$: 0.4-1.2 μM; $SiO_3$: 0.4-4.2 μM), CB4 ($NO_3$: 0.1-8.8 μM; $PO_4$: 0.2-1.2 μM; $SiO_3$: 0.9-5.0 μM) and CB5 ($NO_3$: 0.1-14.8 μM; $PO_4$: 0.2-1.5 μM; $SiO_3$: 2.3-9.3 μM).

During WM, the $NO_3$ concentration in the top 40 m (<0.2 μM) was the lowest among the four seasons observed in the CB. $NO_3$ and $SiO_3$ (< 2 μM) were higher at CB1, CB4 and CB5. In the top 40 m, $PO_4$ was observed to be higher at CB2 and CB4.

Higher concentration of all three nutrients was observed during SpIM at CB1 ($NO_3$: 0.2-1.2 μM; $PO_4$: 0.1-0.2 μM; $SiO_3$: 1.7-2.2 μM). $PO_4$ concentration was the least observed during this season (<0.2 μM).

*Western Bay*

In the SUM, the highest concentrations of nutrients (Table 3.3) were observed at WB3 ($NO_3$: 0-14.4 μM; $PO_4$: 0-1.0 μM; $SiO_3$: 0-6.0 μM) in the upper 40m.

While $NO_3$ (0.1-17 μM) and $PO_4$ (0.4-1.7 μM) concentrations were the highest again at WB3 during FIM, the $SiO_3$ was only moderate (1.4-7.6 μM) with its highest concentration being at WB4 (4.3-9.7 μM).

During WM, a decreasing gradient in nutrient concentration was discernible in the 120 m towards the northern Bay.

During SpIM again, the highest values of nutrients were obtained at WB3 ($NO_3$: 0.2-14 μM; $PO_4$: 0.3-1.4 μM; $SiO_3$: 2.0-6.3 μM).

Table 3.2. Ranges of nutrient concentrations (Nitrate- $NO_3$, Phosphate- $PO_4$ and Silicate- $SiO_4$) in the top 40 m (**bold**) and 60-120 m in the central Bay of Bengal during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM)

| Station | $NO_3$ (μM) | $PO_4$ (μM) | $SiO_4$ (μM) | $NO_3$ (μM) | $PO_4$ (μM) | $SiO_4$ (μM) |
|---|---|---|---|---|---|---|
| | | SUM | | | FIM | |
| CB1 | **0*- 9.00** | **0*** | **1.00-3.80** | **0.16-9.61** | **0.35-1.19** | **0.43-4.25** |
| | 17.10-25.00 | 0* | 7.50-14.80 | 13.90-22.60 | 1.20-1.70 | 6.80-14.80 |
| CB2 | **0*** | **0*** | **0*** | **0.02-1.27** | **0.06-0.18** | **1.05-1.68** |
| | 0*-25.40 | 0*-2.15 | 0*-12.80 | 5.02-28.54 | 0.56-1.72 | 3.57-15.7 |
| CB3 | **0*** | **0*** | **0*** | **0.03- 0.07** | **0.19-0.35** | **0.81-1.09** |
| | 3.70-25.80 | 0.16-1.82 | 1.80-17.2 | 5.58-27.76 | 0.84-2.22 | 3.45-20.9 |
| CB4 | **0*** | **0*** | **0*-0.80** | **0.07- 8.77** | **0.21-1.19** | **0.89-4.99** |
| | 8.00-27.40 | 0.53-1.88 | 4.60-27.6 | 21.43-36.9 | 2.02-2.36 | 11.44-21.9 |
| CB5 | **0*- 2.80** | **0*-0.31** | **0.60- 2.90** | **0.11-14.82** | **0.19-1.51** | **2.28- 9.28** |
| | 12.80-27.00 | 0.95-2.18 | 4.70-22.10 | 21.2-30.69 | 2.19-2.37 | 13.79-26.50 |
| | | WM | | | SpIM | |
| CB1 | **0.11-0.16** | **0.19-0.97** | **1.79-1.82** | **0.20-1.20** | **0.10-0.21** | **1.71-2.23** |
| | 1.70-17.90 | 0.28-0.90 | 3.00-12.20 | 15.70-22.80 | 1.02-1.70 | 10.20-21.20 |
| CB2 | **0*-0.06** | **0.21-0.46** | **0.48-0.56** | **0*-0.20** | **0.02-0.27** | **1.60-2.13** |
| | 4.18-21.3 | 0.68-1.74 | 3.60-14.40 | 2.10-26.30 | 0.39-2.21 | 2.2-19.5 |
| CB3 | **0*-0.05** | **0.14-0.30** | **0.86-0.96** | **0.30-0.40** | **0.02-0.06** | **1.86-1.94** |
| | 0.21-21.7 | 0.27-1.72 | 1.98-13.7 | 2.90-30.6 | 0.34-1.96 | 2.71-21.3 |
| CB4 | **0.09-0.14** | **0.30-0.56** | **1.27-1.57** | **0.20-0.30** | **0.03-0.06** | **1.77-2.02** |
| | 0.16-17.50 | 0.25-1.58 | 1.28-9.57 | 0.50-25.6 | 0.13-1.644 | 1.67-15.9 |
| CB5 | **0.12-0.17** | **0.20-0.31** | **1.18-1.52** | **0.20-0.20** | **0*-0.08** | **1.60-1.64** |
| | 0.20-26.80 | 0.14-1.80 | 1.24-15.70 | 6.80-30.20 | 0.63-2.09 | 4.59-24.8 |

*denotes non-detectable levels of nutrients

Table 3.3. Ranges of nutrient concentrations (Nitrate- $NO_3$, Phosphate- $PO_4$ and Silicate- $SiO_4$) in the top 40 m (**bold**) and 60-120 m in the western Bay of Bengal during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and Spring intermonsoon (SpIM)

| Station | $NO_3$ (μM) | $PO_4$ (μM) | $SiO_4$ (μM) | $NO_3$ (μM) | $PO_4$ (μM) | $SiO_4$ (μM) |
|---|---|---|---|---|---|---|
| | | SUM | | | FIM | |
| WB1 | **$0^*$** | **$0^*$-0.08** | **$0^*$** | **0.15-0.40** | **0.11-0.64** | **1.05-1.10** |
| | 9.70-23.30 | 0.37-0.95 | 2.70-13.7 | 19.41-29.5 | 1.68-2.4 | 9.58-26.9 |
| WB2 | **$0^*$** | **$0^*$** | **$0^*$** | **0.11-5.36** | **0.03-0.52** | **1.49-3.96** |
| | $0^*$-20.60 | 0.11-1.53 | $0^*$-11.90 | 14.02-27.49 | 1.22-2.13 | 8.04-22.5 |
| WB3 | **$0^*$-14.40** | **$0^*$-0.96** | **$0^*$-6.00** | **0.13-17.04** | **0.37-1.69** | **1.38-7.58** |
| | 19.00-24.80 | 1.41-1.80 | 10.20-15.80 | 21.46-32.25 | 1.95-2.43 | 11.86-28.00 |
| WB4 | **$0^*$-0.20** | **$0^*$** | **0.10-4.00** | **0.22-4.52** | **0.99-1.39** | **4.28-9.69** |
| | 5.70-21.60 | 0.41-1.52 | 2.00-9.70 | 11.48-32.88 | 2.09-3.37 | 7.39-25.10 |
| | | WM | | | SpIM | |
| WB1 | **0.22-0.70** | **0.03-0.10** | **3.07-4.71** | **0.30-0.50** | **0.03-1.08** | **1.67-2.04** |
| | 23.10-30.40 | 1.79-2.36 | 37.35-45.5 | 0.30-26.20 | $0^*$-1.68 | 1.75-18.5 |
| WB2 | **0.18-0.60** | **0.11-1.04** | **2.41-2.98** | **0.20-0.20** | **0.05-0.12** | **1.76-2.02** |
| | 19.5-27.3 | 0.95-2.44 | 21.19-42.5 | 0.20-19.9 | 0.14-1.29 | 1.66-13.7 |
| WB3 | **0.01-0.04** | **0.05-0.20** | **1.14-1.28** | **0.20-14.00** | **0.27-1.42** | **1.97-6.30** |
| | 0.01-24.80 | 0.02-1.99 | 1.11-18.3 | 22.8-32.7 | 2.13-2.55 | 14.83-28.30 |
| WB4 | **$0^*$-0.10** | **$0^*$-0.16** | **1.27-1.42** | **0.10-1.00** | **0.26-0.40** | **1.3-2.46** |
| | 0.05-20.6 | 0.09-1.68 | 1.14-16.1 | 12.2-30.6 | 1.09-2.27 | 7.63-28.7 |

*denotes non-detectable levels of nutrients

### 3.2.5. Chlorophyll *a*

*Central Bay*

Chlorophyll *a* (chl *a*) concentrations ranged from 0.01 to 0.28 mg m$^{-3}$ in the CB during SUM. The deep chl *a* maximum (DCM) was between 40 and 60 m (Fig. 3.8). Integrated chl *a* varied from 9 to11.5 mg m$^{-2}$ with its highest concentration at CB1 (Fig. 3.9 A).

During FIM, it was in the range of 0.001-0.42 mg m$^{-3}$. The DCM was between 40 and 60 m. Integrated chl *a* varied from 13.8 to 23.4 mg m$^{-2}$ with the highest concentration again at CB1 and also at CB2.

Ranging from 0.01 to 0.25 mg m$^{-3}$ during WM, its concentration was higher than other seasons. The DCM was at depths of 40-60 m and the integrated concentrations varied from 17.3 to 21.3 mg m$^{-2}$.

During SpIM (range: 0.02-0.44 mg m$^{-3}$), the DCM was at 80 m; deepest in comparison with other seasons. Column concentrations varied from 13.4- to 18.3 mg m$^{-2}$ with the values increasing northwards.

The 0-120 m integrated chl *a* carbon (mg C m$^{-2}$; Fig. 3.9 B) was lower during SUM (518) and SpIM (789) compared to FIM (904) and WM (1023).

*Western Bay*

Chl *a* concentrations ranged from 0.01 to 0.36 mg m$^{-3}$ in the WB during SUM. The DCM was between 20 and 60 m (Fig. 3.10). Integrated chl *a* concentration varied from 12 to 18.7 mg m$^{-2}$, with the highest value observed at WB4 (Fig. 3.11 A).

During FIM, it was in the range of -0.01- 0.77 mg m$^{-3}$. The DCM was between 20 and 40 m. Integrated chl *a* concentration varied between 11.3 and 18.7 mg m$^{-2}$, with higher values at WB1 and WB3.

Ranging from 0.005-0.44 mg m$^{-3}$, its concentration during WM was the maximum at 40 m. Integrated chl *a* concentration varied between 17 and 27 mg m$^{-2}$, with the highest concentration observed at WB2.

During SpIM (range: 0.02-to1.00 mg m$^{-3}$), the DCM was generally at 80 m, again deepest compared to that during other seasons. Column concentrations were varying between 11 and 43 mg m$^{-2}$ with the highest value at WB3.

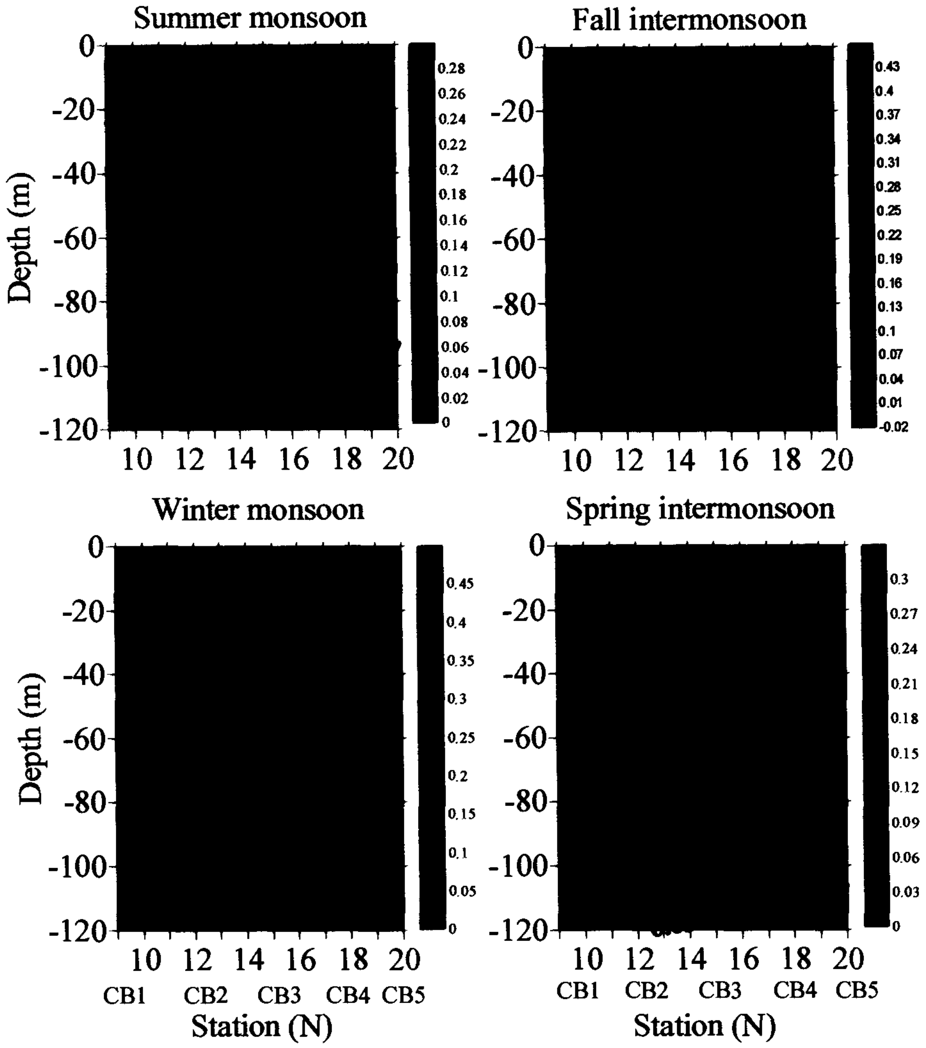


Fig 3.8: Variation of chlorophyll *a* (mg $m^{-3}$) in the upper 120 m of the central Bay during different seasons

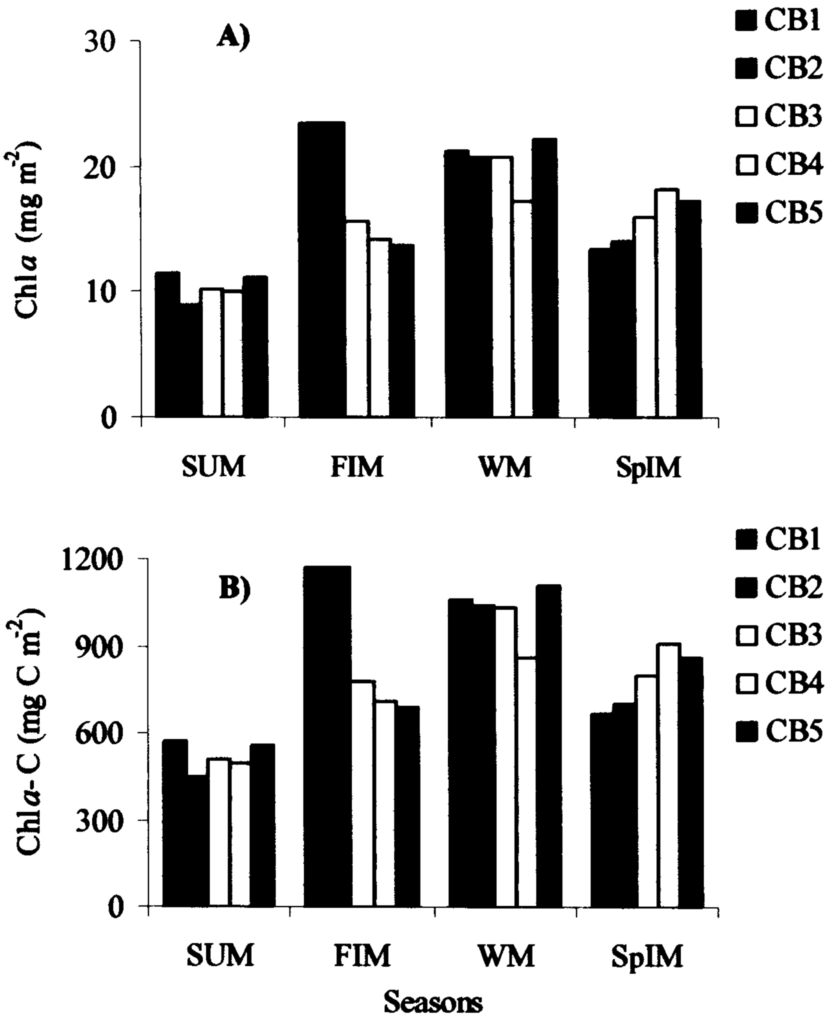


Fig. 3.9. Surface -120 m column integrated chlorophyll *a* (Chl *a*; A) and chlorophyll *a* carbon (Chl *a*-C; B) along central Bay during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM)

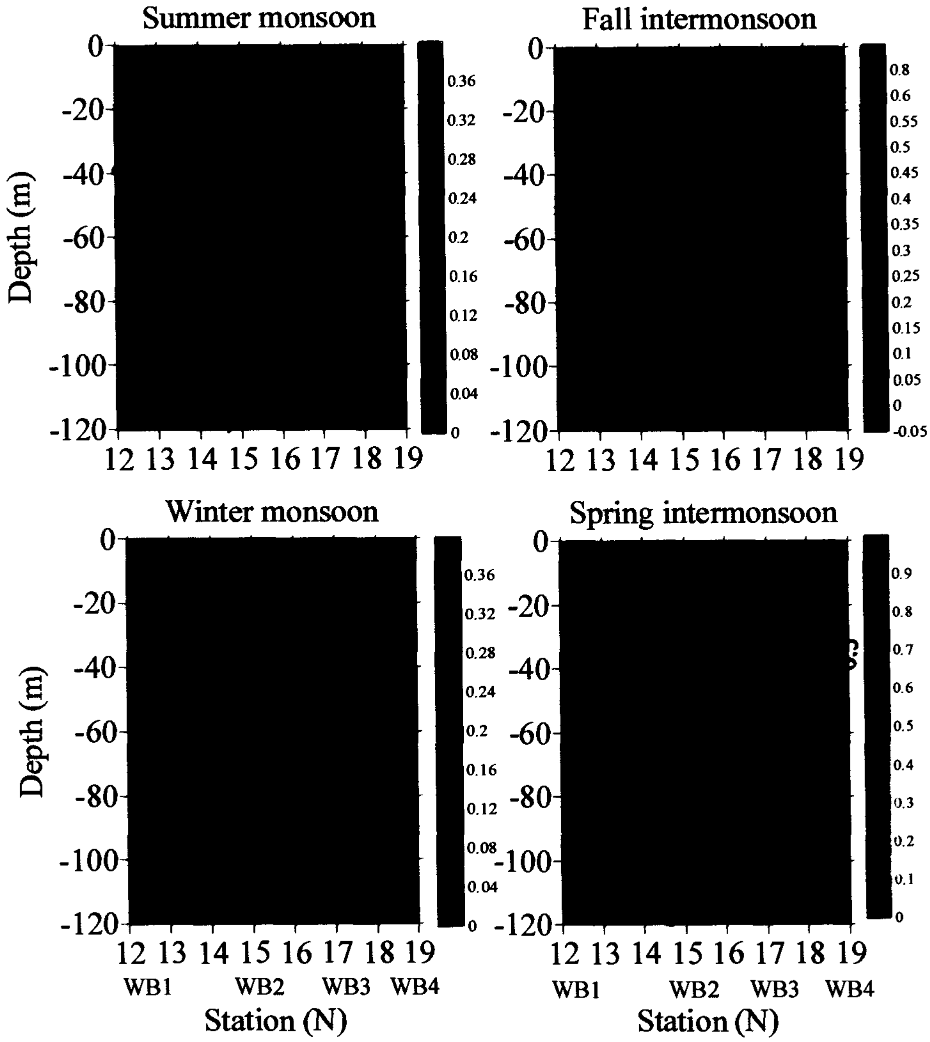


Fig 3.10: Variation of chlorophyll *a* (mg m$^{-3}$) in the upper 120 m of the western Bay during different seasons

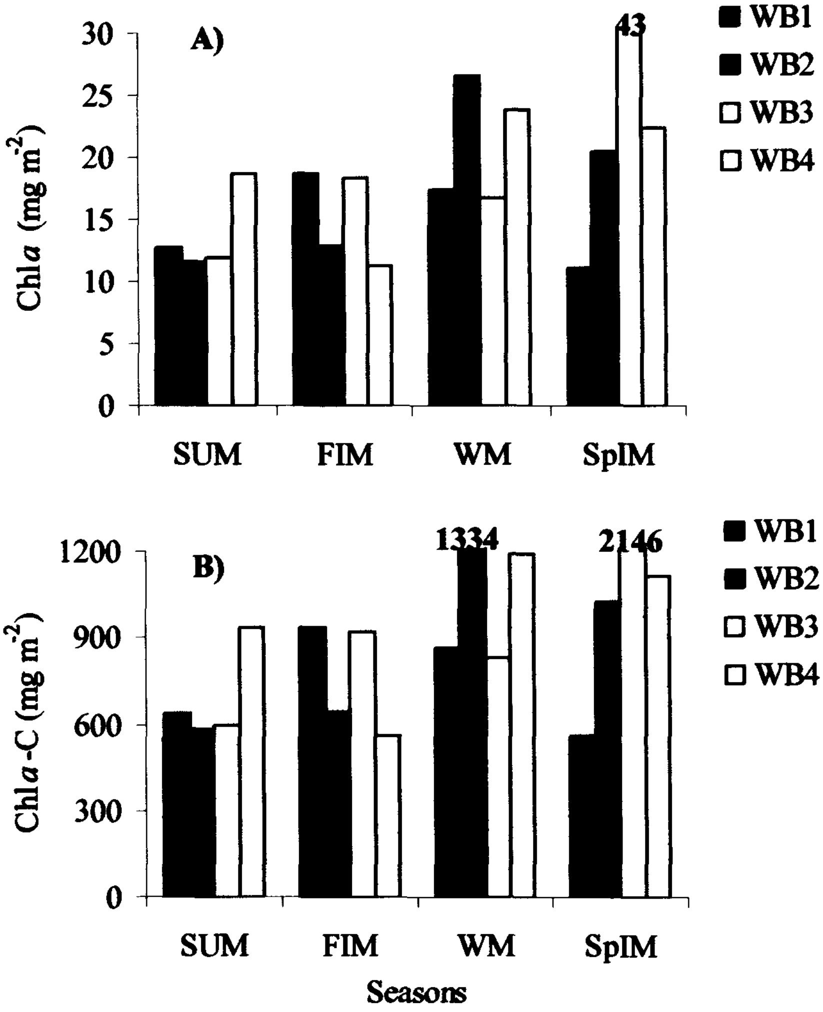


Fig. 3.11. Surface -120 m column integrated chlorophyll *a* (Chl *a*; A) and chlorophyll *a* carbon (Chl *a*-C; B) along western Bay during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM)

The 0-120 m integrated chl *a* carbon (mg C $m^{-2}$; Fig 3.11B) increased from SUM (688), FIM (767), WM (1057) to SpIM (1212).

### 3.2.6. Statistical analyses

There was no significant difference in the SST and SSS between stations in the CB as well as in the WB. Between seasons, only SST varied significantly along both transects (Table 3.4). Dissolved oxygen varied significantly with depths and stations in the CB (Table 3.5 CB). In the WB, although the DO decreased significantly with depth in all seasons, its variation between stations during FIM and WM was not significant (Table 3.5 WB). Also there was no significant difference in the DO concentrations between seasons or between CB and WB.

The chl *a* varying significantly between seasons in the CB also varied significantly with depth. However, between stations, a significant difference was observed only during FIM (Table 3.6 CB). In the WB, there was no significant difference in the chl *a* between depths during SUM and SpIM. During SpIM, a significantly higher proportion of chl *a* was observed in the DCM at WB3. In all other seasons, the difference between stations was statistically insignificant (Table 3.6 WB).

Nutrients ($NO_3$, $PO_4$, $SiO_4$) varied significantly with depth in all seasons in the CB. Nitrate varied significantly between stations only during FIM. Between stations, $PO_4$ and $SiO_4$ were significantly different during all seasons except during WM. However, between seasons, only $PO_4$ varied significantly (Table 3.7 CB). In WB, all the nutrients varied significantly with depths and stations. However, between seasons, this difference was significant only in case of $PO_4$ and $SiO_3$ (Table 3.7 WB).

## 3.3. Discussion

The hydrography of the typically tropical ocean basin, the Bay of Bengal, is influenced by semi-annually reversing monsoon wind system. During SUM, the strong (10 m $s^{-1}$) southwesterly winds bring humid maritime air from Southwest Indian Ocean into the Bay of Bengal. In contrast, during WM, the weak northeasterly winds (5 m $s^{-1}$) bring in cool and dry continental air from the Asian landmass to the Bay of Bengal (http://en.wikipedia.org/wiki/Monsoon). The surface circulation within the basin reverses

Table 3.4. One-way ANOVA for understanding the spatio-temporal variation in sea surface temperature (SST) and sea surface salinity (SSS) in the central (CB) and western Bay (WB)

| | Groups | SST | SSS |
|---|---|---|---|
| CB | Between stations | $F_{(4,19)}=0.5, p>0.05$ | $F_{(4,19)}=2.25, p>0.05$ |
| | Between seasons | $F_{(3,19)}=9.7$, **$p<0.001$** | $F_{(3,19)}=0.9, p>0.05$ |
| WB | Between stations | $F_{(3,15)}=0.1, p>0.05$ | $F_{(3,15)}=1.1, p>0.05$ |
| | Between seasons | $F_{(3,15)}=54.9$, **$p<0.001$** | $F_{(3,15)}=3.0, p>0.05$ |

Significant results are marked **bold**

Table 3.5. One-way ANOVA (between seasons) and two-way ANOVA (between depths and also stations) for understanding the spatio-temporal variation in dissolved oxygen concentration in the top 1000 m in the central and western Bay during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM)

| Groups | ANOVA | |
|---|---|---|
| | **Central Bay** | |
| | SUM | FIM |
| Between depths | $F_{(14,74)}=57.6$, **$p<0.001$** | $F_{(13,69)}=43.7$, **$p<0.001$** |
| Between stations | $F_{(14,74)}=57.6$, **$p<0.001$** | $F_{(4,69)}=8.5$, **$p<0.001$** |
| | WM | SpIM |
| Between depths | $F_{(13,69)}=73.7$, **$p<0.001$** | $F_{(14,74)}=80.9$, **$p<0.001$** |
| Between stations | $F_{(4,69)}=4.0$, **$p<0.05$** | $F_{(4,74)}=2.5$, **$p<0.05$** |
| Between seasons | $F_{(3,302)}=1.4, p>0.05$ | |
| | **Western Bay** | |
| | SUM | FIM |
| Between depths | $F_{(13,55)}=37.6$, **$p<0.001$** | $F_{(13,55)}=61.1$, **$p<0.001$** |
| Between stations | $F_{(3,55)}=4.5$, **$p<0.05$** | $F_{(3,55)}=1.4, p>0.05$ |
| | WM | SpIM |
| Between depths | $F_{(13,55)}=53.4$, **$p<0.001$** | $F_{(13,41)}=9.0$, **$p<0.001$** |
| Between stations | $F_{(3,55)}=1.7, p>0.05$ | $F_{(2,41)}=7.2$, **$p<0.05$** |
| Between seasons | $F_{(3,241)}=0.9, p>0.05$ | |
| Between transects | $F_{(1,153)}=0.3, p>0.05$ | |

Significant results are marked **bold**

Table 3.6. One-way ANOVA (between seasons) and two-way ANOVA (between depths and also stations) to decipher the spatio-temporal variations in chlorophyll *a* concentration in the central and western Bay during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM)

| **Groups** | **ANOVA** | |
|---|---|---|
| | **Central Bay** | |
| | SUM | FIM |
| Between depths | $F_{(7, 39)}=5.9$, **$p<0.001$** | $F_{(7, 39)}=14.3$, **$p<0.001$** |
| Between stations | $F_{(4, 39)}=1.1$, $p>0.05$ | $F_{(4, 39)}=4.2$, **$p<0.05$** |
| | WM | SpIM |
| Between depths | $F_{(7, 39)}=12.3$, **$p<0.001$** | $F_{(7, 39)}=13.2$, **$p<0.001$** |
| Between stations | $F_{(4, 39)}=0.5$, $p>0.05$ | $F_{(4, 39)}=1.52$, $p>0.05$ |
| Between seasons | $F_{(3, 156)}=3.2$, **$p<0.05$** | |
| | **Western Bay** | |
| | SUM | FIM |
| Between depths | $F_{(7, 31)}=1.9$, $p>0.05$ | $F_{(7, 31)}=4.3$, **$p<0.05$** |
| Between stations | $F_{(3, 31)}=1.2$, $p>0.05$ | $F_{(3, 31)}=1.6$, $p>0.05$ |
| | WM | SpIM |
| Between depths | $F_{(6, 27)}=14.4$, **$p<0.001$** | $F_{(7, 31)}=1.7$, $p>0.05$ |
| Between stations | $F_{(3, 27)}=3.5$, **$p<0.05$** | $F_{(3, 31)}=2.1$, $p>0.05$ |
| Between seasons | $F_{(3, 120)}=1.2$, $p>0.05$ | |
| Between transects | $F_{(1, 305)}=0.6$, $p>0.05$ | |

Significant results are marked **bold**

Table 3.7. One-way ANOVA (between seasons) and two-way ANOVA (between depths and also stations) to decipher the spatio-temporal variation in nutrient (Nitrate; $NO_3$, Phosphate: $PO_4$, Silicate: $SiO_3$) concentration in the central and western Bay of Bengal during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM)

| Parameter | Groups | SUM | FIM | WM | SpIM |
|---|---|---|---|---|---|
| | | | **Central Bay** | | |
| $NO_3$ | Depths | $F_{(7,39)}=71$, **$p<0.01$** | $F_{(7,39)}=48$, **$p<0.01$** | $F_{(7,39)}=51.9$, **$p<0.01$** | $F_{(7,39)}=44.8$, **$p<0.01$** |
| | Stations | $F_{(4,39)}=2.5$, $p>0.05$ | $F_{(4,39)}=5.2$, **$p<0.01$** | $F_{(4,39)}=2.3$, $p>0.05$ | $F_{(4,39)}=2.3$, $p>0.05$ |
| | Seasons | $F_{(3,159)}=1.5$, $p>0.05$ | | | |
| $PO_4$ | Depths | $F_{(7,39)}=13.1$, **$p<0.01$** | $F_{(7,39)}=34.4$, **$p<0.01$** | $F_{(7,39)}=21.7$, **$p<0.01$** | $F_{(7,39)}=45$, **$p<0.01$** |
| | Stations | $F_{(4,39)}=5.2$, **$p<0.01$** | $F_{(4,39)}=8.7$, **$p<0.01$** | $F_{(4,39)}=1.0$, $p>0.05$ | $F_{(4,39)}=3.5$, $p>0.05$ |
| | Seasons | $F_{(3,159)}=3.8$, **$p<0.05$** | | | |
| $SiO_4$ | Depths | $F_{(7,39)}=31$, **$p<0.01$** | $F_{(7,39)}=49$, **$p<0.01$** | $F_{(7,39)}=60.8$, **$p<0.01$** | $F_{(7,39)}=47$, **$p<0.01$** |
| | Stations | $F_{(4,39)}=5$, **$p<0.01$** | $F_{(4,39)}=12$, **$p<0.01$** | $F_{(4,39)}=0.5$, $p>0.05$ | $F_{(4,39)}=39$, **$p<0.01$** |
| | Seasons | $F_{(3,159)}=1.7$, $p>0.05$ | | | |
| | | | **Western Bay** | | |
| $NO_3$ | Depths | $F_{(7,31)}=31$, **$p<0.01$** | $F_{(7,31)}=88.7$, **$p<0.01$** | $F_{(7,31)}=21.8$, **$p<0.01$** | $F_{(7,31)}=14.7$, **$p<0.01$** |
| | Stations | $F_{(3,31)}=5$, **$p<0.01$** | $F_{(3,31)}=3.7$, **$p<0.05$** | $F_{(3,31)}=5$, **$p<0.01$** | $F_{(3,31)}=8$, **$p<0.01$** |
| | Seasons | $F_{(3,127)}=0.5$, $p>0.05$ | | | |
| $PO_4$ | Depths | $F_{(7,31)}=21$, **$p<0.01$** | $F_{(7,31)}=44$, **$p<0.01$** | $F_{(7,31)}=24$, **$p<0.01$** | $F_{(7,31)}=11.6$, **$p<0.01$** |
| | Stations | $F_{(3,31)}=7$, **$p<0.01$** | $F_{(3,31)}=25.4$, **$p<0.01$** | $F_{(3,31)}=5.4$, **$p<0.01$** | $F_{(3,31)}=11.8$, **$p<0.01$** |
| | Seasons | $F_{(3\ 127)}=4.7$, **$p<0.01$** | | | |
| $SiO_4$ | Depths | $F_{(7,31)}=19$, **$p<0.01$** | $F_{(7,31)}=63$, **$p<0.01$** | $F_{(7,31)}=8$, **$p<0.01$** | $F_{(7,31)}=15$, **$p<0.01$** |
| | Stations | $F_{(3,31)}=5.3$, **$p<0.01$** | $F_{(3,31)}=5$, **$p<0.01$** | $F_{(3,31)}=4.4$, **$p<0.01$** | $F_{(7,31)}=7.3$, **$p<0.01$** |
| | Seasons | $F_{(3,127)}=3.5$, **$p<005$** | | | |

Significant results are marked **bold**

semi-annually, in accordance with the wind reversal. During SUM, the Summer Monsoon Current advects warm, high-salinity water mass at shallower depths (40-100 m) from the Arabian Sea into the southwestern CB up to 14°N (Sastry et al. 1985; Murty et al. 1992). The East India Coastal Current (EICC) along the western boundary weakens and even reverses in the northern part to a southward flow (Shetye et al. 1991). The open-ocean circulation at this time of the year consists of multiple gyres, re-circulations, meanders and eddies.

During FIM, the EICC reverses completely, flowing towards the south carrying BoB low-salinity water almost along the entire coast, forming a part of the cyclonic gyre. The southward EICC peaks in December and decays in January, completing its annual cycle. By end of February (WM), EICC again reverses carrying the Arabian Sea high-salinity waters towards north. EICC peaks during March–April (spring intermonsoon), when the winds are weak (Shetye et al. 1993) and the open-ocean circulation during this period is anticyclonic.

The estimated freshwater influxes into the BOB from local precipitation and through river discharge are 4700 and 3000 $km^3 yr^{-1}$ respectively. Ganges, Brahmaputra, Mahanadi and Irrawady are the major rivers that discharge in the head Bay whereas Godavari, Krishna and Pennar along the WB. The loss due to evaporation is ~ 3600 $km^3 yr^{-1}$. Thus, on an annual scale, freshwater input exceeds the loss due to evaporation substantially (Rajamani et al. 2006). This tends to make the water of the BOB relatively less saline compared to the rest of the Indian Ocean (Wyrtki 1971). The salinity (~24-33 psu) in the top ~10–20 m layer decreases from south to north (Gallagher 1966). The top ~30 m layer is highly stratified and cannot be eroded by the weaker winds that prevail over the Bay (Shenoi et al. 2002). Below this low-salinity water mass, three water masses can be identified in the Bay of Bengal, which include the layer between 50-200 m characterized by Arabian Sea high-salinity water mass in the southern central Bay. The layer between 200-600 m is the Bay of Bengal subsurface water mass (Salinity 34.9 to 35.05). Below 600 m, where salinity decreases gradually to lower values (<35.0) at deeper depths is identified as the Indian equatorial intermediate water (Gallagher 1966).

During the study period that covered different seasons, most of the Bay remained a warm pool as SSTs were ≥28°C. Being land-locked in the north and in the absence of wind-induced upwelling, pole ward transport of the surface heat is restricted, thereby giving rise to Bay of Bengal warm pool (Vinayachandran and Shetye 1991). While the SpIM SSTs were the highest (≥30°C), the lowest were during winter, mostly in the WB. Inspite of low SST in the north, winter cooling during WM did not lead to convective mixing. As reported by many authors (Prasannakumar and Prasad 1996; Madhupratap et al. 1996 b; Jyothibabu et al. 2004), the intense stratification by freshwater that hardly changes with seasons in the Bay, prevents such mixing. The thermal structures obtained from the *in situ* hydrographic measurements clearly indicated the presence of cyclonic eddies (cold-core) by way of doming isopleths/thermocline oscillation, in the CB and WB during both monsoons (Prasannakumar et al. 2004) as well as intermonsoons (Prasannakumar et al. 2007).

Mixed layer depths (MLD) varied seasonally between CB1 and CB3. They were deeper during the SUM and WM owing to higher wind forcing in addition to intrusion of Arabian Sea high salinity water, in particular during SUM. The shallower MLDs during intermonsoons were due to light winds, and primary/secondary solar heating. Surprisingly at CB1, where cold-core eddy was present, the MLD was relatively shallower. North of CB3, MLD was mostly shallower due to the increased stability caused by perennial fresh water capping (Narvekar and Prasannakumar 2006).

Oxygen distribution is generally governed by physical processes like atmospheric interaction, fresh water influx, upwelling, water mass transport and, biological processes like photosynthesis and respiration. The seasonal variability and distribution of dissolved oxygen in the surface layer in the Bay of Bengal appears to be significantly influenced by physical processes like eddies and water circulation in the intermediate and deeper layers (Sardessai et al. 2007). The pronounced OMZ at depths between 100 and 700 m is typical of the northern Indian Ocean. As explained by Naqvi (2006), the presence of Asian landmass restricts adequate ventilation of the thermocline from the north. To a smaller extent, a porous eastern boundary (openings between the Indonesian islands), also facilitates exchange of water with the Pacific Ocean.

Although large influx of freshwater adds biogenic matter to the Bay (Khodse et al. 2007) along with the mineral particles, the biological demand for oxygen does not lead to anoxic or oxygen depleted conditions as is prevalent in the Arabian Sea (De Sousa et al.

1996; Naqvi et al. 2000). Ittekkot et al. (1991) through their study of particle fluxes using sediment traps estimate 40-50% of the total annual flux to occur during the SUM, probably leading to a larger OMZ compared to the other seasons. This zone was thicker in the WB due to the higher remineralization rates (Sardessai et al. 2007) observed in this season. However, the seasonal variations in the overall oxygen concentrations in the CB as well as WB are insignificant.

In the CB, in the region of eddies, high concentrations of chl *a* was observed in response to the enhanced levels of nitrate and silicate, more significantly during fall intermonsoon. Cyclonic eddies cause upward displacement of nutricline therefore making the essential nutrients available into the impoverished euphotic zone, thus enhancing chl *a* concentrations (Falkowski et al. 1991; McGillicuddy et al. 1998; Seki et al. 2001; Vaillancourt et al. 2003). The average concentrations of surface and column integrated chl *a* were similar to those reported from offshore waters by Madhu et al. (2006) and Gomes et al. (2000). The DCM seated between 40 and 80 m, deepest during SpIM, reflect oligotrophy (intense solar heating, stratified upper layer and weak winds) in the Bay during all the sampled seasons. The occurrence of DCM in the nitracline is essential feature of the typical tropical structure in the Atlantic (Herbland and Voituriez 1979) and in the Arabian Sea (Madhupratap et al. 1996 a). Eddy-pumping of nutrients not only helps increase the chl *a* concentrations to >1.5 times but also pushes the DCM to shallower depths as can be discerned at ~CB1 and CB4/5. The 0-120 m column integrated chl *a* and PP were maximum during WM and minimum during SUM, probably due to the higher suspended particulate matter (0.2-15 mg $l^{-1}$; Sardessai et al. 2007) and persistent cloud cover during the latter season (Madhupratap et al. 2003). Also the top 40 m was impoverished of nutrients during SUM except in the region of eddies.

In the WB, enhanced chl *a* was observed between WB3 and WB4 and, to an extent, at WB1. The higher phytoplankton biomass production in the northern region appears to be due to combined effect of nutrient input from cold-core eddy and riverine source albeit the input from latter is very meager. Unlike in the open ocean, the column integrated chl *a* in this transect was maximum during SpIM. Sengupta et al. (1977) reported that rivers did not contribute to the inorganic nutrient pool of the western BoB during SpIM. Contrary to this, high nutrient concentrations were observed in the upper 40 m at all the stations in the WB during this season. Also, it appears that the cold-core eddy and the deep-seated nutrients enhanced the chl *a* concentration in the deeper DCM to more than double. The chl *a* minimum during SUM could be related to the high-suspended matter and stratified upper waters (temperature: ≥30°C, salinity: 23-33 psu).

Seasonal variations in chl *a* were associated with the seasonally changing hydrographical and meteorological conditions. Differences were also evident between transects, with the central transect becoming more productive in phytoplankton biomass during winter monsoon, compared to the western transect which is most productive during SpIM. Cold-core eddies at CB1, CB4/5 and WB3 seem to govern the overall productivity of the Bay. Though the subsurface oxygen minimum zone is the largest during SUM, especially in the WB, there is no prevalence of anoxia (<0.5 μM) during any season.

# Chapter 4

# Chapter 4

## *Different Groups of Mesozooplankton from Central Bay*

Hydrographic settings in the Bay of Bengal are influenced by reversing surface currents and freshening of the top layers. For instance, the surface flows are different during Southwest and Northeast monsoons. Further, the freshening caused by excess precipitation (~2 m $yr^{-1}$; Prasad 1997) and by rivers discharging into the Bay stratifies the upper 50 m column. The monsoon winds and stratification produce dramatic changes in upper-ocean circulation, biological productivity and mesozooplankton abundance. During summer monsoon (May-September), the Summer Monsoon Current (SMC) flows eastward south of India, turns around Sri Lanka, and enters the Bay of Bengal. Confined to the upper 200 m in the southern part of the central Bay during the onset of summer monsoon, SMC transports Arabian Sea high-salinity water into the Bay (Wyrtki 1971; Murty et al. 1992; Gopalakrishna et al. 1996; Han and McCreary 2001; Vinayachandran et al. 1999). During winter monsoon (November–February), the Winter Monsoon Current (WMC) flows westward, even south of Sri Lanka carrying low-salinity water (Bay of Bengal Water) into the eastern Arabian Sea. Though no open ocean upwelling seems to occur in the Bay, many cold-core eddies are reported to enhance chlorophyll *a* concentration and primary productivity (Prasannakumar et al. 2004, 2007). Increased biovolumes of mesozooplankton in such eddy regions are observed in the Bay (Muraleedharan et al. 2007).

Seasonal variability in zooplankton biomass and composition has been deciphered from the data collected during the International Indian Ocean Expedition (IIOE; Currie 1963; IIOE Plankton Atlas 1968, 1970 a, 1970 b). In the IIOE survey, mesozooplankton biomass showed an increase in the Arabian Sea, especially off the coasts of Oman and Somalia, during summer monsoon (SUM; July–September) compared with March–April, May–June, October–November, and December–February (Rao 1973). In the region off Oman from 15° to 20°N, average zooplankton volumes (IIOE Plankton Atlas, 1968) were about two times higher during the Southwest monsoon periods (40–60 ml) than during the Northeast monsoon ones (20–30 ml). Using the conversion equations of Wiebe et al.

(1975), this would correspond to average dry weights of 11-18 and 5-8 g, respectively. Off Somalia, Smith (1982) also found that zooplankton stocks varied with monsoon reversal. Zooplankton stocks during the upwelling period of the Southwest monsoon ranged from 0.8–7.0 g dry weight $m^{-2}$. There are indications that the currents associated with the Somali upwelling area are so swift that mesozooplankton is advected into the central Arabian Sea before achieving the biomass that could be supported by the upwelled nutrients if the Somali area had a less vigorous circulation (Baars 1999; Baars and Oosterhuis 1998; Hitchcock et al. 2002). High zooplankton standing stocks in the mixed layer are known to occur in the central Arabian Sea irrespective of seasons (Madhupratap et al. 1996 a) due to open ocean upwelling during SUM, convective mixing during winter and/or through the microbial loop during the intermonsoon. Many studies on the seasonal cycles of mesozooplankton are available for the Arabian Sea (Madhupratap et al. 1996 a, b; Wishner et al. 1998; Smith 1982, 1998, 1999, 2000, 2001; Smith et al. 1998; Stelfox et al. 1999; Hitchcock et al. 2002; Koppelmann et al. 2005; Smith and Madhupratap 2005).

Zoogeographic aspects of many groups and species in the Indian Ocean have been published (UNESCO 1965-72; IOBC Atlas and Handbook 1-5, 1968-73; Zeitzschel 1973). Later studies by Nair et al. (1977, 1978) and Peter and Nair (1978) also augment this. Almost all of the zooplankton taxa studied in detail showed patterns of increased abundance during SUM. These included polychaete worms (Peter 1969 a), fish larvae (Peter 1969 b), euthecosome molluscs (Sakthivel 1969), cephalopod juveniles (Aravindakshan and Sakthivel 1973), amphipods (Nair et al. 1973) and euphausiids (Gopalakrishnan and Brinton 1969; Brinton and Gopalakrishnan 1973). Euphausiids have probably been under-sampled in most studies. The IIOE collections contained mainly larvae and immature adults (Gopalakrishnan and Brinton 1969). While zooplankton biomass showed a seasonal increase during the SUM (Rao 1973), the concentration of copepods (total number per volume), the main zooplanktonic taxa, did not (Panikkar 1970). The two other common forms, ostracods (George 1969) and chaetognaths (Nair 1969; Nair and Rao 1973), also did not show marked increases during the SUM season. An upwelling specialized copepod species, *Calanoides carinatus*, was found in the mesopelagic layers of the central Arabian Sea during winter. Diel- (Smith et al. 1998;

Goswami et al. 2000; Jayalakshmy 2000; Madin et al. 2001; Schnetzer and Steinberg 2002 b), depth-wise (Madhupratap et al. 1996 a; Padmavati et al. 1998; Pieper et al. 2001; Koppelmann et al. 2003, 2005) and latitudinal- (Mauny and Dauvin 2002; Gaudy et al. 2003; Kang et al. 2004; Roman et al. 1995; Yamaguchi et al. 2005; Li et al. 2006; Fernandez-Alamo and Farber-Lorda 2006; Alcaraz et al. 2007) variability in zooplankton has been studied in many parts of the world oceans. However, even after the IIOE (1960-1965), the Bay of Bengal still remains one of the sparsely investigated regions of the Indian Ocean especially in terms of zooplankton below 200 m depth from the open ocean region.

Secondary producers, the zooplankton, are the major consumers linking primary production to tertiary production. Thus, they are important contributors of vertical flux of organic matter (Wishner et al. 1998). Knowledge of their abundance and distribution and composition in space and time is important for understanding the carbon budgets and, to decipher the effects of climate change on marine fauna. Keeping the first objective of this study in the fore, the spatial and seasonal differences in mesozooplankton biomass, their numerical abundance, and group composition in the upper 1000 m were studied from five stations in the central Bay during summer monsoon, fall intermonsoon, winter monsoon and spring intermonsoon.

## 4.1. Methods

### 4.1.1. Sampling

Sampling was carried out in the central Bay (CB) between 9°N and 20°N along 88°E (Fig. 3.1) during the cruises 166, 182 and 191 onboard ORV *"Sagar Kanya"* and cruise 240 on ORV "*Sagar Sampada*". The four seasons covered were summer monsoon (SUM, July 6 to August 2, 2001), fall inter monsoon (FIM, September 14 to October 12, 2002), spring inter monsoon (SpIM, April 10 to May 10, 2003) and winter monsoon (WM, November 26 2005 to January 7, 2006). Mesozooplankton samples were collected from five stations. Sample collections were made around noon and midnight at each station by vertical hauls from five discrete depths in the upper 1000 m using a multiple plankton net (MPN-Hydro-Bios, mouth area 0.25 $m^2$, mesh size 200 μm). Sampling strata were decided according to temperature profiles obtained from CTD. The five strata sampled were:

mixed layer, top of thermocline (TT) to base of thermocline (BT), BT - 300 m, 300 - 500 m, and 500 - 1000 m. During SpIM, only the first four strata were sampled due to non-functionality of one net. The net was hauled up at 0.8 m $s^{-1}$ and the volume of water filtered was calculated by multiplying the sampling depth by mouth area of the net. The wire angle was taken into account by the pressure sensors fitted on the MPN.

### 4.1.2. Biovolume measurements

Biovolume (ml) was estimated by the standard displacement volume method (ICES 2000). For this, samples from each stratum were filtered on to a 200-µm mesh-piece; excess water blotted out using a wad of absorbent paper and transferred to a measuring cylinder with known volume of water to determine the volume displaced. Thereafter, the samples were fixed with 4% buffered formaldehyde-seawater solution and brought to the laboratory for further analyses. The conversion factor provided for tropical zooplankton by Madhupratap and Haridas (1990) was used to calculate the dry weight. In that, 1 ml displacement volume is equivalent to 0.075 g dry wt. As also provided by these authors 34.2% of the dry weight was used to calculate gram equivalent of carbon biomass.

### 4.1.3. Numerical abundance

When the sample size was large, usually in the first and second strata, it was split using a Folsom splitter and, in general, 25% aliquots were taken up for enumeration (abundance) and identification. Entire sample was analyzed for enumeration and speciation from other three deeper layers where the volumes were usually small or negligible. All the samples were sorted group-wise and the groups identified by following standard references (UNESCO 1968). A stereo zoom microscope (Zeiss, Germany) with 90X magnification was used for differentiating the groups and, most genera.

### 4.1.4. Statistics

In order to detect variability if any, arising due to day and night differences, biomass, abundance and groups data were subjected to Wilcoxon matched pair test. Friedman ANOVA (non parametric test; Zar 1974; Conover 1980) was carried out to test for variability between depths, stations and seasons. Bray-Curtis similarity indices (Bray-

Curtis 1957) for cluster analysis and non-metric multidimensional scaling (NMDS; Gray et al. 1988) were done to understand similarity in distribution of biovolume and abundance of zooplankton between seasons. Correlation analysis (Excel software program or STATISTICA 6.0) was carried out between zooplankton and the abiotic/biotic parameters to understand the relation between the two.

## 4.2. Results

### 4.2.1. Biovolume

Mesozooplankton biovolume (ml 100 $m^{-3}$) was the highest in the mixed layer (MLD) during all four seasons (Fig. 4.1-4.4; Table 4.1). Diel difference in biovolume from the entire column was not significant except during SUM. Biovolume decreased significantly with increasing depth (Table 4.12). Nearly 95 - 99% of the biovolume during SUM and SpIM was in the MLD. It was mostly negligible below this depth. During FIM and WM, the biovolume in MLD was relatively less *i.e.,* average 73 and 53% respectively.

In the upper 1000 m, biovolume ranged from 0.2 to 404 (mean: 39 ml 100 $m^{-3}$) during SUM, from negligible to 120 (12.7 ml 100 $m^{-3}$) during FIM, 0.3-75 (13.8 ml 100 $m^{-3}$) during WM and 1.3-230 (40.4 ml 100 $m^{-3}$) during SpIM. *Pyrosoma* swarms and scyphomedusae contributed to the higher biovolumes during SUM and SpIM respectively. The average biovolumes for the upper 1000 m were higher during SUM and SpIM compared to either FIM and/or WM. Seasonal differences in the biovolumes were highly significant (Table 4.12). The biovolumes were greater at CB1 and CB5 during SUM; at CB1 and CB4 during FIM; at CB5 during WM and; at CB3 and CB4 during SpIM. This heterogeneity in biovolume distribution between stations was however significant only during FIM.

Though higher biovolumes were recorded at locations in the vicinities of cold-core eddies, negative correlation between biovolume and temperature was observed only during SUM and WM (Table 4.13). It had a good positive correlation with chlorophyll (chl) *a* during all seasons, however was significant during FIM and SpIM.

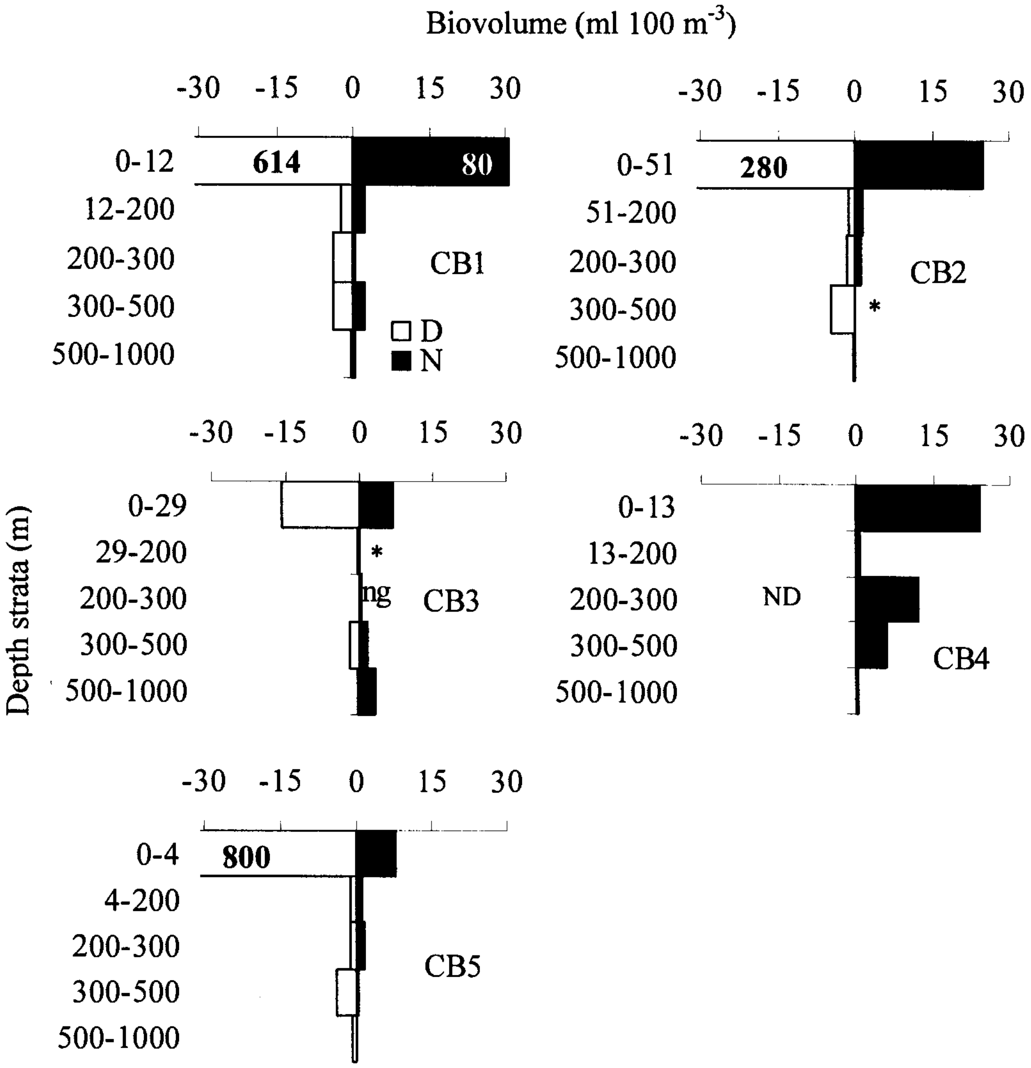


Figure 4.1. Vertical distribution of mesozooplankton biovolume during day and night sampling at different stations in the central Bay during summer monsoon. *indicates *Pyrosoma* swarms; ng: negligible biovolume; ND: No data

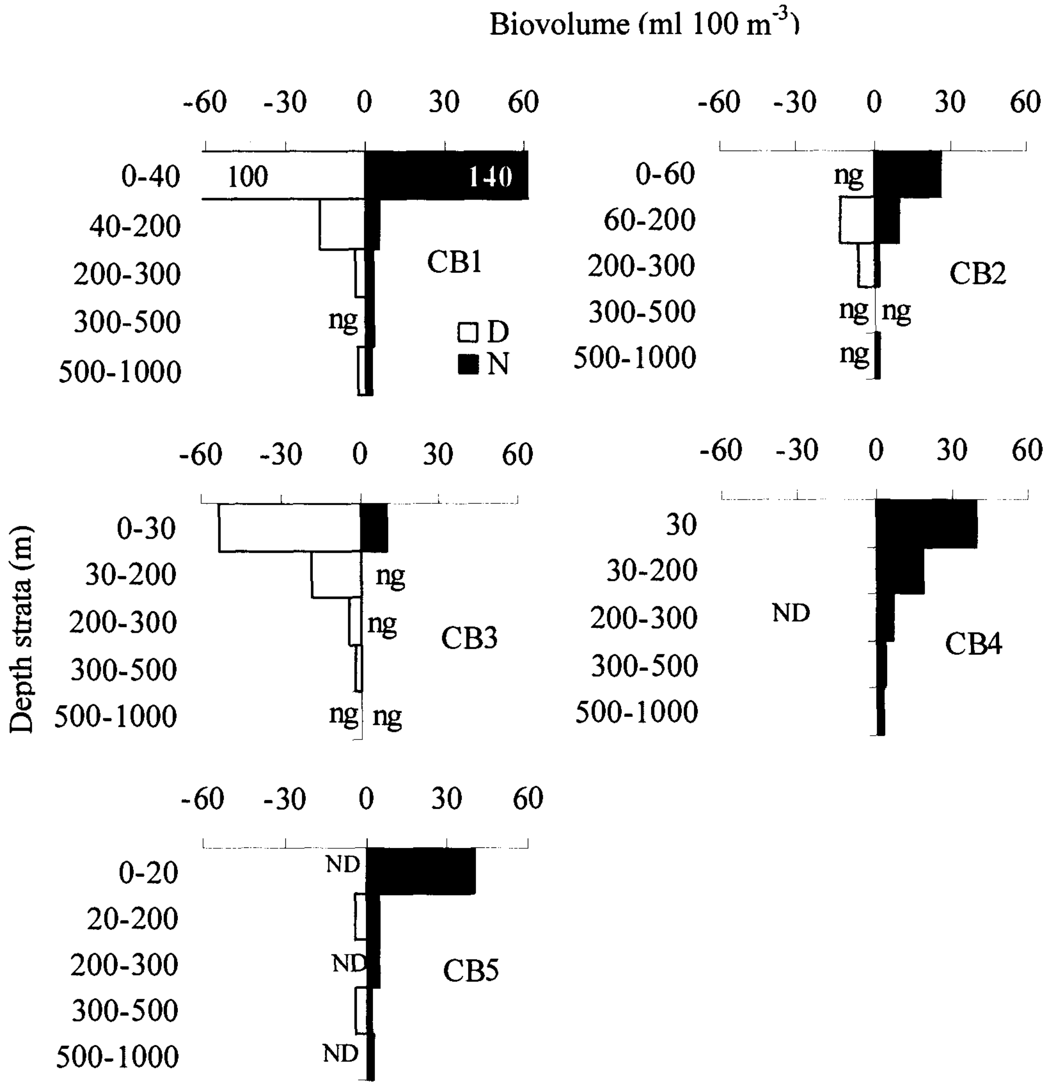


Figure 4.2. Vertical distribution of mesozooplankton biovolume during day and night sampling at different stations in the central Bay during fall intermonsoon. ng: negligible biovolume; ND: No data

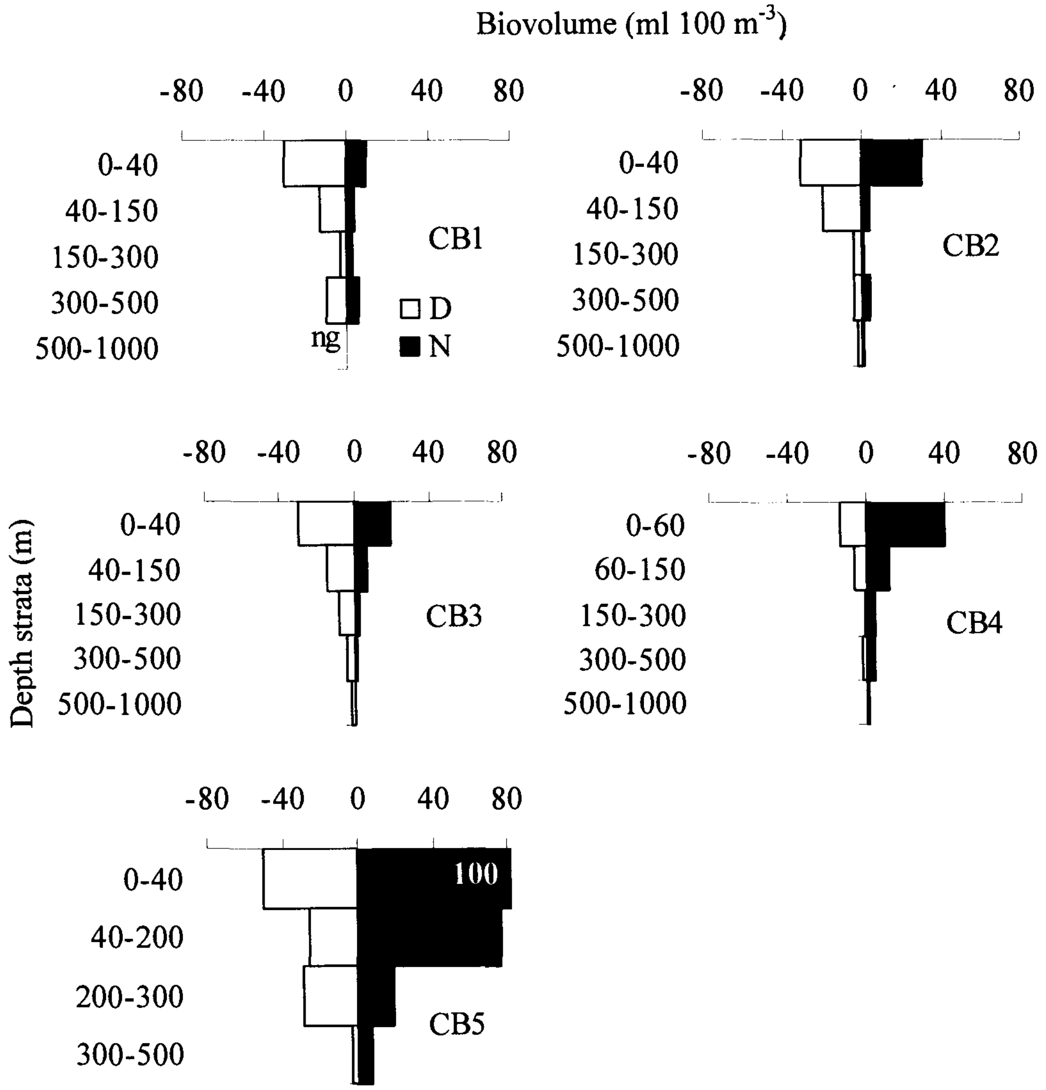


Figure 4.3. Vertical distribution of mesozooplankton biovolume during day and night sampling at different stations in the central Bay during winter monsoon. ng: negligible biovolume

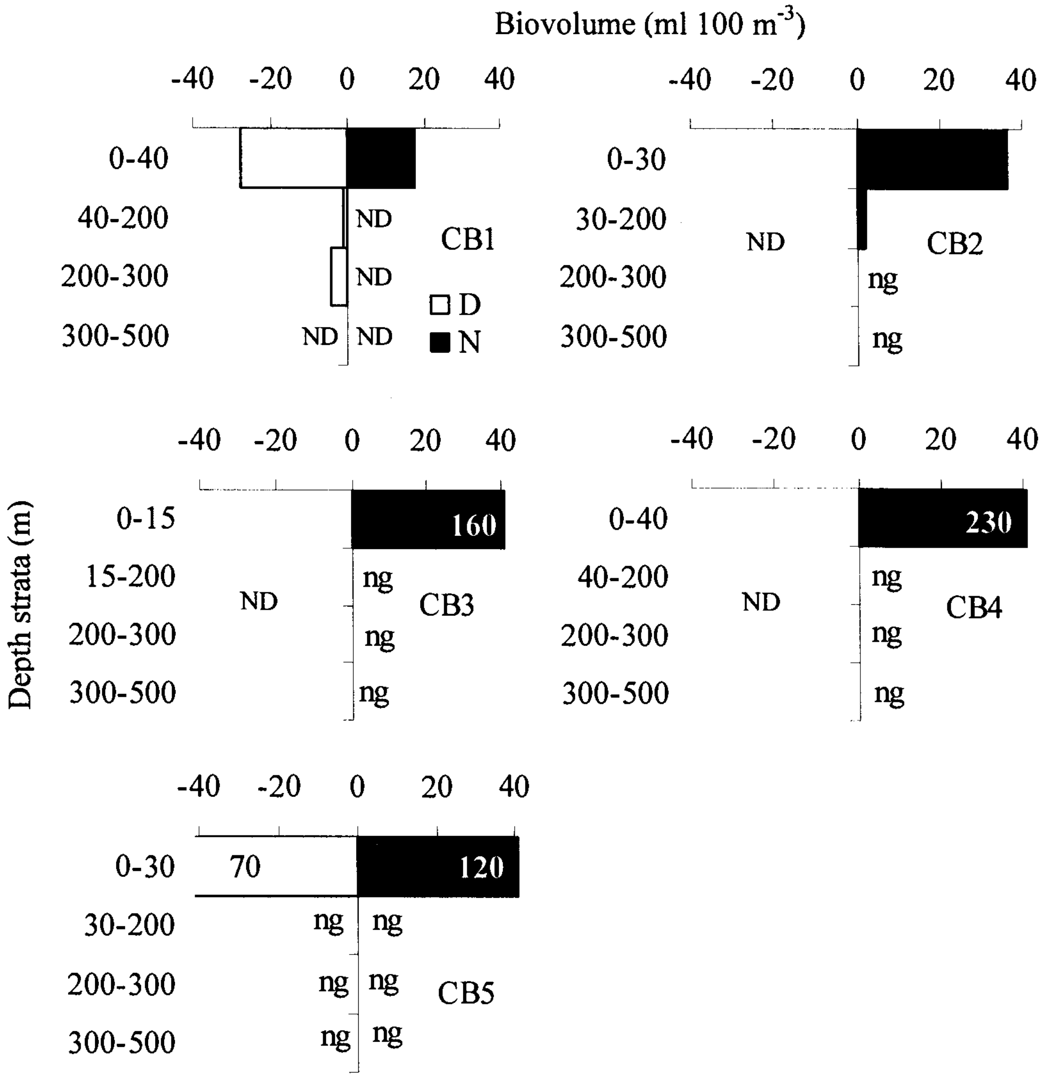


Figure 4.4. Vertical distribution of mesozooplankton biovolume during day and night sampling at different stations in the central Bay during spring intermonsoon. ng: negligible biovolume; ND: No data

Table 4.1. Mesozooplankton biovolume (ml 100 $m^{-3}$) and carbon biomass (mM C $m^{-2}$; in parentheses) in the central Bay of Bengal during different seasons

| | **Sampling Stations** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Depth (m)** | **CB1** | | **CB2** | | **CB3** | | **CB4** | | **CB5** | |
| **Summer monsoon** | | | | | | | | | | |
| 0-MLD | *347.2 | (65.9) | *152.5 | (38.1) | 11.4 | (10.7) | 24.0 | (25.7) | *404 | (89.8 |
| TT-BT | 2.3 | (8.5) | 1.4 | (3.8) | 0.4 | (1.1) | 0.7 | (2.2) | 1.3 | (3.8) |
| BT-300 | 2.3 | (4.8) | 1.4 | (2.9) | 0.4 | (1.2) | 12.0 | (21.4) | 1.5 | (3.3) |
| 300-500 | 3.3 | (13.9) | *4.5 | (19.2) | 1.8 | (7.5) | 6.0 | (25.7) | 2.2 | (9.2) |
| 500-1000 | 0.2 | (2.1) | 0.3 | (2.7) | 1.9 | (20.3) | ng | (ng) | 0.5 | (4.8) |
| **Fall intermonsoon** | | | | | | | | | | |
| 0-MLD | 120.0 | (102.6) | 20.0 | (34.1) | 31.7 | (38.5) | 40.0 | (25.7) | 20.0 | (25.7) |
| TT-BT | 11.3 | (37.6) | 7.9 | (34.9) | 9.6 | (56.3) | 18.8 | (68.3) | 4.6 | (17.0) |
| BT-300 | 3.5 | (7.5) | 1.0 | (8.2) | 2.4 | (8.6) | 7.0 | (15.0) | 2.5 | (10.7) |
| 300-500 | 1.5 | (12.8) | ng | (ng) | 0.6 | (5.1) | 3.5 | (15.0) | 3.0 | (12.8) |
| 500-1000 | 2.8 | (29.9) | 1.6 | (17.1) | 0.6 | (0.0) | 2.8 | (29.9) | 1.2 | (12.8) |
| **Winter monsoon** | | | | | | | | | | |
| 0-MLD | 20.0 | (17.1) | 30.0 | (13.3) | 25.0 | (21.4) | 26.7 | (34.2) | 75.0 | (64.1) |
| TT-BT | 8.2 | (19.2) | 10.9 | (15.4) | 10.9 | (25.7) | 8.9 | (26.6) | 50.9 | (106.4) |
| BT-300 | 2.7 | (5.7) | 2.3 | (7.3) | 5.3 | (17.1) | 2.7 | (7.8) | 24.0 | (32.7) |
| 300-500 | 8.0 | (28.6) | 4.0 | (17.1) | 3.0 | (12.8) | 3.0 | (12.8) | 5.0 | (21.4) |
| 500-1000 | 0.3 | (2.7) | 1.7 | (18.0) | 0.9 | (9.4) | 0.8 | (8.6) | ND | (ND) |
| **Spring intermonsoon** | | | | | | | | | | |
| 0-MLD | 22.5 | (19.2) | 36.6 | (15.6) | 160.0 | (51.3) | 230.0 | (196.7) | 95.0 | (55.6) |
| TT-BT | 1.3 | (2.1) | 2.4 | (8.5) | ng | (ng) | ng | (ng) | ng | (ng) |
| BT-300 | 4.0 | (4.3) | ng | (ng) | ng | (ng) | ng | (ng) | ng | (ng) |
| 300-500 | ng | (ng) | ng | (ng) | ng | (ng) | ng | (ng) | ng | (ng) |

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

*high volumes due to swarms of *Pyrosoma*; ng- negligible biovolume; ND- no data (due to shallower depth at the northern most station)

### 4.2.2. Abundance

Similar to the biovolume distribution, the mesozooplankton abundance (No. x $10^3$ individuals 100 $m^{-3}$) observed was more in the MLD during all seasons (Table 4.2). The diel difference in abundance was also negligible (Table 4.12). However, unlike that of the biovolume, the abundance decreased significantly with increasing depth only during FIM and SpIM. In these two seasons, the abundance in MLD accounted respectively for 87 and 96% of total numbers. During SUM and WM, it accounted for 79 and 66% respectively. The abundance ranged from 0.04 to 35.8 (mean: 7 x $10^3$ ind. 100 $m^{-3}$) during SUM, 0.2 to 356 (29.3 x $10^3$ ind. 100 $m^{-3}$) during FIM, 0.4 to 308 (24.5 x $10^3$ ind. 100 $m^{-3}$) during WM and 0.04 to 248 (28 x $10^3$ ind. 100 $m^{-3}$) during SpIM.

The abundance in the upper 1000 m differed significantly between seasons (Table 4.12), with higher averages during FIM and, SpIM, followed by WM and least during SUM. Station-wise differences in abundance were also noticeable. During SUM, the abundance was higher at CB1, CB2 and CB5. During FIM, it was very high at CB1 followed by CB4. While during WM, it was found to be very high at CB5, during SpIM, it was higher at CB3 and CB5. Higher abundances were at locations in the vicinities of cold-core eddies as is also implicit from the negative correlations with temperature (Table 4.13). It also had strong positive correlation with salinity and chl *a* during FIM.

### 4.2.3. Cluster and non-metric multidimensional scaling analysis (NMDS)

Results from cluster and NMDS analyses imply that during the seasons FIM and WM, the distribution pattern of both biovolume and abundance at depths as well as stations is similar. This differed from other two seasons (Fig. 4.5).

### 4.2.4. Column (1000-surface) integrated carbon biomass and abundance

The abundance during SUM, FIM, WM and SpIM ranged respectively from 6 to 37 (mean: 24 x $10^3$ ind. $m^{-2}$), 33 to 166 (80 x $10^3$ ind. $m^{-2}$), 40 to 223 (88 x $10^3$ ind. $m^{-2}$) and 7 to 50 (33 x $10^3$ ind. $m^{-2}$). Similarly, calculated carbon biomass during these seasons ranged respectively from 95 to 111 (mean: 78 mM C $m^{-2}$); 79 to 190 (112 mM C $m^{-2}$); 71 to 225 (134 mM C $m^{-2}$) and from 24 to 197 (75 mM C $m^{-2}$; Fig. 4.6). Overall, numerical abundance and carbon biomass in the upper 1000 m were higher during WM and FIM.

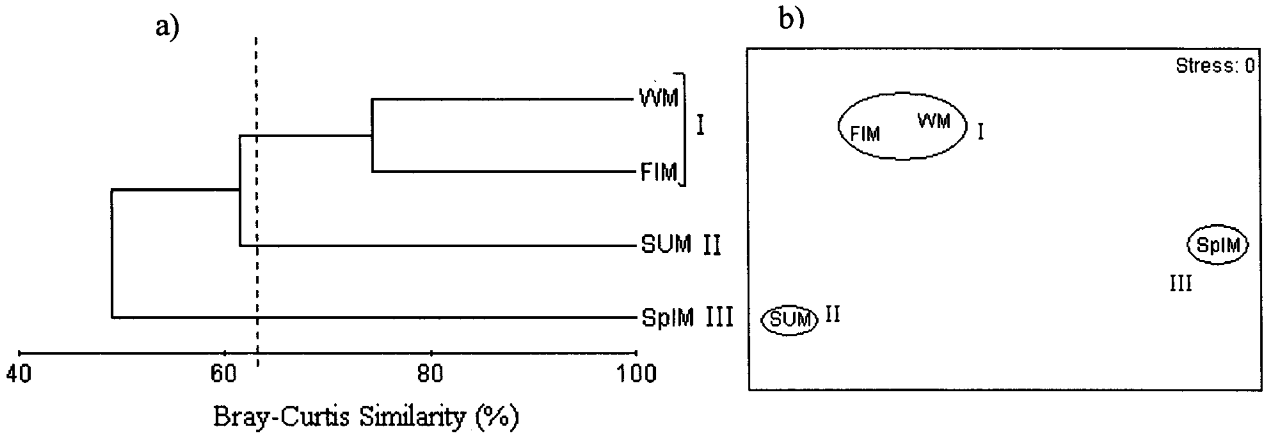
Table 4.2. Mesozooplankton numerical abundance (x $10^3$ individuals 100 $m^{-3}$) in the central Bay of Bengal during different seasons

| | **Sampling stations** | | | | |
|---|---|---|---|---|---|
| **Depth (m)** | **CB1** | **CB2** | **CB3** | **CB4** | **CB5** |
| **Summer monsoon** | | | | | |
| 0-MLD | 35.8 | 35.8 | 5.2 | 19.9 | 34.8 |
| TT-BT | 0.5 | 0.5 | 0.2 | 1.5 | 2.0 |
| BT-300 | 0.3 | 0.3 | 0.2 | 0.2 | 16.7 |
| 300-500 | 0.7 | 5.4 | 2.5 | 3.0 | 0.0 |
| 500-1000 | 0.1 | 0.1 | 0.2 | 0.0 | 1.2 |
| **Fall intermonsoon** | | | | | |
| 0-MLD | 355.9 | 66.1 | 47.9 | 96.5 | 72.1 |
| TT-BT | 8.6 | 18.8 | 8.5 | 26.4 | 7.3 |
| BT-300 | 3.7 | 1.5 | 0.7 | 2.4 | 2.8 |
| 300-500 | 0.7 | 0.2 | 0.7 | 2.2 | 1.8 |
| 500-1000 | 2.0 | 0.5 | 0.8 | 1.9 | 1.1 |
| **Winter monsoon** | | | | | |
| 0-MLD | 16.0 | 12.3 | 26.9 | 27.6 | 308.2 |
| TT-BT | 32.4 | 16.2 | 37.6 | 21.4 | 43.7 |
| BT-300 | 6.0 | 3.4 | 4.4 | 2.0 | 9.4 |
| 300-500 | 5.4 | 4.6 | 1.6 | 1.7 | 5.6 |
| 500-1000 | 0.4 | 0.7 | 0.8 | 0.4 | ND |
| **Spring intermonsoon** | | | | | |
| 0-MLD | 3.8 | 48.3 | 248.0 | 85.7 | 124.5 |
| TT-BT | 0.8 | 6.6 | 0.8 | 0.8 | 0.6 |
| BT-300 | 3.8 | 3.6 | 0.6 | 2.2 | 0.4 |
| 300-500 | ng | 0.3 | 0.1 | 0.4 | ng |

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

Only at one depth in northernmost station, there was no data (ND) due to shallower depth; ng- negligible abundance

Biovolume



Abundance

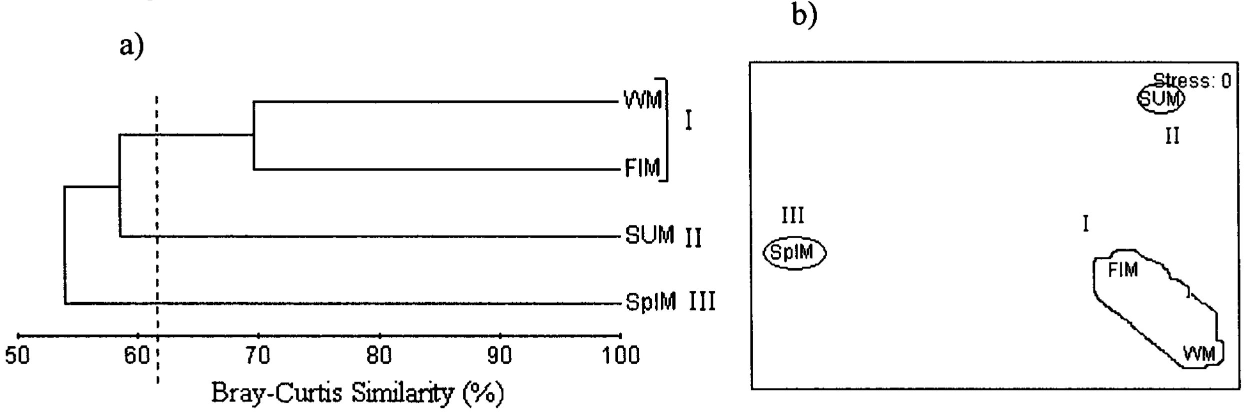


Figure 4.5. a) Cluster dendrograms depicting similarity between seasons based on biovolume and abundance of zooplankton in the central Bay. b) Non- metric multidimensional scaling (NMDS) ordination based on the Bray- Curtis similarity coefficients.

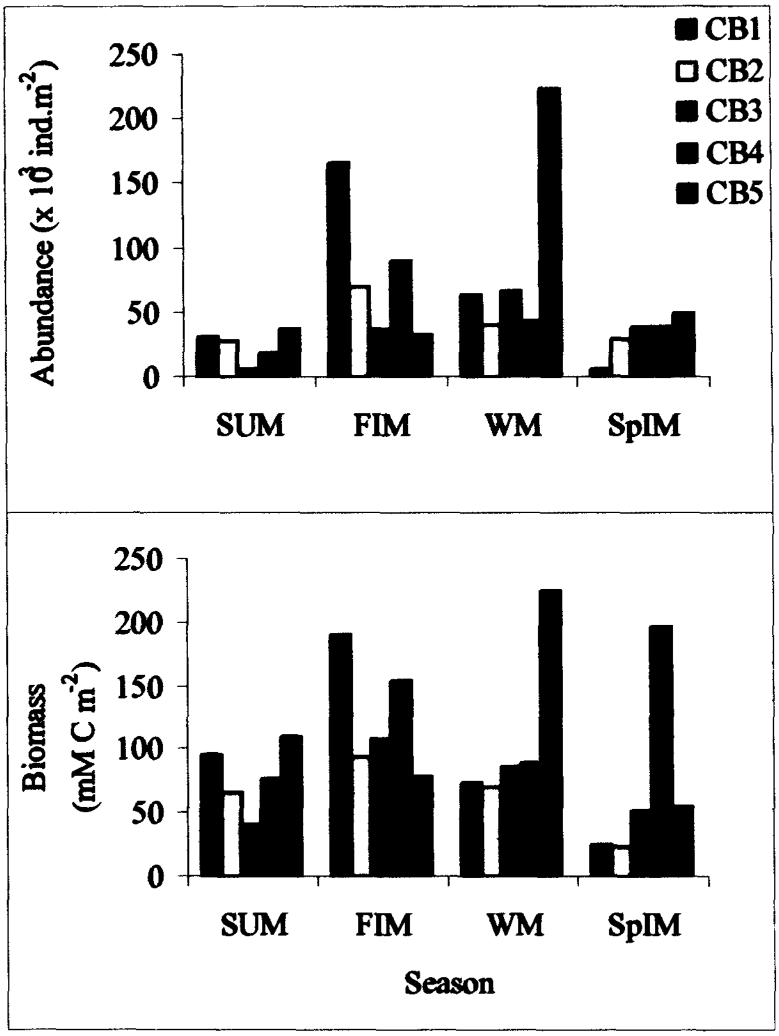


Figure 4.6. Latitudinal variations in the 0-1000 m column integrated mesozooplankton abundance ($10^3$ individuals $m^{-2}$) and biomass in the central Bay during different seasons (SUM: summer monsoon, FIM: fall intermonsoon, WM: winter monsoon; SpIM: spring intermonsoon)

### 4.2.5. Groups

A total of 37 groups were identified from CB (Table 4.3). The number of groups varied significantly between seasons as well as between depths but not between stations (Table 4.14). Of these, 21 groups *viz.* Amphipoda, Appendicularia, Chaetognatha, crustacean nauplii, Copepoda, Decapoda, Doliolida, Euphausiacea, fish larvae, Foraminifera, Gastropoda, invertebrate eggs, Isopoda, Medusae, Mysida, Ostracoda, Polychaeta, Pteropoda, Radiolaria, Salpida and Siphonophora were recorded during all four sampling seasons. As can be seen from Tables 4.4- 4.11, not all groups were recorded from all the stations during any given season.

Cirripedia and Sipuncula were recorded only during SUM. *Pyrosoma* swarms in MLD and in deeper depths contributed much of the biomass during SUM. Only a few of its colonies were observed during WM. Anthozoa and Pterotrachea were observed only during FIM. Echinoderm larvae were in large numbers during WM. Carinaria was rare, that too was found only during SpIM. Acantharia was observed during WM and SpIM. Members of Ctenophora and Stomatopoda were present during all seasons except SpIM.

The least numbers of groups were recorded during SpIM and, the highest during WM. As many as eight groups *i.e.*, Acantharia, Anthozoa, Bivalvia, Carinaria, Cephalopoda, Echinodermata, Pterotrachea and Stomatopoda were absent during SUM (Table 4.4, 4.5) and six (Acantharia, Carinaria, Cirripedia, Echinodermata, Pyrosomida and Sipuncula; Table 4.6, 4.7) were absent during FIM. During WM, Anthozoa, Carinaria, Cirripedia, Halobates, Pterotrachea and Sipuncula were not found in any samples (Table 4.8, 4.9). Since as many as nine groups (Anthozoa, Cephalochordata, Cirripedia, Echinodermata, fish eggs, Pterotrachea, Pyrosomida Sipuncula and Stomatopoda; Table 4.10, 4.11) were absent during SpIM, the incidence of groups was the lowest.

The number of groups decreased rapidly below MLD. Interestingly however, their number was more in the 500-1000 m column, in particular during SUM and FIM. The lowest number of groups during these seasons occurred in the thermocline (range: 2-9) and the 300-500 m stratum (range: 7-16) respectively (Fig. 4.7; Table 4.5, 4.7). During SUM, 23 of the 37 groups were absent in the samples collected from the thermocline. During FIM, 14 groups were absent in the 300-500 m strata. However, during WM and SpIM, the number decreased gradually till 1000/500 m (Fig. 4.7; Table 4.9, 4.11).

Table 4.3. List of groups found in the central Bay

| Gr. No: | Group | Gr. No: | Group | Gr. No: | Group |
|---|---|---|---|---|---|
| 1 | Acantharia | | Callianasa | 22 | Gastropoda |
| 2 | Amphipoda | | Lucifer | 23 | Halobates |
| 3 | Anthozoa | | Lucifer mysis | 24 | Invertebrate eggs |
| 4 | Appendicularia | | Lucifer protozoea | 25 | Isopoda |
| 5 | Bivalvia | | Megalopa | 26 | Medusae |
| 6 | Carinaria | | Palaemon | 27 | Mysida |
| 7 | Cephalochordata | | Sergestes larvae | 28 | Ostracoda |
| 8 | Cephalopoda | | Thalassocaris | 29 | Polychaeta |
| 9 | Chaetognatha | | Unidentified larvae | 30 | Pteropoda |
| 10 | Cirrripedia | 16 | Doliolida | 31 | Pterotrachea |
| 11 | Cladocera | 17 | Echinodermata | 32 | Pyrosomida |
| | Evadna | 18 | Euphausiacea | 33 | Radiolaria |
| 12 | Crustacean larvae | | Euphausiid larvae | 34 | Salpida |
| 13 | Copepoda | | Euphausiid protozoea | 35 | Siphonophora |
| 14 | Ctenophora | | Euphausiids | 36 | Sipuncula |
| 15 | Decapoda | 19 | Fish eggs | 37 | Stomatopoda |
| | Alpheid | 20 | Fish larvae | | |
| | Brachyuran zoea | 21 | Foraminifera | | |

Gr. No: Group Number

Table 4.4. Percent abundance of different groups of mesozooplankton in central Bay during summer monsoon (SUM)

| Gr No: | Groups | Various depth strata (m) at the stations sampled | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CB1 | | | | | CB2 | | | | |
| | | 0-12 | 12-200 | 200-300 | 300-500 | 500-1000 | 0-51 | 51-200 | 200-300 | 300-500 | 500-1000 |
| 2 | Amphipoda | A | A | 0.27 | A | A | 0.27 | 1.06 | A | 0.74 | 0.70 |
| 4 | Appendicularia | 1.06 | A | A | A | 0.64 | A | A | A | A | A |
| 7 | Cephalochordata | A | A | A | A | A | 0.22 | A | A | A | A |
| 9 | Chaetognatha | 1.83 | 1.99 | A | 2.38 | 0.64 | 7.12 | 2.75 | 28.95 | 5.50 | 12.40 |
| 12 | Crustacean larvae | 0.24 | A | A | A | A | A | A | A | A | A |
| 13 | Copepoda | 92.76 | 93.63 | 94.81 | 94.29 | 95.54 | 88.27 | 85.65 | 48.68 | 75.78 | 79.91 |
| 15 | Decapoda | 0.13 | 0.40 | A | 0.16 | A | 0.49 | A | A | 0.30 | 0.21 |
| | Lucifer | A | A | A | A | A | 0.45 | A | A | 0.30 | 0.21 |
| | Unidentified larvae | 0.13 | 0.40 | A | 0.16 | A | 0.04 | A | A | A | A |
| 16 | Doliolida | A | A | A | A | A | 0.06 | A | A | 0.15 | A |
| 18 | Euphausiacea | A | A | 0.82 | A | 2.55 | 1.20 | 2.34 | 15.79 | 0.45 | 2.29 |
| | Euphausiid protozoea | A | A | A | A | 0.64 | A | A | A | A | A |
| | Euphausiids | A | A | 0.82 | A | 1.91 | 1.20 | 2.34 | 15.79 | 0.45 | 2.29 |
| 19 | Fish eggs | 0.13 | A | A | A | A | A | A | A | A | A |
| 20 | Fish larvae | A | 0.40 | 0.54 | 0.16 | A | A | A | 1.32 | 0.30 | A |
| 23 | Halobates | A | A | A | 0.16 | A | A | A | A | A | A |
| 24 | Invertebrate eggs | 0.36 | A | A | 2.06 | A | A | A | A | A | A |
| 25 | Isopoda | A | A | A | A | A | A | A | A | A | 0.70 |
| 27 | Mysida | A | A | A | A | A | 0.06 | A | A | 0.15 | 0.21 |
| 28 | Ostracoda | 0.59 | 3.19 | 3.56 | 0.48 | A | 1.44 | 7.99 | 3.95 | 1.49 | 1.33 |
| 29 | Polychaeta | 0.12 | 0.40 | A | A | 0.64 | 0.71 | 0.21 | 1.32 | 0.15 | 0.21 |
| 30 | Pteropoda | A | A | A | A | A | A | A | A | 14.86 | 0.21 |
| 32 | Pyrosomida | * | A | A | A | A | * | A | A | * | A |
| 33 | Radiolaria | 0.12 | A | A | A | A | A | A | A | A | A |
| 34 | Salpida | 0.13 | A | A | 0.16 | A | 0.15 | A | A | 0.15 | 1.83 |
| 35 | Siphonophora | A | A | A | 0.16 | A | A | A | A | A | A |
| 36 | Sipuncula | 2.53 | A | A | A | A | A | A | A | A | A |
| | Number of groups | 13 | 6 | 5 | 9 | 5 | 12 | 6 | 6 | 13 | 11 |
| | Individuals 100 $m^{-3}$ | 35840 | 469 | 253 | 673 | 124 | 35840 | 469 | 253 | 5384 | 124 |

*swarms of *Pyrosoma* that could not be counted; 'A' denotes absent

Table 4.4. Contd.

| Gr No: | Groups | Various depth strata (m) at the stations sampled | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CB3 | | | | | CB4 | | | |
| | | 0-29 | 29-200 | 200-300 | 300-500 | 500-1000 | 0-13 | 13-200 | 200-300 | 300-500 |
| 2 | Amphipoda | A | A | A | 0.33 | A | 0.48 | A | A | A |
| 4 | Appendicularia | 0.57 | A | 4.55 | A | 0.65 | 2.01 | A | A | A |
| 7 | Cephalochordata | A | A | A | A | A | A | 0.17 | A | A |
| 9 | Chaetognatha | 11.88 | 5.26 | 10.62 | 4.40 | 11.07 | 5.58 | 3.12 | 5.00 | 0.27 |
| 10 | Cirrripedia | 0.97 | A | A | A | A | A | A | A | A |
| 11 | Cladocera | 0.04 | A | A | A | A | 0.96 | A | A | A |
| 12 | Crustacean larvae | A | A | A | A | A | 0.88 | A | A | A |
| 13 | Copepoda | 77.91 | 78.95 | 76.86 | 91.21 | 81.43 | 84.41 | 95.15 | 70.00 | 98.14 |
| 14 | Ctenophora | A | A | A | A | A | 0.04 | A | A | A |
| 15 | Decapoda | 0.16 | A | A | 0.16 | A | 1.00 | A | A | A |
| | Lucifer | 0.16 | A | A | 0.16 | A | 0.76 | A | A | A |
| | Unidentified larvae | A | A | A | A | A | 0.24 | A | A | A |
| 16 | Doliolida | A | A | A | A | A | 0.08 | A | A | A |
| 18 | Euphausiacea | A | A | A | 0.16 | 0.98 | 0.60 | 0.17 | 12.50 | 0.27 |
| | Euphausiids | A | A | A | 0.16 | 0.98 | 0.60 | 0.17 | 12.50 | 0.27 |
| 19 | Fish eggs | 2.21 | A | A | A | A | A | A | A | A |
| 20 | Fish larvae | 0.12 | A | A | 0.16 | A | 0.28 | A | A | 0.27 |
| 21 | Foraminifera | A | A | A | A | 0.65 | A | 0.17 | A | A |
| 22 | Gastropoda | 0.08 | A | A | A | A | 0.24 | A | A | A |
| 24 | Invertebrate eggs | A | A | 0.38 | A | A | A | A | A | A |
| 26 | Medusae | 2.17 | A | A | A | 0.33 | 0.12 | 0.17 | A | 0.27 |
| 27 | Mysida | A | A | A | A | 0.33 | A | A | 2.50 | A |
| 28 | Ostracoda | 0.24 | 3.95 | 3.05 | 3.09 | 2.28 | 0.84 | 0.35 | 7.50 | 0.53 |
| 29 | Polychaeta | 0.08 | 11.84 | 4.55 | 0.49 | 0.33 | 1.00 | 0.52 | A | A |
| 30 | Pteropoda | 0.04 | A | A | A | A | 0.40 | A | A | A |
| 32 | Pyrosomida | A | * | A | A | A | A | A | A | A |
| 34 | Salpida | 2.13 | A | A | A | 0.33 | 0.04 | A | A | A |
| 35 | Siphonophora | 1.88 | A | A | A | 1.63 | 1.00 | 0.17 | 2.50 | 0.27 |
| | Number of groups | 15 | 5 | 6 | 8 | 11 | 18 | 9 | 6 | 7 |
| | Individuals 100 $m^{-3}$ | 5237 | 234 | 168 | 2456 | 246 | 19912 | 1539 | 160 | 3016 |

*swarms of *Pyrosoma* that could not be counted; 'A' denotes absent

Table 4.4. Contd.

| Gr No: | Groups | Various depth strata (m) sampled at CB5 | | | | |
|---|---|---|---|---|---|---|
| | | 0-13 | 13-200 | 200-300 | 300-500 | 500-1000 |
| 4 | Appendicularia | 1.08 | 6.60 | 0.37 | A | 2.31 |
| 9 | Chaetognatha | 1.40 | A | 2.01 | 8.33 | 2.31 |
| 12 | Crustacean larvae | 0.08 | A | A | A | A |
| 13 | Copepoda | 92.72 | 83.02 | 91.11 | 91.67 | 79.62 |
| 15 | Decapoda | 0.25 | 0.94 | 0.18 | A | A |
| | Lucifer | 0.08 | 0.94 | 0.09 | A | A |
| | Unidentified larvae | 0.17 | A | 0.09 | A | A |
| 16 | Doliolida | 0.08 | A | A | A | A |
| 18 | Euphausiacea | A | A | 0.82 | A | 0.38 |
| | Euphausiids | A | A | 0.82 | A | 0.38 |
| 19 | Fish eggs | 0.08 | A | 0.09 | A | A |
| 20 | Fish larvae | 0.08 | A | 0.37 | A | A |
| 21 | Foraminifera | 0.58 | A | A | A | A |
| 24 | Invertebrate eggs | A | A | 0.18 | A | A |
| 26 | Medusae | 0.25 | A | 0.09 | A | 0.38 |
| 28 | Ostracoda | A | 2.83 | 1.75 | A | 3.08 |
| 29 | Polychaeta | 2.57 | 6.60 | 2.67 | A | 10.77 |
| 30 | Pteropoda | 0.17 | A | 0.09 | A | A |
| 32 | Pyrosomida | * | A | A | A | A |
| 34 | Salpida | A | A | 0.09 | A | A |
| 35 | Siphonophora | 0.66 | A | 0.18 | A | 1.15 |
| | Number of groups | 14 | 5 | 14 | 2 | 8 |
| | Individuals 100 m$^{-3}$ | 34792 | 1957 | 16734 | 38 | 1248 |

*swarms of *Pyrosoma* that could not be counted;
'A' denotes absent

Table 4.5. Mesozooplankton groups absent from different depth strata in the central Bay during summer monsoon. Refer to Table 4.3 for the names of individual groups corresponding to the group numbers

| Sampling station | Groups absent in different depth strata (m) | | | | |
|---|---|---|---|---|---|
| | 0-MLD | TT-BT | 200-300 | 300-500 | 500-1000 |
| CB1 | 1-3, 5-8, 10, 11, 14, 16-18, 20-23, 25-27, 30-32, 35, 37 | 1-8, 10-12, 14-19, 21-27, 30-37 | 1, 3-12, 14-17, 19, 21-27, 29-37 | 1-8, 10-12, 14, 16-19, 21, 22, 25-27, 29-33, 36, 37 | 1-3, 5-8, 10-12, 14-17, 19-28, 30-37 |
| CB2 | 1, 3-6, 8, 10-12, 14, 17, 19-27, 30-33, 35-37 | 1,3-8, 10-12, 14-17, 19-27, 30-37 | 1-8, 10-12, 14-17, 19, 21-27, 30-37 | 1, 3-8, 10-12, 14, 15, 17, 19, 21-26, 31-33, 35-37 | 1, 3-8, 10-12, 14-17, 19-24, 26, 31-33, 35-37 |
| CB3 | 1-3, 5-8, 12, 14, 16-18, 21, 23-25, 27, 31-33, 36, 37 | 1-8, 10-12, 14-27, 30-37 | 1-3, 5-8, 10-12, 14-23, 25-27, 30-37 | 1, 3-8, 10-12, 14, 16, 17, 19, 21-27, 30-37 | 1-3, 5-8, 10-12, 14-17,19, 20, 22-25, 30-33, 36, 37 |
| CB4 | 1, 3, 5-8, 10, 17, 19, 21, 23-25, 27, 31-33, 36, 37 | 1-6, 8, 10-12, 14-17, 19, 20, 22-25, 27, 30-34, 36, 37 | 1-8, 10-12, 14-17, 19-26, 29-34, 36, 37 | 1-8, 14-17, 19, 21-25, 27, 29-34, 36, 37 | NO DATA |
| CB5 | 1-3, 5-8, 10, 11, 14, 17, 18, 22-25, 27, 28, 31-34, 36, 37 | 1-3, 5-12, 14, 16-27, 30-37 | 1-3, 5-8, 10-12, 14, 16, 17, 21-23, 25, 27, 31-33, 36, 37 | 1-8, 10-12, 14-37 | 1-3, 5-8, 10-12, 14-17, 19-25, 27, 30-34, 36, 37 |

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

Table 4.6. Percent abundance of different groups of mesozooplankton in central Bay during fall intermonsoon

| Gr. No: | Groups | Various depth strata (m) at the stations sampled | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CB1 | | | | | CB2 | | | | |
| | | 0-40 | 40-200 | 200-300 | 300-500 | 500-1000 | 0-60 | 60-200 | 200-300 | 300-500 | 500-1000 |
| 2 | Amphipoda | 0.28 | A | A | A | A | 0.05 | 0.08 | A | A | A |
| 4 | Appendicularia | 1.24 | 0.20 | 0.12 | 0.13 | 0.16 | 0.81 | 0.38 | 0.41 | A | 0.08 |
| 5 | Bivalvia | 0.05 | A | A | A | A | A | 0.02 | A | 0.33 | 0.16 |
| 7 | Cephalochordata | A | A | A | A | 0.05 | A | A | A | A | A |
| 8 | Cephalopoda | A | A | A | A | A | A | 0.01 | A | A | A |
| 9 | Chaetognatha | 3.99 | 10.73 | 4.60 | 3.52 | 1.93 | 10.51 | 7.11 | 4.84 | 10.43 | 1.43 |
| 12 | Crustacean larvae | 0.03 | A | 5.41 | A | A | 0.01 | 0.06 | A | A | A |
| 13 | Copepoda | 74.75 | 64.88 | 77.59 | 72.08 | 85.61 | 75.43 | 78.49 | 87.31 | 80.56 | 94.89 |
| 15 | Decapoda | 0.24 | A | A | A | A | 1.76 | 0.67 | A | A | 0.08 |
| | Callianasa | A | A | A | A | A | 0.01 | 0.05 | A | A | A |
| | Lucifer | 0.08 | A | A | A | A | 0.53 | 0.16 | A | A | A |
| | Lucifer mysis | 0.03 | A | A | A | A | 0.06 | 0.03 | A | A | A |
| | Lucifer protozoea | 0.06 | A | A | A | A | 0.05 | 0.26 | A | A | 0.08 |
| | Megalopa | 0.02 | A | A | A | A | A | A | A | A | A |
| | Palaemon | A | A | A | A | A | 0.46 | 0.07 | A | A | A |
| | Sergestes larvae | 0.04 | A | A | A | A | 0.01 | A | A | A | A |
| | Thalassocaris | 0.02 | A | A | A | A | 0.64 | 0.09 | A | A | A |
| 16 | Doliolida | 0.12 | 0.07 | A | 0.13 | 0.10 | 0.06 | A | A | A | A |
| 18 | Euphausiacea | 0.61 | 5.52 | 2.11 | 1.13 | 1.57 | 0.25 | 1.11 | 1.27 | 4.23 | A |
| | Euphausiid larvae | 0.01 | A | A | A | A | A | 0.06 | A | A | A |
| | Euphausiid protozoea | 0.33 | A | A | A | A | 0.04 | 0.24 | 0.14 | A | A |
| | Euphausids | 0.27 | 5.52 | 2.11 | 1.13 | 1.57 | 0.22 | 0.81 | 1.13 | 4.23 | A |
| 19 | Fish eggs | 0.03 | A | A | 0.16 | A | 0.09 | 0.10 | A | A | A |
| 20 | Fish larvae | 0.07 | A | 0.13 | 1.28 | 0.24 | 0.07 | 0.11 | A | 1.41 | 0.24 |
| 21 | Foraminifera | 5.18 | 5.16 | 1.44 | 5.84 | 7.13 | 1.62 | 1.99 | 0.25 | A | 1.11 |
| 22 | Gastropoda | 0.07 | A | 0.34 | 3.27 | A | 0.32 | 0.48 | 1.51 | A | A |
| 24 | Invertebrate eggs | 0.63 | 2.61 | 2.71 | 1.71 | 1.10 | 8.09 | 5.12 | 0.76 | 0.98 | 0.48 |
| 25 | Isopoda | 0.01 | A | A | A | A | A | 0.01 | A | A | A |
| 26 | Medusae | 0.01 | 1.04 | 0.59 | 0.29 | 0.26 | 0.01 | 0.03 | A | A | A |
| 27 | Mysida | 0.08 | A | A | A | A | 0.03 | 0.04 | A | A | A |
| 28 | Ostracoda | 0.39 | 3.08 | 5.95 | 2.37 | 1.44 | 0.43 | 3.74 | 4.14 | 0.65 | 1.58 |
| 29 | Polychaeta | 0.38 | 0.65 | 0.33 | 0.13 | 0.43 | 0.28 | 0.32 | 0.14 | 0.70 | A |
| 30 | Pteropoda | 11.20 | 4.43 | 1.13 | 0.81 | A | 0.03 | 0.02 | A | A | A |
| 33 | Radiolaria | 0.33 | 0.92 | A | A | A | A | A | A | A | A |
| 34 | Salpida | 0.08 | A | A | 0.16 | A | A | A | A | 0.70 | A |
| 35 | Siphonophora | 0.24 | 1.18 | 0.44 | 8.64 | 0.24 | 0.15 | 0.10 | 1.26 | A | A |
| 37 | Stomatopoda | 0.02 | A | A | A | A | A | A | A | A | A |
| | Number of groups | 24 | 13 | 14 | 16 | 13 | 19 | 21 | 10 | 9 | 9 |
| | Individuals 100 $m^{-3}$ | 355940 | 8630 | 3698 | 707 | 1984 | 66120 | 18796 | 1532 | 224 | 505 |

‘A’ denotes absent

Table 4.6. Contd.

| Gr. No: | Groups | Various depth strata (m) at the stations sampled | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CB3 | | | | | CB4 | | | | |
| | | 0-30 | 30-200 | 200-300 | 300-500 | 500-1000 | 0-30 | 30-200 | 200-300 | 300-500 | 500-1000 |
| 2 | Amphipoda | 0.24 | 0.34 | A | A | 0.27 | 0.22 | 0.18 | A | 0.09 | 0.04 |
| 3 | Anthozoa | A | A | 0.48 | A | A | A | A | A | A | A |
| 4 | Appendicularia | 13.24 | 2.07 | 0.64 | A | 1.37 | 10.53 | 2.39 | 3.36 | 1.19 | 2.35 |
| 5 | Bivalvia | 0.03 | A | A | A | 0.12 | 0.04 | 0.04 | A | A | A |
| 8 | Cephalopoda | 0.01 | A | A | A | A | A | A | A | A | A |
| 9 | Chaetognatha | 6.48 | 5.14 | 0.32 | A | 2.02 | 3.91 | 1.96 | 1.51 | 1.10 | 1.03 |
| 11 | Cladocera | A | 0.03 | A | A | A | 0.51 | A | A | A | A |
| 12 | Crustacean larvae | 0.01 | 0.03 | A | A | A | 0.03 | A | 0.17 | 0.09 | 0.04 |
| 13 | Copepoda | 68.15 | 76.97 | 87.46 | 81.93 | 83.44 | 74.36 | 86.49 | 88.93 | 95.53 | 94.49 |
| 14 | Ctenophora | 0.01 | A | A | A | A | A | A | A | A | A |
| 15 | Decapoda | 0.17 | 0.15 | A | A | 0.01 | 0.35 | 0.11 | A | 0.09 | A |
| | Alpheid | 0.01 | A | A | A | A | A | A | A | A | A |
| | Brachyuran zoea | A | A | A | A | A | 0.01 | A | A | A | A |
| | Callianasa | A | 0.06 | A | A | A | 0.01 | 0.04 | A | A | A |
| | Lucifer | 0.03 | A | A | A | 0.01 | 0.14 | A | A | 0.09 | A |
| | Lucifer mysis | 0.08 | 0.03 | A | A | A | A | A | A | A | A |
| | Lucifer protozoea | A | A | A | A | A | A | 0.04 | A | A | A |
| | Megalopa | 0.03 | A | A | A | A | A | A | A | A | A |
| | Palaemon | 0.03 | 0.06 | A | A | A | A | A | A | A | A |
| | Sergestes larvae | 0.01 | A | A | A | A | 0.18 | 0.04 | A | A | A |
| 16 | Doliolida | 0.07 | 0.26 | 0.16 | A | 0.01 | 0.26 | 0.43 | A | A | 0.08 |
| 18 | Euphausiacea | 0.41 | 0.42 | 4.47 | 7.23 | 0.55 | 2.36 | 0.39 | A | A | 0.37 |
| | Euphausiid larvae | A | 0.13 | A | A | 0.11 | A | A | A | A | A |
| | Euphausiid protozoea | 0.20 | A | A | A | A | 0.06 | A | A | A | A |
| | Euphausiids | 0.21 | 0.29 | 4.47 | 7.23 | 0.44 | 2.31 | 0.39 | A | A | 0.37 |
| 19 | Fish eggs | 0.03 | 0.13 | A | A | A | 0.01 | A | A | A | A |
| 20 | Fish larvae | 0.57 | 0.28 | A | A | 0.22 | 0.19 | 0.04 | A | A | A |
| 21 | Foraminifera | 0.50 | 1.06 | 1.60 | 2.41 | 4.19 | A | 0.25 | 0.84 | 0.82 | 0.37 |
| 22 | Gastropoda | 0.27 | 0.09 | 1.52 | A | 0.04 | 0.28 | 0.11 | 0.17 | A | 0.04 |
| 23 | Halobates | 0.02 | A | A | A | A | 0.03 | A | A | A | A |
| 24 | Invertebrate eggs | 0.85 | 0.16 | 0.48 | A | 0.28 | 0.99 | 0.18 | 2.01 | 0.27 | A |
| 25 | Isopoda | 0.05 | 0.06 | A | A | A | A | A | A | A | A |
| 26 | Medusae | 0.23 | 0.85 | 1.12 | A | 0.24 | 0.43 | 0.39 | 1.01 | 0.09 | 0.08 |
| 27 | Mysida | 0.05 | A | A | A | 0.01 | 0.04 | 0.04 | A | A | A |
| 28 | Ostracoda | 6.01 | 9.94 | 0.96 | 3.61 | 4.84 | 2.53 | 4.31 | 0.34 | 0.27 | A |
| 29 | Polychaeta | 1.68 | 1.03 | A | 1.20 | 0.33 | 0.86 | 1.11 | 1.34 | 0.46 | 0.86 |
| 30 | Pteropoda | A | A | 0.32 | 2.41 | A | 0.11 | A | A | A | A |
| 31 | Pterotrachea | A | A | A | 1.20 | A | 0.04 | A | A | A | A |
| 33 | Radiolaria | 0.15 | A | A | A | 0.01 | A | A | 0.17 | A | A |
| 34 | Salpida | 0.08 | A | 0.16 | A | A | 0.12 | A | A | A | A |
| 35 | Siphonophora | 0.69 | 0.98 | 0.32 | A | 2.09 | 1.80 | 1.60 | 0.17 | A | 0.25 |
| 37 | Stomatopoda | A | 0.03 | A | A | A | A | A | A | A | A |
| | Number of groups | 25 | 20 | 14 | 7 | 18 | 23 | 17 | 12 | 11 | 12 |
| | Individuals 100 $m^{-3}$ | 47907 | 8495 | 692 | 737 | 798 | 96520 | 26400 | 2384 | 2190 | 1943 |

‘A’ denotes absent

Table 4.6. Contd.

| Gr.No: | Groups | Various depth strata (m) at CB5 | | | | |
|---|---|---|---|---|---|---|
| | | 0-20 | 20-200 | 200-300 | 300-500 | 500-1000 |
| 2 | Amphipoda | A | 0.09 | A | A | A |
| 4 | Appendicularia | 9.18 | 8.80 | A | 0.08 | 0.67 |
| 9 | Chaetognatha | 1.89 | 3.72 | 11.35 | 0.63 | 1.40 |
| 11 | Cladocera | 0.93 | A | A | A | 0.22 |
| 13 | Copepoda | 77.97 | 79.11 | 83.43 | 90.37 | 93.77 |
| 15 | Decapoda | 0.24 | 0.56 | 0.11 | A | 0.44 |
| | Lucifer | 0.24 | 0.06 | 0.11 | A | 0.44 |
| | Lucifer mysis | A | 0.19 | A | A | A |
| | Lucifer protozoea | A | 0.03 | A | A | A |
| | Palaemon | A | 0.18 | A | A | A |
| | Sergestes larvae | A | 0.10 | A | A | A |
| 16 | Doliolida | 0.64 | 0.42 | A | A | 0.07 |
| 18 | Euphausiacea | 1.09 | 0.50 | A | 6.41 | 0.30 |
| | Euphausiids | 1.09 | 0.50 | A | 6.41 | 0.30 |
| 19 | Fish eggs | 0.08 | A | A | A | A |
| 20 | Fish larvae | 0.08 | 0.27 | 0.07 | A | 0.15 |
| 21 | Foraminifera | 0.36 | 0.03 | 0.07 | 0.34 | A |
| 22 | Gastropoda | 0.12 | 0.02 | A | A | A |
| 24 | Invertebrate eggs | 0.56 | 0.35 | 1.20 | 0.08 | 0.59 |
| 25 | Isopoda | A | 0.01 | A | A | A |
| 26 | Medusae | 0.32 | 0.81 | 0.07 | A | 0.07 |
| 27 | Mysida | 0.28 | A | A | A | A |
| 28 | Ostracoda | 2.70 | 2.77 | 2.28 | 0.98 | 6.43 |
| 29 | Polychaeta | 2.26 | 1.74 | 0.63 | 0.54 | 1.18 |
| 30 | Pteropoda | A | 0.03 | A | A | A |
| 33 | Radiolaria | 0.12 | 0.01 | A | A | A |
| 34 | Salpida | 0.04 | A | A | A | A |
| 35 | Siphonophora | 1.13 | 0.76 | 0.78 | 0.56 | 0.96 |
| | Number of groups | 19 | 18 | 10 | 9 | 13 |
| | Individuals 100 $m^{-3}$ | 72145 | 7280 | 2818 | 1834 | 1085 |

‘A’ denotes absent

Table 4.7. Mesozooplankton groups absent from different depth strata in the central Bay during fall intermonsoon. Refer to Table 4.3 for the names of individual groups corresponding to the group numbers

| | Groups absent in different depth strata (m) | | | | |
|---|---|---|---|---|---|
| Sampling station | 0-MLD | TT-BT | BT-300 | 300-500 | 500-1000 |
| CB1 | 1, 3, 6-8, 10-11,14, 17, 23, 31, 32, 36 | 1-3, 5-8, 10-12, 14, 15, 17, 19, 20, 22, 23, 25, 27, 31, 32, 34, 36, 37 | 1-3, 5-8, 10, 11, 14-17, 19, 23, 25, 27, 31-34, 36, 37 | 1-3, 5-8, 10-12, 14, 15, 17, 23, 25, 27, 31-33, 36, 37 | 1-3, 5-6, 8, 10-12, 14-17, 19, 22, 23, 25, 27, 30-34, 36,37 |
| CB2 | 1, 3, 5-8, 10, 11, 14, 17, 23, 25, 31-34, 36, 37 | 1, 3, 6, 7, 10, 11, 14, 17, 23, 31-34, 36, 37 | 1-3, 5-8, 10-12, 14-17, 19, 20, 23, 25-27, 30-34, 36, 37 | 1-4, 6-8, 10-12, 14-17, 19, 21-23, 25-27, 30-33, 35-37 | 1-3, 6-8, 10-12, 14, 16-19, 22, 23, 25-27, 29-37 |
| CB3 | 1, 3, 6, 7, 10, 11, 17, 30-32, 36, 37 | 1, 3, 5-8, 10, 14, 17, 23, 27, 30-34, 36 | 1,2, 5-8, 10-12, 14, 17, 19, 20, 23, 25, 27, 29, 31-33, 36, 37 | 1-12, 14-17, 19, 20, 22-27, 32-37 | 1, 3, 6-8, 10-12, 14, 17, 19, 23, 25, 30-32, 34, 36, 37 |
| CB4 | 1, 3, 6-8, 10, 14, 17, 21, 25, 32, 33, 36, 37 | 1, 3, 6-8, 10-12, 14, 17, 19, 23, 25, 30-34, 36, 37 | 1-3, 5-8, 10, 11, 14-20, 23, 25, 27, 30-32, 34, 36, 37 | 1, 5-8, 10, 11, 14-20, 22, 23, 25, 27, 30-37 | 1, 3, 5-8, 10-11, 14, 15, 17, 19, 20, 23-25, 27, 28, 30-34, 36, 37 |
| CB5 | 1-3, 5-8, 10, 11, 12, 14, 17, 23, 25, 30-32, 36, 37 | 1, 3, 5-8, 10-12, 14, 17, 19, 23, 27, 31, 32, 34, 36, 37 | 1-8, 10-12, 14, 16-19, 22, 23, 25, 27, 30-34, 36, 37 | 1-3, 5-8, 10-12, 14-17, 19, 20, 22, 23, 25-27, 30-34, 36, 37 | 1-3, 5-8, 10, 12, 14, 17, 21-23, 25, 27, 30-34, 36, 37 |

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

Table 4.8. Percent abundance of different groups of mesozooplankton in central Bay during winter monsoon

| Gr. No: | Groups | Various depth strata (m) at the stations sampled | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CB1 | | | | | CB2 | | | | |
| | | 0-40 | 40-150 | 150-300 | 300-500 | 1000-500 | 0-40 | 40-150 | 150-300 | 300-500 | 1000-500 |
| 1 | Acantharia | A | A | A | A | A | A | 0.17 | A | 0.10 | A |
| 2 | Amphipoda | 0.81 | 0.03 | 0.02 | 0.05 | A | 0.08 | 0.07 | A | 0.05 | A |
| 4 | Appendicularia | 1.88 | 0.79 | A | 0.28 | 0.47 | 2.80 | A | 0.05 | 0.16 | A |
| 5 | Bivalvia | A | A | 0.05 | A | A | A | A | A | A | A |
| 7 | Cephalochordata | A | A | A | A | A | A | A | 0.02 | A | A |
| 8 | Cephalopoda | A | A | A | A | A | A | 0.14 | A | 0.03 | A |
| 9 | Chaetognatha | 9.22 | 2.06 | 0.68 | 0.93 | 0.35 | 11.42 | 2.66 | 1.42 | 2.98 | 0.50 |
| 11 | Cladocera | 0.36 | 0.02 | A | 0.19 | A | 0.33 | A | A | A | 0.11 |
| 12 | Crustacean larvae | 0.24 | A | A | 0.46 | A | A | 0.11 | A | 0.03 | 0.11 |
| 13 | Copepoda | 68.95 | 90.89 | 87.22 | 90.04 | 94.88 | 58.97 | 91.18 | 85.93 | 89.83 | 94.18 |
| 15 | Decapoda | 1.47 | 0.09 | 0.04 | 0.05 | 0.07 | 1.01 | 0.14 | A | 0.03 | 0.24 |
| | Lucifer | 0.16 | A | A | A | A | 0.39 | 0.02 | A | 0.03 | A |
| | Lucifer mysis | A | A | A | A | A | 0.08 | A | A | A | A |
| | Thalassocaris | 1.31 | 0.09 | 0.04 | A | 0.07 | 0.46 | 0.12 | A | A | A |
| | Unidentified larvae | A | A | A | 0.05 | A | 0.08 | A | A | A | 0.24 |
| 16 | Doliolida | A | A | A | 0.05 | 0.07 | A | A | A | A | A |
| 17 | Echinoderm larvae | A | A | A | A | A | 3.09 | 0.07 | 0.05 | 0.14 | A |
| 18 | Euphausiacea | 1.33 | 0.30 | 0.74 | 0.65 | A | 1.18 | 0.38 | 0.76 | 1.21 | 0.04 |
| | Euphausiid larvae | 0.28 | 0.05 | A | A | A | 0.63 | 0.07 | 0.22 | 0.05 | 0.04 |
| | Euphausiids | 1.05 | 0.24 | 0.74 | 0.65 | A | 0.55 | 0.31 | 0.54 | 1.16 | A |
| 19 | Fish eggs | A | A | A | A | A | 0.26 | A | A | A | A |
| 20 | Fish larvae | 0.13 | 0.07 | A | 0.05 | A | 0.15 | 0.11 | 0.02 | 0.44 | 0.26 |
| 21 | Foraminifera | 0.34 | 0.29 | 0.09 | 1.21 | 0.40 | 0.39 | 1.63 | 1.25 | 0.61 | 1.18 |
| 22 | Gastropoda | A | A | A | A | A | A | A | 0.02 | 0.03 | A |
| 24 | Invertebrate eggs | 2.19 | 0.18 | 0.02 | 0.65 | A | 0.31 | 0.12 | 0.22 | 0.12 | 0.22 |
| 25 | Isopod | A | 0.02 | A | A | A | A | A | A | A | A |
| 26 | Medusae | A | A | A | 0.14 | A | 0.51 | 0.02 | A | A | A |
| 27 | Mysida | A | 0.02 | 0.02 | A | A | A | 0.14 | 0.07 | A | A |
| 28 | Ostracoda | 11.23 | 4.62 | 10.91 | 3.89 | 3.28 | 11.52 | 1.66 | 8.24 | 3.81 | 2.95 |
| 29 | Polychaeta | 0.71 | 0.27 | 0.08 | 0.70 | 0.07 | 2.14 | 1.11 | 0.24 | 0.32 | 0.17 |
| 30 | Pteropoda | 0.46 | 0.15 | 0.11 | A | 0.20 | 0.15 | A | 0.05 | A | A |
| 32 | Pyrosomida | A | A | A | A | A | 0.17 | A | A | A | A |
| 33 | Radiolaria | A | 0.02 | A | A | A | 1.54 | 0.17 | 1.50 | A | 0.04 |
| 34 | Salpida | 0.24 | 0.09 | A | 0.05 | 0.20 | 0.32 | 0.07 | 0.05 | 0.05 | A |
| 35 | Siphonophora | 0.43 | 0.08 | 0.02 | 0.65 | A | 0.66 | 0.09 | 0.07 | 0.06 | A |
| | Number of groups | 16 | 18 | 13 | 17 | 10 | 20 | 19 | 17 | 18 | 12 |
| | Individuals100 $m^{-3}$ | 16025 | 32411 | 6016 | 5410 | 368 | 12310 | 16187 | 3385 | 4605 | 656 |

‘A’ denotes absent

Table 4.8. Contd.

| Gr. No: | Groups | Various depth strata (m) at the stations sampled | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CB3 | | | | | CB4 | | | | |
| | | 0-40 | 40-150 | 150-300 | 300-500 | 1000-500 | 0-60 | 60-150 | 150-300 | 300-500 | 1000-500 |
| 1 | Acantharia | A | 0.11 | A | A | A | 0.04 | 0.05 | A | A | A |
| 2 | Amphipoda | 0.11 | 0.05 | 0.05 | A | A | 0.48 | 0.20 | A | A | 0.36 |
| 4 | Appendicularia | 0.99 | 0.89 | 0.24 | A | A | 0.28 | 0.35 | A | A | 0.42 |
| 5 | Bivalvia | 0.22 | 0.01 | A | A | A | A | A | 0.10 | A | 0.18 |
| 7 | Cephalochordata | A | 0.05 | A | A | A | 0.06 | 0.12 | A | A | A |
| 8 | Cephalopoda | 0.04 | 0.02 | A | A | A | A | 0.14 | A | A | A |
| 9 | Chaetognatha | 5.96 | 4.22 | 0.62 | 0.99 | 0.83 | 8.31 | 3.58 | 1.83 | 0.74 | 4.02 |
| 11 | Cladocera | 0.04 | A | A | A | A | 0.21 | A | A | A | A |
| 12 | Crustacean larvae | A | A | 0.11 | A | A | 0.06 | 0.15 | A | A | A |
| 13 | Copepoda | 80.02 | 87.69 | 87.67 | 91.72 | 95.94 | 75.32 | 84.92 | 86.08 | 95.95 | 87.19 |
| 15 | Decapoda | 0.34 | 0.03 | 0.09 | A | A | 0.50 | 0.04 | A | 0.06 | 0.18 |
| | Lucifer | 0.19 | A | A | A | A | 0.34 | A | A | A | 0.18 |
| | Megalopa | 0.04 | A | 0.05 | A | A | A | A | A | A | A |
| | Sergestes larvae | 0.04 | 0.01 | A | A | A | A | A | A | A | A |
| | Thalassocaris | 0.08 | 0.01 | 0.04 | A | A | 0.16 | 0.04 | A | 0.06 | A |
| 16 | Doliolida | 0.08 | 0.04 | A | A | A | 0.10 | 0.04 | A | A | A |
| 17 | Echinoderm larvae | 0.66 | 0.26 | 0.08 | A | A | 0.25 | 0.34 | A | A | A |
| 18 | Euphausiacea | 0.48 | 0.13 | 0.42 | 1.21 | 0.16 | 0.64 | 0.53 | 0.99 | 0.47 | 0.08 |
| | Euphausiid larvae | 0.07 | 0.02 | 0.08 | A | 0.03 | 0.04 | 0.05 | A | A | A |
| | Euphausiid protozoea | 0.15 | A | A | 0.06 | A | A | A | A | A | A |
| | Euphausiids | 0.26 | 0.11 | 0.34 | 1.15 | 0.13 | 0.60 | 0.48 | 0.99 | 0.47 | 0.08 |
| 19 | Fish eggs | 0.15 | A | 0.04 | 0.06 | A | A | 0.05 | A | A | A |
| 20 | Fish larvae | 0.19 | 0.22 | 0.08 | 0.44 | 0.12 | A | 0.14 | A | A | 0.16 |
| 21 | Foraminifera | 1.63 | 0.58 | 2.06 | 0.19 | 0.03 | 6.23 | 0.25 | 2.29 | 0.22 | 2.09 |
| 22 | Gastropoda | 0.22 | 0.10 | A | A | A | A | A | A | A | A |
| 24 | Invertebrate eggs | 1.10 | 0.31 | 0.04 | A | A | 0.94 | A | 0.52 | 0.11 | 0.18 |
| 25 | Isopoda | A | A | 0.05 | A | A | A | A | A | A | A |
| 26 | Medusae | A | 0.05 | 0.05 | 0.19 | A | 0.13 | 0.09 | 0.20 | 0.17 | A |
| 27 | Mysida | A | 0.06 | 0.05 | A | A | 0.06 | 0.17 | 0.30 | A | A |
| 28 | Ostracoda | 6.18 | 3.91 | 6.88 | 4.30 | 2.90 | 3.41 | 6.03 | 6.99 | 2.14 | 2.11 |
| 29 | Polychaetes | 0.86 | 0.76 | 0.62 | 0.24 | A | 1.81 | 2.55 | 0.30 | 0.12 | 2.43 |
| 30 | Pteropoda | 0.29 | 0.03 | A | 0.06 | 0.03 | 0.06 | A | A | A | A |
| 32 | Pyrosomida | A | A | A | A | A | 0.33 | A | A | A | A |
| 33 | Radiolaria | A | A | 0.83 | 0.06 | A | 0.11 | 0.05 | 0.31 | A | A |
| 34 | Salpida | 0.04 | 0.14 | 0.04 | A | A | 0.23 | 0.05 | A | A | 0.08 |
| 35 | Siphonophora | 0.41 | 0.34 | A | 0.54 | A | 0.45 | 0.19 | 0.09 | A | 0.36 |
| | Number of groups | 21 | 23 | 19 | 12 | 7 | 23 | 22 | 12 | 9 | 14 |
| | Individuals 100 $m^{-3}$ | 26910 | 37622 | 4364 | 1621 | 843 | 27627 | 21431 | 1997 | 1718 | 362 |

'A' denotes absent

Table 4.8. Contd.

| Gr. No: | Groups | Various depth strata (m) at CB5 | | | | |
|---|---|---|---|---|---|---|
| | | 0-20 | 20-200 | 200-300 | 300-500 | 500-1000 |
| 2 | Amphipoda | A | 0.09 | A | A | A |
| 4 | Appendicularia | 9.18 | 8.80 | A | 0.08 | 0.67 |
| 9 | Chaetognatha | 1.89 | 3.72 | 11.35 | 0.63 | 1.40 |
| 11 | Cladocera | 0.93 | A | A | A | 0.22 |
| 13 | Copepoda | 77.97 | 79.11 | 83.43 | 90.37 | 93.77 |
| 15 | Decapoda | 0.24 | 0.56 | 0.11 | A | 0.44 |
| | Lucifer | 0.24 | 0.06 | 0.11 | A | 0.44 |
| | Lucifer mysis | A | 0.19 | A | A | A |
| | Lucifer protozoea | A | 0.03 | A | A | A |
| | Palaemon | A | 0.18 | A | A | A |
| | Sergestes larvae | A | 0.10 | A | A | A |
| 16 | Doliolida | 0.64 | 0.42 | A | A | 0.07 |
| 18 | Euphausiacea | 1.09 | 0.50 | A | 6.41 | 0.30 |
| | Euphausiids | 1.09 | 0.50 | A | 6.41 | 0.30 |
| 19 | Fish eggs | 0.08 | A | A | A | A |
| 20 | Fish larvae | 0.08 | 0.27 | 0.07 | A | 0.15 |
| 21 | Foraminifera | 0.36 | 0.03 | 0.07 | 0.34 | A |
| 22 | Gastropoda | 0.12 | 0.02 | A | A | A |
| 24 | Invertebrate eggs | 0.56 | 0.35 | 1.20 | 0.08 | 0.59 |
| 25 | Isopoda | A | 0.01 | A | A | A |
| 26 | Medusae | 0.32 | 0.81 | 0.07 | A | 0.07 |
| 27 | Mysida | 0.28 | A | A | A | A |
| 28 | Ostracoda | 2.70 | 2.77 | 2.28 | 0.98 | 6.43 |
| 29 | Polychaeta | 2.26 | 1.74 | 0.63 | 0.54 | 1.18 |
| 30 | Pteropoda | A | 0.03 | A | A | A |
| 33 | Radiolaria | 0.12 | 0.01 | A | A | A |
| 34 | Salpida | 0.04 | A | A | A | A |
| 35 | Siphonophora | 1.13 | 0.76 | 0.78 | 0.56 | 0.96 |
| | Number of groups | 19 | 18 | 10 | 9 | 13 |
| | Individuals 100 $m^{-3}$ | 72145 | 7280 | 2818 | 1834 | 1085 |

‘A’ denotes absent

Table 4.9. Mesozooplankton groups absent from different depth strata in the central Bay during winter monsoon. Refer to Table 4.3 for the names of individual groups corresponding to the group numbers

| | Groups absent in different depth strata (m) | | | | |
|---|---|---|---|---|---|
| Sampling station | 0-MLD | TT-BT | BT-300 | 300-500 | 500-1000 |
| CB1 | 1, 3, 5-8, 10, 12, 14-17, 19, 22, 23, 26, 31, 32, 36, 37 | 1, 3, 5-8, 10, 12, 14, 16, 17, 19, 22, 23, 26, 31, 32, 36, 37 | 1, 3, 4, 6-8, 10-12, 14, 16, 17, 19, 20, 22, 23, 25, 26, 31-34, 36, 37 | 1, 3, 5-8, 10, 14, 17, 19, 22, 23, 25, 27, 30-33, 36,37 | 1-3, 5-8, 10-12, 14, 17-20, 22-27, 31-33, 35-37 |
| CB2 | 1, 3,5-8, 10, 14, 16, 22, 23, 25, 27, 31, 36, 37 | 3-7, 10, 11, 14, 16, 19, 22, 23, 25, 30-32, 36, 37 | 1-3, 5-6, 8, 10-12, 14-16, 19, 23, 25, 26, 31, 32, 36, 37 | 1, 3, 5-8, 10, 11, 14, 16, 19, 23, 25-27, 30-33, 36, 37 | 1-8, 10, 14, 16, 17, 19, 22, 23, 25-27, 30-32, 35-37 |
| CB3 | 1, 3,6, 7, 10, 12, 14, 23, 25-27, 31-33, 36, 37 | 3, 6, 10-12, 14, 15, 19, 23, 25, 31-33, 36, 37 | 1, 3, 5-8, 10, 11, 14, 16, 22, 23, 30-32, 35-37 | 1-8, 10-12, 14-17, 22-25, 27,31, 32, 34, 36, 37 | 1-8, 10-12, 14-17, 19, 22-27, 29, 31-37 |
| CB4 | 3, 5, 6, 8, 10, 14, 19, 20, 22, 23, 25, 31, 36, 37 | 1, 3, 5, 6, 10, 11, 14, 22-25, 30-32, 36, 37 | 1-4, 6-8, 10-12, 14-17, 19, 20, 22, 23, 25, 30-32, 34, 36, 37 | 1-8, 10-12, 14, 16, 17, 19, 20, 22, 23, 25, 27, 30-37 | 1, 3, 6-8, 10-12, 14, 16, 17, 19, 22, 23, 25-27, 30-33, 36-37 |
| CB5 | 3, 6-8, 10, 11, 14, 16, 17, 23, 31, 33, 36 | 1, 3, 6-8, 10, 11, 16, 17, 23, 25, 31-33, 36, 37 | 3, 5-8, 10-12, 14,17, 22, 23, 25, 31-33, 36, 37 | 1, 3, 6-8, 10-12, 14, 16, 22, 23, 25, 31, 32, 34-37 | ND |

ND: No data due to shallower depth;

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

Table 4.10. Percent abundance of different groups of mesozooplankton in central Bay during spring intermonsoon

| Gr. No: | Groups | Various depth strata (m) at the stations sampled | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | CB1 | | | CB2 | | | |
| | | 0-40 | 40-200 | 200-300 | 0-30 | 30-200 | 200-300 | 300-500 |
| 1 | Acantharia | A | 0.40 | A | A | A | A | A |
| 2 | Amphipoda | A | 0.10 | A | 0.28 | 0.96 | A | A |
| 4 | Appendicularia | 1.41 | A | 0.03 | 0.55 | 2.02 | 0.33 | A |
| 5 | Bivalvia | 0.20 | A | A | 0.06 | 0.04 | A | A |
| 6 | Carinaria | A | A | A | 0.19 | A | A | A |
| 8 | Cephlaopoda | 0.20 | A | A | A | A | A | A |
| 9 | Chaetognatha | 1.91 | 2.87 | 1.74 | 2.71 | 8.95 | 1.75 | 0.67 |
| 11 | Cladocera | A | A | A | 0.75 | 0.04 | A | A |
| 12 | Crustacean larvae | A | A | 0.59 | A | 0.07 | 1.86 | A |
| 13 | Copepoda | 71.83 | 71.94 | 87.40 | 82.04 | 70.17 | 67.54 | 75.84 |
| 15 | Decapoda | A | A | 0.15 | 1.02 | 0.14 | 0.11 | A |
| | Brachyuran zoea | A | A | A | 0.14 | A | A | A |
| | Lucifer | A | A | A | 0.33 | A | A | A |
| | Lucifer protozoea | A | A | A | 0.08 | 0.14 | A | A |
| | Megalopa | A | A | A | 0.39 | 0.00 | A | A |
| | Sergestes larvae | A | A | A | 0.08 | A | A | A |
| | Unidentified | A | A | 0.15 | A | A | 0.11 | A |
| 16 | Doliolida | A | A | A | 0.03 | 0.14 | A | A |
| 18 | Euphausiacea | 0.20 | 2.80 | 0.99 | 0.17 | 0.96 | 0.66 | A |
| | Euphausiid protozoea | 0.20 | A | A | 0.11 | 0.67 | 0.22 | A |
| | Euphausiids | A | 2.80 | 0.99 | 0.06 | 0.28 | 0.44 | A |
| 21 | Foraminifera | 8.76 | 2.35 | 1.59 | 0.66 | 1.35 | 0.33 | 4.03 |
| 22 | Gastropoda | 0.57 | A | A | 0.53 | 0.07 | A | A |
| 24 | Invertebrate egg | 10.03 | 2.88 | 0.31 | 8.07 | 7.42 | 20.50 | 4.70 |
| 25 | Isopoda | A | 0.10 | A | 0.03 | 0.21 | A | A |
| 26 | Medusae | 0.20 | 0.20 | 0.03 | 0.47 | 0.36 | A | A |
| 27 | Mysida | A | A | A | 0.66 | A | A | A |
| 28 | Ostracoda | 2.72 | 12.50 | 3.76 | 0.33 | 4.62 | 5.59 | 14.09 |
| 29 | Polychaeta | 0.20 | 0.10 | 0.34 | 0.75 | 1.31 | 0.77 | 0.67 |
| 30 | Pteropoda | A | A | A | 0.11 | 0.39 | A | A |
| 33 | Radiolaria | 0.20 | 3.77 | 2.38 | A | 0.25 | 0.44 | A |
| 34 | Salpida | A | A | 0.15 | 0.08 | 0.04 | A | A |
| 35 | Siphonophora | 1.58 | A | A | 0.36 | 0.25 | A | A |
| | Number of groups | 14 | 12 | 13 | 21 | 21 | 11 | 6 |
| | Individuals 100 $m^{-3}$ | 3840 | 831 | 3820 | 48253 | 6626 | 3648 | 298 |

'A' denotes absent

Table 4.10. Contd.

| Gr. No: | Groups | Various depth strata (m) at the stations sampled | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CB3 | | | | CB4 | | | |
| | | 0-15 | 15-200 | 200-300 | 300-500 | 0-40 | 40-200 | 200-300 | 300-500 |
| 1 | Acantharia | 0.15 | A | A | A | A | A | A | A |
| 2 | Amphipoda | 0.43 | A | A | A | 0.40 | 0.33 | 0.37 | A |
| 4 | Appendicularia | 3.10 | A | A | 5.13 | 1.31 | A | 1.66 | A |
| 9 | Chaetognatha | 3.51 | 0.26 | 0.68 | A | 8.29 | 0.33 | 4.79 | 2.11 |
| 11 | Cladocera | 0.37 | A | A | A | 0.16 | A | 0.18 | 0.53 |
| 12 | Crustacean larvae | 0.02 | A | A | A | A | A | A | A |
| 13 | Copepoda | 81.48 | 87.63 | 87.16 | 87.18 | 74.70 | 86.60 | 83.06 | 88.42 |
| 15 | Decapoda | 0.39 | 0.26 | A | A | 0.28 | A | A | A |
| | Brachyuran zoea | 0.02 | A | A | A | A | A | A | A |
| | Lucifer | 0.15 | A | A | A | 0.19 | A | A | A |
| | Lucifer protozoea | 0.09 | 0.26 | A | A | 0.05 | A | A | A |
| | Megalopa | A | A | A | A | 0.02 | A | A | A |
| | Sergestes larvae | 0.13 | A | A | A | A | A | A | A |
| | Unidentified larvae | A | A | A | A | 0.02 | A | A | A |
| 16 | Doliolida | 0.09 | A | A | A | 0.09 | A | A | A |
| 18 | Euphausiacea | 0.13 | 0.26 | A | A | 0.72 | A | 0.37 | A |
| | Euphausiid larva | A | A | A | A | 0.02 | A | A | A |
| | Euphausiid protozoea | 0.06 | A | A | A | 0.49 | A | A | A |
| | Euphausiids | 0.06 | 0.26 | A | A | 0.21 | A | 0.37 | A |
| 21 | Foraminifera | 0.43 | 3.61 | 0.68 | 2.56 | 0.47 | 7.19 | 0.37 | A |
| 22 | Gastropoda | 0.32 | 0.26 | A | A | 0.02 | A | 0.55 | 1.05 |
| 23 | Halobates | A | A | A | A | 0.02 | A | A | A |
| 24 | Invertebrate egg | 5.10 | 1.80 | 1.35 | A | 6.37 | A | 2.39 | A |
| 25 | Isopoda | 0.02 | A | A | A | 0.02 | A | A | A |
| 26 | Medusae | 0.39 | A | A | A | 0.28 | A | 0.18 | A |
| 28 | Ostracoda | 1.12 | 3.87 | 8.78 | 5.13 | 5.14 | 0.98 | 3.50 | 4.74 |
| 29 | Polychaeta | 1.01 | 1.03 | 1.35 | A | 0.75 | 4.58 | 1.84 | 2.63 |
| 30 | Pteropoda | 0.30 | A | A | A | 0.19 | A | 0.55 | A |
| 33 | Radiolaria | 0.19 | 0.77 | A | A | 0.05 | A | 0.18 | 0.53 |
| 34 | Salpida | 0.43 | 0.26 | A | A | 0.28 | A | A | A |
| 35 | Siphonophora | 0.56 | A | A | A | 0.42 | A | A | A |
| | Number of groups | 21 | 11 | 6 | 4 | 20 | 6 | 14 | 7 |
| | Individuals 100 $m^{-3}$ | 248000 | 839 | 592 | 78 | 85680 | 765 | 2172 | 380 |

‘A’ denotes absent

Table 4.10. Contd.

| | | Various depth strata (m) at CB5 | | | |
|---|---|---|---|---|---|
| Gr. No: | Groups | 0-30 | 30-200 | 200-300 | 300-500 |
| 2 | Amphipoda | 0.57 | 0.21 | A | A |
| 4 | Appendicularia | 0.75 | A | A | A |
| 5 | Bivalvia | 0.03 | A | A | A |
| 8 | Cephlaopod larva | 0.01 | A | A | A |
| 9 | Chaetognatha | 3.43 | 1.05 | 3.27 | 4.88 |
| 11 | Cladocera | 0.12 | A | A | A |
| 13 | Copepoda | 81.42 | 85.47 | 91.59 | 90.24 |
| 15 | Decapoda | 0.14 | A | A | A |
| | Brachyuran zoea | 0.04 | A | A | A |
| | Lucifer | 0.02 | A | A | A |
| | Lucifer protozoea | 0.02 | A | A | A |
| | Megalopa | 0.01 | A | A | A |
| | Sergestes larvae | 0.05 | A | A | A |
| | Thalassocaris | 0.01 | A | A | A |
| 16 | Doliolida | 0.03 | A | A | A |
| 18 | Euphausiacea | 0.65 | 1.26 | 3.74 | A |
| | Euphausiid larva | 0.02 | A | A | A |
| | Euphausiid protozoea | 0.30 | A | A | A |
| | Euphausiids | 0.33 | 1.26 | 3.74 | A |
| 21 | Foraminifera | 1.39 | 0.84 | A | A |
| 22 | Gastropoda | 0.37 | A | A | A |
| 24 | Invertebrate egg | 2.68 | 0.42 | A | A |
| 25 | Isopoda | 0.03 | A | A | A |
| 26 | Medusae | 0.42 | A | A | A |
| 27 | Mysida | 0.21 | A | A | A |
| 28 | Ostracoda | 4.32 | 1.89 | 0.47 | 2.44 |
| 29 | Polychaeta | 1.10 | 2.11 | 0.93 | 2.44 |
| 30 | Pteropoda | 0.30 | 0.21 | A | A |
| 33 | Radiolaria | 0.10 | 6.53 | A | A |
| 34 | Salpida | 0.07 | A | A | A |
| 35 | Siphonophora | 0.45 | A | A | A |
| | Number of groups | 22 | 10 | 5 | 4 |
| | Individuals 100 $m^{-3}$ | 124467 | 594 | 428 | 41 |

‘A’ denotes absent

Table 4.11. Mesozooplankton groups absent from different depth strata in the central Bay during spring intermonsoon. Refer to Table 4.3 for the names of individual groups corresponding to the group numbers

| Sampling station | Groups absent in different depth (m)strata | | | |
|---|---|---|---|---|
| | 0-MLD | TT-BT | 200-300 | 300-500 |
| CB1 | 1-3, 6, 7, 10-12, 14-17, 19, 20, 23, 25, 27, 30-32, 34, 36, 37 | 3-8, 10-12, 14-17, 19, 20, 22, 23, 27, 30-32, 34-37 | 1-3, 5-8, 10, 11, 14, 16, 17, 19, 22, 23, 25, 27, 30-32, 35-37 | ND |
| CB2 | 1, 3, 7, 8, 10, 12, 14, 17, 19, 23, 31-33, 36, 37 | 1, 3, 6-8, 10, 14, 17, 19, 23, 27, 31, 32, 36, 37 | 1-3, 5-8, 10, 11, 14, 16, 17, 22, 23, 25-27, 30-32, 34-37 | 1-8, 10-12, 14-20, 22, 23, 25-27, 30-37 |
| CB3 | 3, 5-8, 10, 14, 17, 19, 23, 27, 31, 32, 36, 37 | 1-8, 10-12, 14, 16, 17, 19, 20, 23, 25-27, 30-32, 35-37 | 1-8, 10-12, 14-20, 22, 23, 25-27, 30-37 | 1-3, 5-12, 14-20, 22-27, 29-37 |
| CB4 | 1, 3, 5-8, 10, 12, 14, 17, 19, 27, 31, 32, 36, 37 | 1, 3-8, 10-12, 14-20, 22-27, 30-37 | 1, 3, 5-8, 10, 12, 14-17, 19, 20, 23, 25, 27, 31, 32, 34-37 | 1-8, 10, 12, 14-21, 23-27, 30-32, 34-37 |
| CB5 | 1, 3, 6, 7, 10, 12, 14, 17, 19, 23, 31, 32, 36, 37 | 1, 3-8, 10-12, 14-17, 19, 20, 22, 23, 25-27, 31-32, 34-37 | 1-8, 10-12, 14-17, 19-27, 30-37 | 1-8, 10-12, 14-27, 30-37 |

ND: No data as no zooplankton was present

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

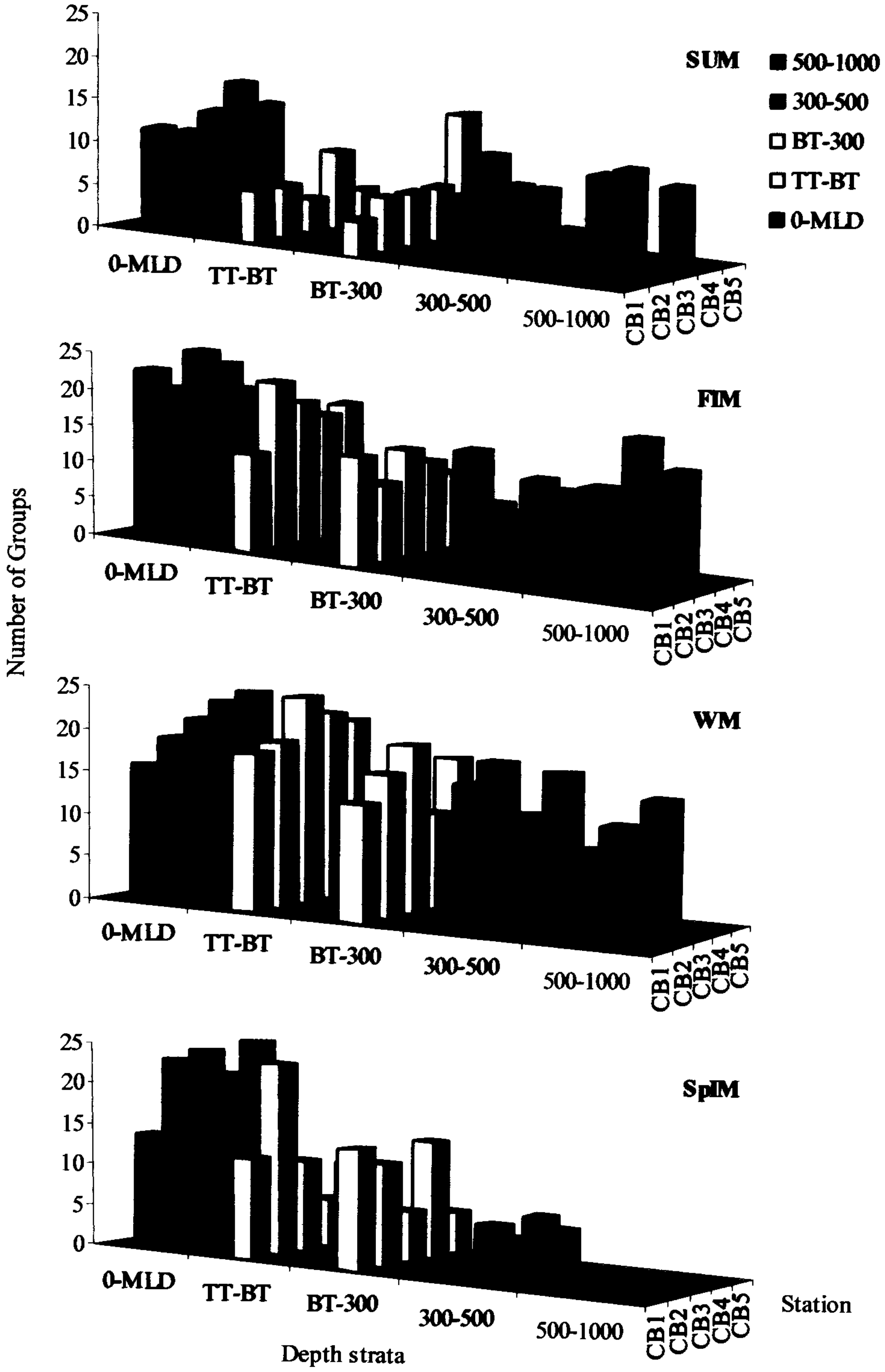


Figure 4.7. Depth-wise variation in the number of groups at each station in the central Bay during different seasons (SUM: summer monsoon, FIM: fall intermonsoon, WM: winter monsoon; SpIM: spring intermonsoon)

Only four to six of the 37 groups observed dominated numerically in the CB ( Fig. 4.8). Groups having an abundance ≥2% of the total mesozooplankton abundance were considered as dominant. Some salient features on their spatio-temporal distribution are listed below. In the overall, Copepoda was predominant during all the seasons, at all stations and depths. Distribution (depth-wise and latitudinal) of the predominant groups is described below.

### 4.2.6. Vertical distribution of predominant groups

Copepods ranged from 76 to 90% of the total abundance during SUM (Fig. 4.8). Their percentage decreased to a minimum in the 200-300 m stratum, where the abundance of chaetognaths (range: 2.6-9.3%), the second abundant group, was the maximum. Euphausiacea (0.5-6%) and ostracods (0.6-4%) were also abundant in this stratum. Polychaetes (0.1-4%) were the most abundant in the thermocline.

During FIM too, copepods contributed 74 to 90% of total abundance. Abundance of second major group, Chaetognatha (1.6-5.7%), decreased with increasing depth. Ostracods contributing 1.6-4.8% were most abundant in the thermocline. Euphausiids (0.6-1.6%) were preponderant in the 300-500 m column. Appendicularia (0.3-7%) were more in the first two-strata. Foraminifera (0.8-2.6%) were observed in all the sampled strata.

Copepods accounted for 74 to 93% of the abundance during WM. Ostracods (2.8-7.2%) and chaetognaths (1.4-7.6%) decreased relatively with increasing depth. High abundance of medusae (none-7%) was found only in the150-300 m stratum.

During SpIM, abundance of Copepoda ranged from 78 to 85%. Ostracoda (2.7-6.6%) was the second major group with its percentage increasing from surface to 500 m. In contrast, chaetognaths (1.9-4%) decreased. Foraminifera (0.6-3.1%) and invertebrate eggs (1.2-6.5%) were the other major groups throughout the upper 500 m.

### 4.2.7. Latitudinal distribution of the predominant groups

Except for CB1 during SUM, copepods showed an increasing trend towards northern Bay during SUM, FIM and SpIM (Fig. 4.9). Similar trend was also observed in case of Appendicularia during FIM. Medusae were dominant at the northernmost station, CB5

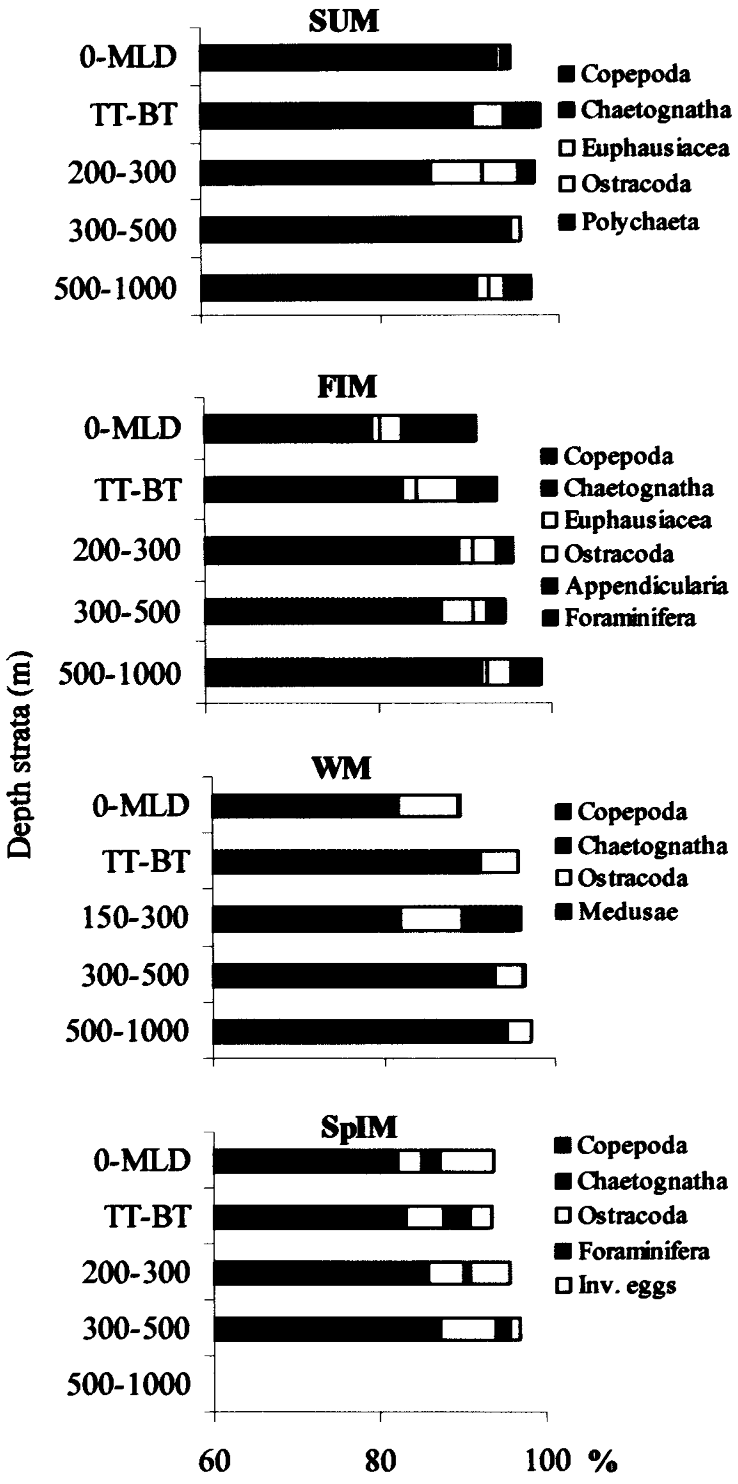


Figure 4.8. Distribution of dominant groups (> 2%) in each stratum in the central Bay during different seasons (SUM: summer monsoon, FIM: fall intermonsoon, WM: winter monsoon; SpIM: spring intermonsoon). Inv. eggs: invertebrate eggs

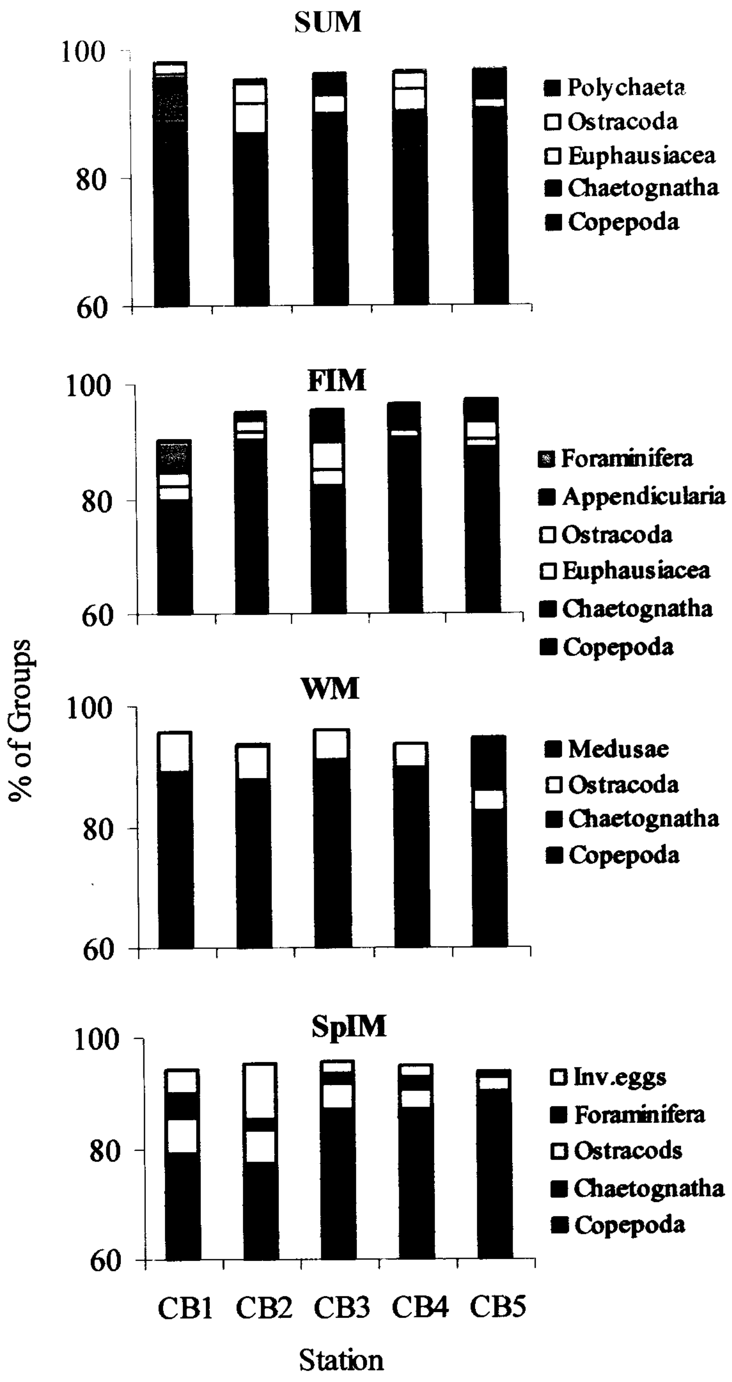


Figure 4.9. Distribution of dominant groups (> 2%) at different stations in the central Bay during different seasons (SUM: summer monsoon, FIM: fall intermonsoon, WM: winter monsoon; SpIM: spring intermonsoon). Inv. eggs: invertebrate eggs

Table 4.12. Various statistical (non-parametric tests) analyses to distinguish diel, spatial and temporal differences in mesozooplankton biovolume and abundance in the central Bay of Bengal

Wilcoxon Matched Pairs Test between day and night

| | Biovolume | | | | Abundance | | | |
|---|---|---|---|---|---|---|---|---|
| Seasons | N | T | Z | *p* | N | T | Z | *p* |
| SUM | 18 | 26.5 | 2.4 | **$p<0.05$** | 20 | 66 | 1.5 | $p>0.05$ |
| FIM | 20 | 81.0 | 0.2 | $p>0.05$ | 18 | 62 | 1.0 | $p>0.05$ |
| WM | 24 | 106.0 | 0.7 | $p>0.05$ | 25 | 121 | 0.8 | $p>0.05$ |
| SpIM | - | - | - | - | - | - | - | - |

Friedman ANOVA to test difference between depths

| | Biovolume | | | | Abundance | | | |
|---|---|---|---|---|---|---|---|---|
| Seasons | Chi Sqr. | N | df | *p* | Chi Sqr. | N | df | p |
| SUM | 14.5 | 5 | 5 | **$p<0.05$** | 14.2 | 5 | 4 | **$p<0.05$** |
| FIM | 18 | 5 | 5 | **$p<0.05$** | 17.1 | 5 | 4 | **$p<0.05$** |
| WM | 15.4 | 4 | 4 | **$p<0.05$** | 18.4 | 4 | 4 | **$p<0.05$** |
| SpIM | 8.4 | 5 | 2 | **$p<0.05$** | 12 | 4 | 3 | **$p<0.05$** |

Friedman ANOVA to test the difference between stations

| | Biovolume | | | | Abundance | | | |
|---|---|---|---|---|---|---|---|---|
| Seasons | Chi Sqr. | N | df | p | Chi Sqr. | N | df | *p* |
| SUM | 3.8 | 5 | 4 | $p>0.05$ | 5.3 | 5 | 4 | $p>0.05$ |
| FIM | 11.1 | 5 | 4 | **$p<0.05$** | 10.4 | 5 | 4 | **$p<0.05$** |
| WM | 6.7 | 4 | 4 | $p>0.05$ | 5.6 | 5 | 4 | $p>0.05$ |
| SpIM | 0.7 | 4 | 4 | $p>0.05$ | 1.3 | 3 | 4 | $p>0.05$ |

Friedman ANOVA to test the difference between seasons

| | Chi Sqr. | N | df | *p* |
|---|---|---|---|---|
| Biovolume | 9.5 | 20 | 3 | $p<0·05$ |
| Abundance | 22.6 | 19 | 3 | $p<0·05$ |

The Wilcoxon test could not be obtained during SpIM due to insufficient data values in day-night pairs; Significant results are marked **bold**

Table 4.13. Correlation coefficients between mesozooplankton biomass, abundance and number of groups (from mixed layer depth) and temperature, salinity, chl *a* (average from upper 120 m) in the central Bay of Bengal

| Parameters | Biovolume | Abundance | Groups |
|---|---|---|---|
| **SUM** | | | |
| Temp | **-0.714** | -0.425 | -0.035 |
| Salinity | 0.168 | 0.262 | -0.336 |
| Chl *a* | 0.659 | 0.175 | 0.231 |
| **FIM** | | | |
| Temp | 0.387 | 0.395 | 0.117 |
| Salinity | **0.769** | **0.840** | -0.098 |
| Chl *a* | **0.939** | **0.908** | 0.441 |
| **WM** | | | |
| Temp | -0.452 | -0.297 | -0.245 |
| Salinity | -0.375 | -0.478 | -0.674 |
| Chl *a* | 0.528 | 0.580 | -0.255 |
| **SpIM** | | | |
| Temp | **0.703** | -0.131 | -0.078 |
| Salinity | -0.349 | -0.673 | -0.497 |
| Chl *a* | **0.876** | 0.394 | 0.475 |

**Bold** **r**-values are significant at $p<0.05$

Table 4.14. Spatio-temporal variation in number of zooplankton groups in the central Bay as determined through one/two way ANOVA

| **Groups** | **ANOVA** | |
|---|---|---|
| | Two-way ANOVA | |
| | SUM | FIM |
| Between depths | $F_{(4, 24)}=4.0$, **$p<0.05$** | $F_{(4, 24)}=12.7$, **$p<0.001$** |
| Between stations | $F (4, 24)=0.4$, $p>0.05$ | $F_{(4, 24)}=0.9$, $p>0.05$ |
| | WM | SpIM |
| Between depths | $F_{(4, 24)}=19.7$, **$p<0.001$** | $F_{(3, 19)}=11.3$, **$p<0.001$** |
| Between stations | $F_{(4, 24)}=0.7$, $p>0.05$ | $F_{(4, 19)}=0.9$, $p>0.05$ |
| | One-way ANOVA | |
| Between seasons | $F_{(3, 91)}=10.9$, $p<0.001$ | |

Significant results are marked **bold**

during WM. High abundance of chaetognaths was observed at stations CB2 and CB3 during SUM coinciding with the lowest copepod abundance. However, they did not show any latitudinal variability during other seasons. Euphausiids and polychaetes did not show any latitudinal trend in any season when they were dominant. Ostracods occurring in higher percentage during WM and SpIM were more in the southern Bay. Similar was the case of Foraminifera and invertebrate eggs during the intermonsoons, FIM and SpIM.

## 4.3. Discussion

### 4.3.1. Spatio-temporal variations in biovolume, biomass and abundance

On a seasonal basis, the average zooplankton biovolume (ml 100 $m^{-3}$) in the 1000 m was higher during SUM (39.3) and SpIM (40.4) compared to FIM (12.7) and WM (13.8). Historical data from the IIOE show that biovolume in the Bay range between 0.1 and 9.9 ml per standard haul during WM (Duing 1970). During March- April (SpIM), large patches in the Bay with volumes ranging from 10 to 19.9 ml have been reported. In other areas in the CB, the volumes were low (in the range of 0.1-9.9 ml). The results from this study indicate that the central Bay has higher mesozooplankton biovolume during SUM and SpIM. In these two seasons, the integrated chl *a* in the upper 120 m was lower (10 and 16 mg $m^{-2}$; Chapter 3) probably due to elevated grazing pressure than that was observed during either FIM or WM (18 and 27 mg $m^{-2}$). Similar results are reported from Arabian Sea by many authors (Smith 1982; Baars and Oosterhuis 1998; Ashjian et al. 2002). They also suggest that the low chl *a* was due to grazing by zooplankton. Also, large swarms of *Pyrosoma*, observed during SUM could have also reduced the phytoplankton.

The IIOE data suggests that the Bay is more productive during WM (Panikkar and Rao 1973). Though this is not reflected in the zooplankton biovolumes, the integrated carbon biomass and abundance in the upper 1000 m in the central Bay is higher during WM and FIM compared to the two other seasons SUM and SpIM. Cold-core eddies are known to pump in or re-supply nutrients into the euphotic layer and, enhance phytoplankton production within such eddies (Falkowski et al. 1991; Vaillancourt et al. 2003). The stations CB1 and CB5 during SUM as well as FIM, CB5 during WM and CB3 and CB4 during SpIM were located in the vicinity of cold-core eddies. At these stations, there was higher biovolume and numerical abundance of mesozooplankton having positive correlations with chl *a*. This observation is similar to one reported earlier by Wiebe (1976), Beckmann et al. (1987) and Huntley et al. (1995).

### 4.3.2. Seasonal variations in community structure

As mentioned earlier, the hydrography of the Bay undergoes seasonal changes. The central Bay experiences a warm pool and low surface salinities throughout the seasons. The SST (28.7, 28.8, 28.1 and 29.9°C during SUM, FIM, WM and SpIM respectively) and SSS (31.4, 31.5, 32.8 and 32.9 psu respectively for the same seasons) did show minor variations seasonally. The dissolved oxygen concentrations and the thickness of the low oxygen (5-10 µM) zone also varied. It was larger during SUM (roughly between 100-700 m), thinner during FIM (100-600 in particular between CB3 and CB5) as well as during SpIM (200-500 m between CB3 and CB5) and was absent during WM. Similarly, the standing stocks and groups of zooplankton are known to vary in the northern Indian Ocean seasonally (Rao 1973, 1979). Jyothibabu et al. (2004) showed that zooplankton biomass from the open waters of BoB was lesser than in the central Arabian Sea by 50%. However, results from present study (75-134 mM C $m^{-2}$) imply that they are closely comparable to those in the Arabian Sea (73-158 mM C $m^{-2}$; Madhupratap et al. 1996 a).

To avoid visual predators in the surface during the day, zooplankton have been reported to move subsurface (Longhurst and Williams 1992; Goswami et al. 2000). During this study, diel variations were insignificant during most seasons. During SUM, the diel difference in biovolume was significant due to the occurrence of large swarms of herbivorous *Pyrosoma* in the surface during day-time. Most of the biovolume was concentrated in the MLD and decreased significantly with increasing depth as also observed in previous studies (Vinogradov 1970, 1997; Banse 1994 and Wishner et al. 1998; Padmavati et al. 1998; Madhupratap et al. 2001). Mesozooplankton are the maximum in the uppermost stratum where concentrations of chlorophyll are more and primary production takes place (Longhurst and Harrison 1989; White et al. 1995). Thus the decrease in their abundance at subsurface depths is a universal feature in tropical oceans (Vinogradov 1997). This was also reflected in the number of groups, which was the largest only in the MLD.

Since only 21 groups occurred during all the seasons, this means that a significant number, *i.e.* ~ 50% of the groups occurred only seasonally. Stereozoom and light microscopy photographs of some groups identified from the Bay are given in Plates 1-5. The number of groups recorded during SUM and SpIM (27) were lower compared to those recorded during FIM and WM (31). Also, in spite of higher biovolumes of zooplankton, their carbon biomass was lower during the former two seasons (SUM: 78, SpIM: 75 mM C $m^{-2}$) than in the latter seasons (FIM: 112 WM: 134 mM C $m^{-2}$). *Pyrosoma*, the holoplanktonic colonial tunicates appeared in dense aggregations and contributed to most of the biovolume during SUM. They are known to be restricted to warmer waters (Van Soest 1981). Their trophic function in the ocean, as well as their ecology and physiology are extremely poorly known (Perissinotto et al. 2007).

During SpIM large biovolumes in the surface were due to scyphomedusae. Though gelatinous zooplankton such as pyrosomes and scyphomedusae have large biovolumes, their carbon content is low compared to crustaceans (Clarke et al. 1992). This might be the major cause for lower carbon biomass during these two seasons in the CB. During SUM, the lowest number of groups was found in the thermocline, which gradually increased in the deeper strata. Also the seasonal difference in the decrease of number of groups with depth seems to be a direct reflection of variations in subsurface oxygen concentration. This can be confirmed from the drastic decrease in the number of groups in the subsurface during SUM, which coincided with the thickest OMZ.

Copepods are the most abundant and diverse metazoans in all pelagic ecosystems (Longhurst 1985). As also reported in many earlier studies (Padmavati et al. 1998; Madhupratap and Haridas 1990; Madhupratap et al. 2001; Koppelmann and Weikert 2000; Rakhesh et al. 2006), it was the dominant taxon in the CB during all the seasons. Carnivorous chaetognaths and omnivorous ostracods were the other major groups present during all the seasons. These three groups were also found to be dominant in the Arabian Sea (Padmavati et al.1998; Madhupratap and Haridas 1990; Madhupratap et al. 2001).

Chaetognath abundance in the upper 200 m (Ulloa et al. 2000) and progressive decrease with increasing depth has already been reported (Nair 1977; Batistic et al. 2003). Their population density is thought to reduce with rapidly decreasing temperature (Nair et al. 2000). Further, their population did not show much of latitudinal variation, as was also found during the IIOE (Nair and Rao 1971). It is very probable that the distribution of chaetognaths in the offshore waters is also severely affected by the reversal of currents caused by monsoon (Tokioka 1962). Contrary to the observations in the IIOE (Panikkar and Rao 1973), ostracod abundance was more in the southern Bay. Albeit poorer in abundance than the Arabian Sea, ostracods showed seasonal fluctuations and were more abundant during WM and SpIM. Latitudinal zonation patterns in ostracod distributions were observed in the Southern Ocean (Angel and Blachowiak-Samolyk 2007). Numerically, they are often the second or third most abundant group in mesoplankton samples and play a significant role in the recycling of organic matter in the marine snow and fecal pellets within subthermocline. Similar to the observations in the Northeast Atlantic (Angel et al. 2007), ostracod abundances increased in the CB rapidly below the thermocline during most seasons, reaching maxima at 200–400 m before declining again with depth.

Investigations on the pelagic polychaetes of the Indian Ocean are few (Fauvel 1953). In general, they are adapted for tubiculous, burrowing or bottom dwelling life style with planktonic larval stages. However, only a few polychaete species are planktonic even in their adult stages, *e.g.*, Tomopteridae and Alciopidae. Pelagic polychaetes were found abundantly in the Bay as well as in the AS (Peter 1973 a, b) with some species in high numbers in the surface waters though with marked seasonal and diurnal variations. In this study, they were present throughout the water column only during SUM. The appendicularians were present in the upper 200 m in the northern CB. They are reported to be remarkably efficient in capturing food particles of nano-and pico-size categories (0.2-20 µm; Flood 1978; King et al. 1980; Alldredge 1981), which can hardly be captured by copepods. From the higher abundance of medusae in the northernmost station observed during the WM, it appears that the Bay of Bengal harbors a peculiar assortment of species/genera of medusae that prefer or tolerate a combination of high temperature and low salinity as also suggested by Vannucci and Navas (1973).

Though diel differences were not clearly evident in biomass values, higher percentage of euphausiids at subsurface depths was a noticeable feature during SUM and FIM. Kinzer (1969) found deep scattering layers (DSL) to be rich in zooplankton biovolumes mostly composed of euphausiids and copepods. Dominance of euphausiids in certain depth levels has been observed in other studies also (Moore 1950; Tucker 1951; Brinton 1967 and Longhurst 1967). Foraminifera became a major group during the warm, high-saline period of SpIM. They also were abundant in the southern Bay in particular during FIM.

As Ryther (1969) pointed out, it has been increasingly apparent that the bulk of primary productivity in oceanic waters is by the nanophytoplankton, which range in size between ~5 and 25 μm. In general, the nanoplanktonic organisms are too small to be captured by most metazoan herbivores. Before the energy they embody can be utilized, it must be assimilated by small herbivores, and these are chiefly the planktonic protozoans, such as Foraminifera. During the intermonsoons, the foraminifers may be preyed upon in turn by small carnivorous zooplankton, including chaetognaths (Croce 1963), thecosome pteropods (Boas 1886), and others. Thus, as also observed in the Arabian Sea (Madhupratap et al. 1996 a, b), the microbial loop may play an important role in sustaining high biomass of zooplankton in the surface in particular during the intermonsoons.

From the foregoing, it can be summarized that the variability in biomass and abundance of zooplankton is affected directly by the seasonal changes in physical parameters, and also indirectly by alterations in nutrient (chemical) and chl *a* (biological) concentrations. During SUM and SpIM, the CB had higher biovolumes consisting of *Pyrosoma* and cnidarians with lower carbon biomass. However, during FIM and WM, despite lower biovolumes, the carbon content was higher. Further, the number of groups was found to be lower during SUM and SpIM than those recorded either during FIM and/or WM. Also, cyclonic eddies play a crucial role in supporting higher zooplankton biomasses (75-134 mM C $m^{-2}$), the values of which nearly match those in the central Arabian Sea (73 –158 mM C $m^{-2}$). From the IIOE data, the zooplankton biomass in the central Bay was estimated to aid in producing tertiary production of 0.5 Million tons per 5X5° square (Cushing et al. 1971). With India's annual fish catch of ~ 30% (CMFRI 1970) coming from the Bay of Bengal, the large amounts of zooplankton carbon in the offshore are indicative of supporting rich pelagic fisheries.

# Chapter 5

# Chapter 5

## *Different Groups of Mesozooplankton from Western Bay*

As described in Chapter 4, the hydrography of the Bay of Bengal is influenced by semi annually reversing monsoon winds, river runoff ($1.6 \times 10^{12}$ $m^3 yr^{-1}$; Subramanian 1993) and annual precipitation (~1m $yr^{-1}$; Baumgartner and Reichel 1975) exceeding evaporation. These physical forcings keep the upper layers in the western bay (WB) highly stratified and the surface salinity is lower in particular in the northern parts. As mentioned earlier, the seasonally reversing EICC (East India Coastal Current) is northward during summer monsoon (SUM) and Equator-ward during fall intermonsoon (Wyrtki 1971; Murty et al. 1992; Gopalakrishna et al. 1996; Han and McCreary 2001). The southwesterly winds prevalent during SUM are favourable for offshore Ekman transport and vertical advection in the WB. La Fond (1957), Murty and Varadachari (1968), Shetye et al. (1991) and Rao (2002) have reported upwelling along the near-shore WB during this season. Wind driven vertical advection and mixing have been observed to transport nutrients from within and below the thermocline up into the euphotic zone. These processes replenish nutrient concentrations in the upper layers during the SUM (Bhavanarayana and La Fond 1957; Thirupad et al. 1959). Madhu et al. (2002) reported primary production and chlorophyll (chl) *a* distribution in the upwelling regions of the southern WB during SUM.

Most previous biological studies in the WB have focused on the seasonal variation in primary productivity. Abundance and composition of mesozooplankton are addressed by a very few studies (Panikkar and Rao 1973; Achuthankutty et al.1980; Nair et al. 1981; Madhupratap et al. 2003; Muraleedharan et al. 2007; Rakhesh et al. 2006). In the stratified layers of the Bay, cyclonic eddy-pumping is thought to be a possible mechanism for transferring nutrients into the euphotic zone and increasing biological production during most part of the year (Gomes et al. 2000; Prasannakumar et al. 2004, 2007). Eddy-mediated elevated zooplankton biovolumes associated with increased primary production has been reported in the Bay (Muraleedharan et al. 2007). As also mentioned in Chapter 4, many studies from the Atlantic and Pacific regions are available on the spatio-temporal distribution of zooplankton (Roman et al. 1995; Smith et al. 1998; Madin et al. 2001; Mauny and Dauvin 2002; Schnetzer and Steinberg 2002 b; Gaudy et al. 2003; Koppelmann et al. 2003; Kang et al. 2004; Yamaguchi et al. 2005; Fernandez-Alamo and Farber-Lorda 2006; Li et al. 2006; Alcaraz et al. 2007).

In the Indian Ocean, investigations of Madhupratap et al. (1996), Padmavati et al. (1998), Goswami et al. (2000) and Jayalakshmy (2000) among many others have addressed these aspects mostly from the Arabian Sea. In particular, a large number of studies on seasonal cycles of mesozooplankton are available from the western Arabian Sea (Wishner et al. 1998; Smith 1998, 1999, 2000, 2001; Smith et al. 1998; Stelfox et al. 1999; Hitchcock et al. 2002; Koppelmann et al. 2005). High zooplankton standing stocks in the mixed layer are known to occur in the eastern Arabian Sea throughout the year (Madhupratap et al. 1996 a) due to coastal upwelling during SUM, convective mixing in winter and through the microbial loop in the intermonsoon.

As also pointed out in Chapter 4, after the IIOE (International Indian Ocean Expedition; 1960-1965), the western Bay of Bengal also remains one of the sparsely investigated regions of the Indian Ocean especially in terms of zooplankton biomass and composition below 200 m depth. The seasonal studies on the distributional patterns of mesozooplankton from the upper 1000 m and their response to primary production associated with basin-scale hydrographic processes in the WB are not yet reported. Knowledge of mesozooplankton abundance, distribution and composition in space and time is important for understanding regime shifts in their communities, their possible effect on fisheries, carbon budgets and climate change. In this chapter, spatial and seasonal variations in mesozooplankton biomass, their numerical abundance, and group composition in the upper 1000 m, at four stations in the western Bay during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM) would be addressed.

## 5.1. Methods

### 5.1.1. Sampling

Sampling sites in the western Bay (WB) of Bengal were from four locations *viz.* WB1 to WB4 (12°N 81°E,15°N 82°E,17°N 83°E, 19°N 85°E). All other details of collection, biovolume measurements and group-wise enumeration of mesozooplankton and statistical analyses are as described in Chapter 4.

## 5.2. Results

### 5.2.1. Biovolume

As also recorded from central Bay (CB), zooplankton biovolume during all four seasons was the highest in the mixed layer depth (MLD; Fig. 5.1-5.4; Table 5.1). It decreased significantly with increasing depth during both monsoons and FIM. Nearly 93, 69, 63 and 80% of the biovolume was present in the MLD during the SUM, FIM, WM and SpIM respectively. In the WM, up to 11% biovolume was observed in the 300-500 m stratum. In the upper 1000 m, biovolume ranged from 0.2 to 120 (mean: 10.0 ml 100 $m^{-3}$) during SUM, negligible to 115 (15.4 ml 100 $m^{-3}$) during FIM, 1.0-142 (34.0 ml 100 $m^{-3}$) during WM and negligible to 533 (76.4 ml 100 $m^{-3}$) during SpIM. The higher biovolumes during SUM and SpIM were due to *Pyrosoma* swarms and scyphomedusae respectively. With the average biovolumes in the top1000 m increasing from SUM to SpIM, seasonal differences were highly significant (Table 5.12). Also, vertical migration patterns were not evident as there was no significant difference in biovolumes between the day and night in any season (Table 5.12).

Biovolumes were higher at WB3 during SUM and FIM, at WB1 and WB2 during WM and at WB3 and WB4 during SpIM. However, these differences were not statistically significant. When compared with the temperature in the top 120 m in different seasons, it was found to correlate negatively (Table 5.13). Temperature was lower and biovolumes higher at stations with cold-core eddies. However the relation with chlorophyll (chl) *a* was negative during all seasons but was significant only during SUM.

### 5.2.2. Abundance

Similar to biovolumes, the abundance (No.x 1000 individuals 100 $m^{-3}$) observed was greatest in the MLD during all seasons (Table 5.2) and decreased significantly with increasing depth. The diel difference in abundance was also negligible except during SpIM (Table 5.12). It ranged from negligible to 462 (mean: 31.8 x $10^3$ ind. 100 $m^{-3}$) during SUM, 0.7 to 136.3 (35.2 x $10^3$ ind. 100 $m^{-3}$) during FIM, 0.4 to 161.8 (38.4 x $10^3$

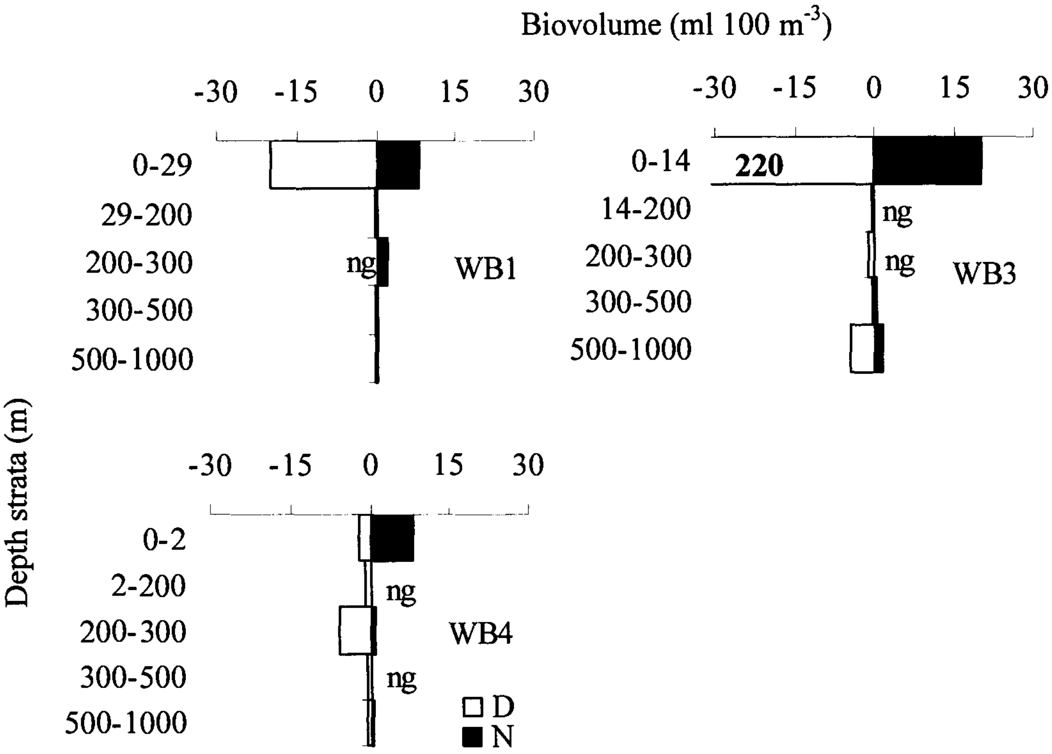


Figure 5.1. Vertical distribution of mesozooplankton biovolume during day and night sampling at different stations in the western Bay of Bengal during summer monsoon. 'ng' denotes negligible biovolume

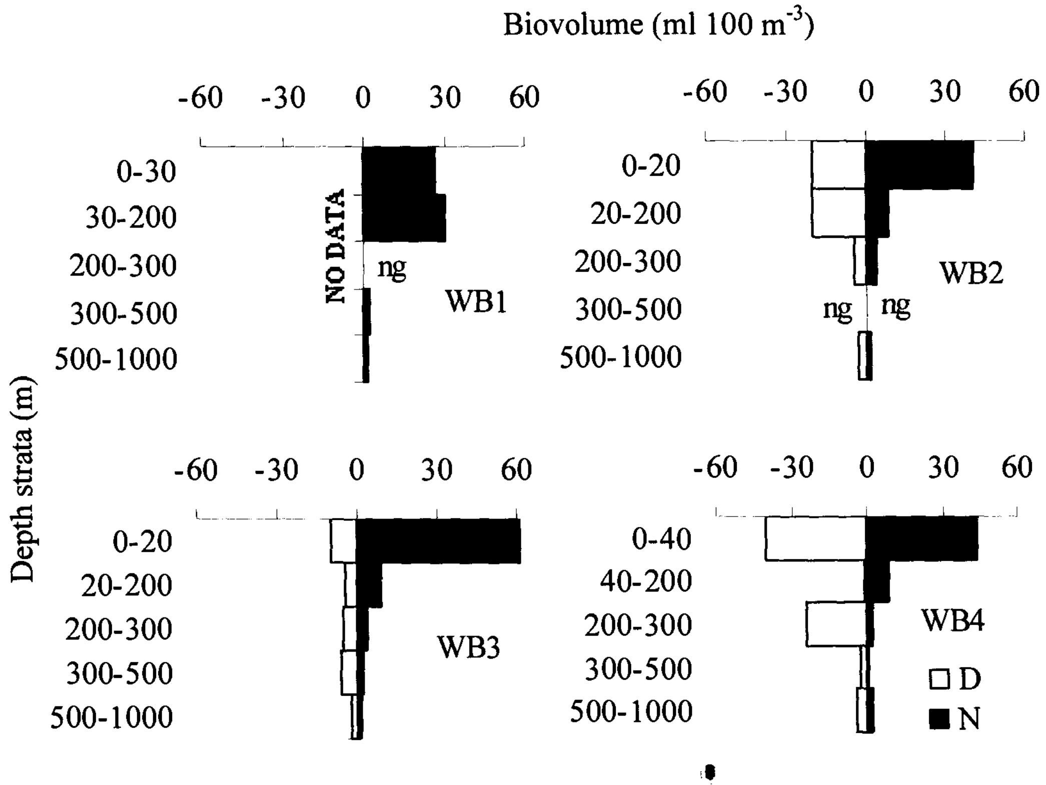


Figure 5.2. Vertical distribution of mesozooplankton biovolume during day and night sampling at different stations in the western Bay of Bengal during fall intermonsoon. 'ng' denotes negligible biovolume and 'NO DATA' is where net failed to open/close

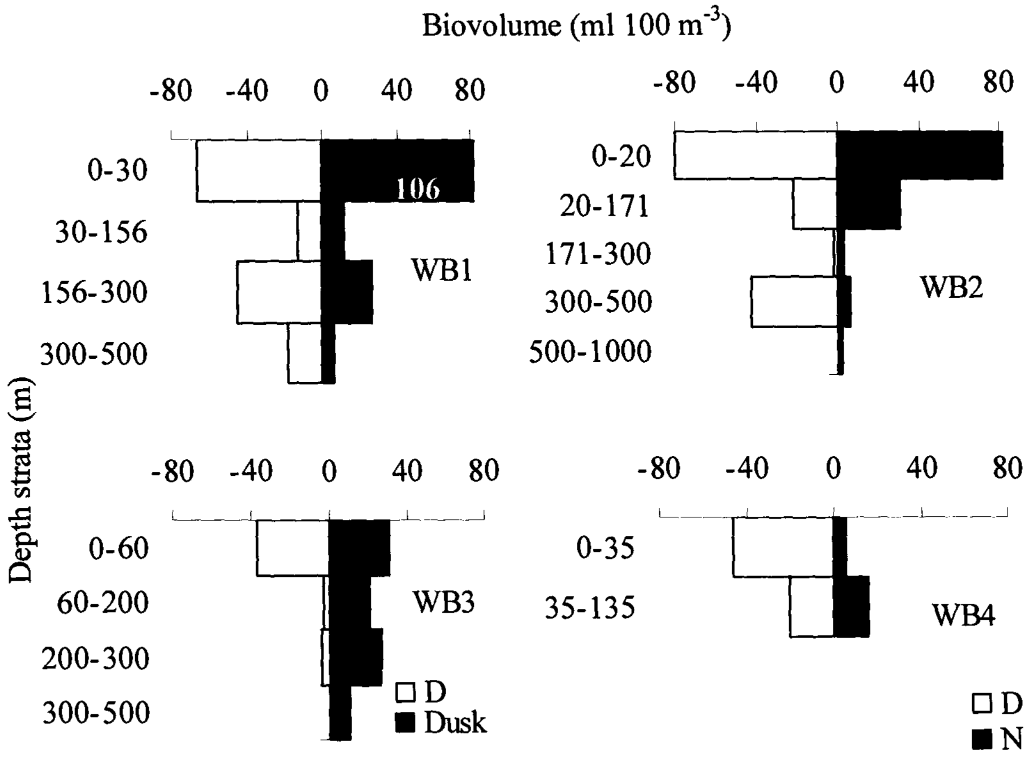


Figure 5.3. Vertical distribution of mesozooplankton biovolume during day and night sampling at different stations in the western Bay of Bengal during winter monsoon

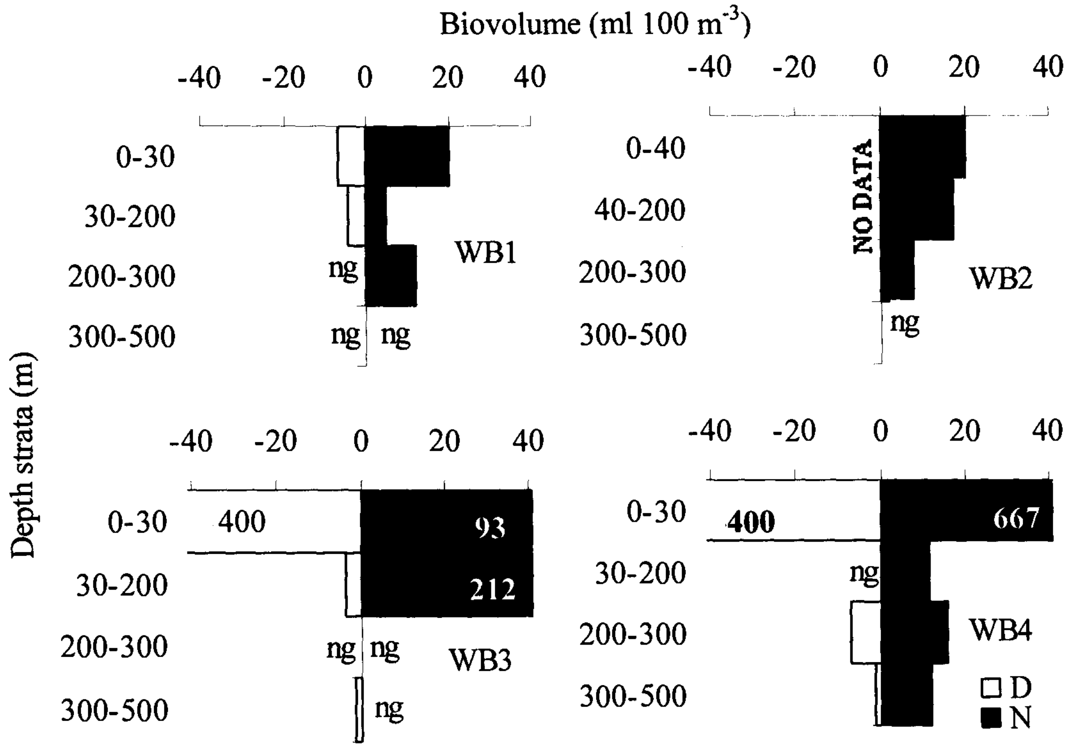


Figure 5.4. Vertical distribution of mesozooplankton biovolume during day and night sampling at different stations in the western Bay of Bengal during spring intermonsoon. 'ng' denotes negligible biovolume and 'NO DATA' is where net failed to open/close

Table 5.1. Mesozooplankton biovolume (ml 100 m$^{-3}$) and carbon biomass (mM C m$^{-2}$; in parentheses) in the western Bay of Bengal during different seasons

| | Sampling stations | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Depth (m)** | **WB1** | | **WB2** | | **WB3** | | **WB4** | |
| **Summer monsoon** | | | | | | | | |
| 0-MLD | 14.0 | (15.0) | ND | (ND) | *120.0 | (53.4) | 5.0 | (5.3) |
| TT-BT | 0.3 | (0.8) | ND | (ND) | ng | (ng) | 0.6 | (0.6) |
| BT-300 | 1.1 | (2.2) | ND | (ND) | ng | (ng) | 3.5 | (6.2) |
| 300-500 | 0.15 | (0.6) | ND | (ND) | 0.4 | (1.7) | 0.3 | (0.6) |
| 500-1000 | 0.15 | (0.5) | ND | (ND) | 3.0 | (32.1) | 0.5 | (1.7) |
| **Fall intermonsoon** | | | | | | | | |
| 0-MLD | 26.6 | (17.1) | 30.0 | (12.8) | 115.0 | (49.2) | 42.0 | (18.0) |
| TT-BT | 30.6 | (111.2) | 14.4 | (55.4) | 6.6 | (25.4) | 5.0 | (19.3) |
| BT-300 | ng | (ng) | 4.0 | (8.6) | 4.6 | (9.8) | 13.0 | (27.8) |
| 300-500 | 2.0 | (8.6) | ng | (ng) | 4.0 | (17.1) | 1.8 | (7.7) |
| 500-1000 | 1.6 | (17.1) | 2.2 | (23.5) | 1.8 | (19.2) | 3.0 | (23.5) |
| **Winter monsoon** | | | | | | | | |
| 0-MLD | 142.0 | (51.2) | 140.0 | (59.9) | 33.7 | (34.2) | 25.7 | (19.2) |
| TT-BT | 12.3 | (28.6) | 26.1 | (67.1) | 11.6 | (37.3) | 18.0 | (38.5) |
| BT-300 | 35.6 | (58.9) | 2.1 | (6.4) | 15.3 | (44.7) | ND | (ND) |
| 300-500 | 12.0 | (51.3) | 24.0 | (27.6) | 10.0 | (27.8) | ND | (ND) |
| 500-1000 | ND | (ND) | 1.0 | (10.7) | ND | (ND) | ND | (ND) |
| **Spring intermonsoon** | | | | | | | | |
| 0-MLD | 13.3 | (5.7) | 20.0 | (17.1) | 246.7 | (86.7) | 533.3 | (228.0) |
| TT-BT | 4.4 | (16.0) | 17.5 | (59.9) | 107.6 | (391.2) | 11.8 | (21.4) |
| BT-300 | 12.0 | (12.8) | 8.0 | (17.1) | ng | (ng) | 11.5 | (24.6) |
| 300-500 | ng | (ng) | ng | (ng) | 1.0 | (2.1) | 6.5 | (14.1) |

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

*high volumes due to swarms of *Pyrosoma*; ng- negligible biovolume; ND- no data (probably due to failure of net or due to shallower depth)

Table 5.2. Mesozooplankton numerical abundance (x $10^3$ individuals 100 $m^{-3}$) in the western Bay of Bengal during different seasons

|  | Sampling stations |  |  |  |
|---|---|---|---|---|
| **Depth (m)** | **WB1** | **WB2** | **WB3** | **WB4** |
| **Summer monsoon** |  |  |  |  |
| 0-MLD | 6.7 | ND | 462.1 | 1.71 |
| TT-BT | 0.0 | ND | 2.5 | 0.08 |
| BT-300 | 1.0 | ND | 0.0 | 0.90 |
| 300-500 | 0.0 | ND | 1.9 | 0.04 |
| 500-1000 | 0.0 | ND | 0.5 | 0.01 |
| **Fall intermonsoon** |  |  |  |  |
| 0-MLD | 136.3 | 99.1 | 129.1 | 131.3 |
| TT-BT | 41.2 | 39.1 | 8.7 | 7.9 |
| BT-300 | 5.5 | 4.8 | 44.3 | 15.1 |
| 300-500 | 2.8 | 0.8 | 15.8 | 13.4 |
| 500-1000 | 0.7 | 2.3 | 2.1 | 3.6 |
| **Winter monsoon** |  |  |  |  |
| 0-MLD | 161.8 | 139.6 | 72.9 | 35.3 |
| TT-BT | 7.3 | 17.8 | 41.6 | 31.8 |
| BT-300 | 34.3 | 3.1 | 5.2 | ND |
| 300-500 | 12.5 | 1.6 | 10.8 | ND |
| 500-1000 | ND | 0.4 | ND | ND |
| **Spring intermonsoon** |  |  |  |  |
| 0-MLD | 31.0 | 37.3 | 49.5 | 533.8 |
| TT-BT | 15.6 | 23.0 | 39.9 | 8.2 |
| BT-300 | 3.1 | 4.2 | 1.4 | 5.1 |
| 300-500 | 0.2 | 0.8 | 1.6 | 1.7 |

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

At some depths, there was no data (ND) either due to failure of the net to open/close or due to shallower depth in northernmost station ind. 100 m$^{-3}$) during WM and 0.2 to 533.8 (47.3 x 10$^3$ ind. 100 m$^{-3}$) during SpIM. The abundance in MLD was 98.6, 70.4, 68.3, and 86.1% during SUM, FIM, WM and SpIM respectively.

The average abundance in the upper 1000 m increased from SUM to SpIM and differed significantly between seasons. Though the station-wise differences in abundance were noticeable during some seasons, they were not statistically significant. During the SUM, the abundance was the highest at WB3; during FIM, it did not vary much. While during WM, the higher abundance was found at WB1, it was at WB4 during SpIM. These locations were in the vicinities of cold-core eddies as is also implicit from the negative correlations with temperature (Table 5.13). Similar to biovolume, abundance too correlated negatively with chl *a*, but significantly during SUM.

### 5.2.3. Cluster analyses and non-metric multidimensional scaling (NMDS)

Cluster and NMDS analyses imply that zooplankton biovolume and abundance distribution at various depths and stations (Fig. 5.5) during SUM were different compared to that during the other three seasons. Among the other three seasons, biovolume distribution was similar during the intermonsoons. However, the numerical abundance was similar during FIM and WM.

### 5.2.4. Column (0-1000 m) integrated abundance and carbon biomass

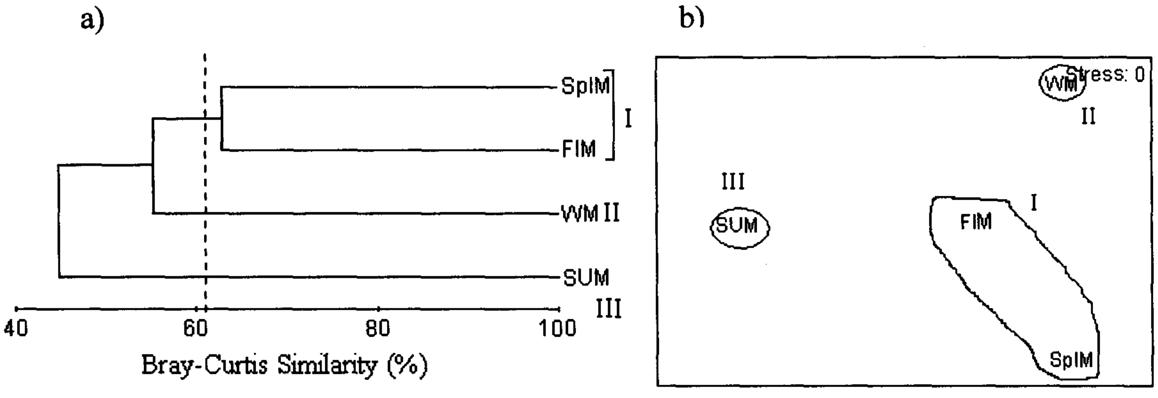
The integrated abundance during SUM, FIM, WM and SpIM respectively ranged from 2 to 53 (mean: 20 x 10$^3$ ind. 100 m$^{-2}$), 108 to 128 (120 x 10$^3$ ind. 100 m$^{-2}$), 44 to 155 (95 x 10$^3$ ind. 100 m$^{-2}$) and 38 to 182 (96 x 10$^3$ ind. 100 m$^{-2}$). It was the least during SUM, moderate during WM and SpIM, and the highest during FIM (Fig 5.6).

Similarly, the integrated carbon biomass (mM C m$^{-2}$) was 14-90 (mean: 42 mM C m$^{-2}$); 96-54 (118 mM C m$^{-2}$); 58-190 (141 mM C m$^{-2}$); and 35-480 (224 mM C m$^{-2}$) during the respective seasons (Fig. 5.6). It was found to increase from SUM to SpIM.

### 5.2.5. Groups

A total of 33 groups were identified from the western Bay (Table 5.3). Acantharia, Carinaria, Pterotrachea and Sipuncula that were present in rare numbers in the CB were

Biovolume



Abundance

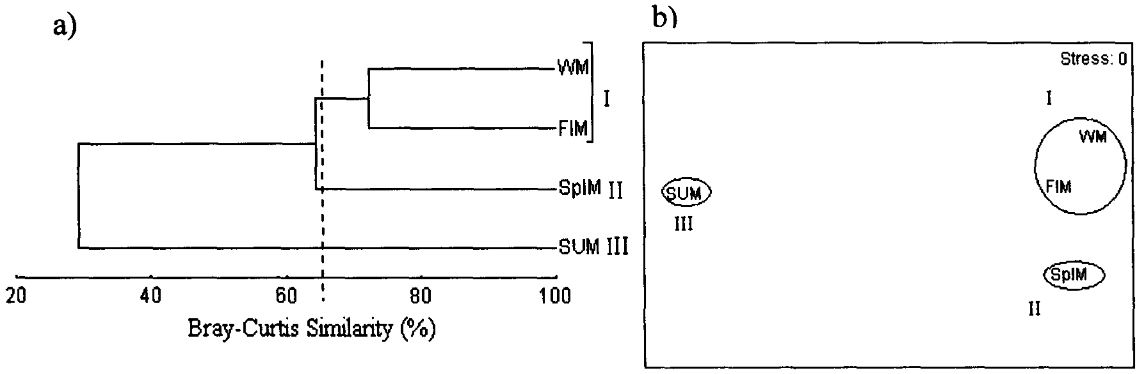


Figure 5.5. a) Cluster dendrograms depicting similarity between seasons based on biovolume and abundance of zooplankton in the western Bay. b) Non- metric multidimensional scaling (NMDS) ordination based on the Bray- Curtis similarity coefficients

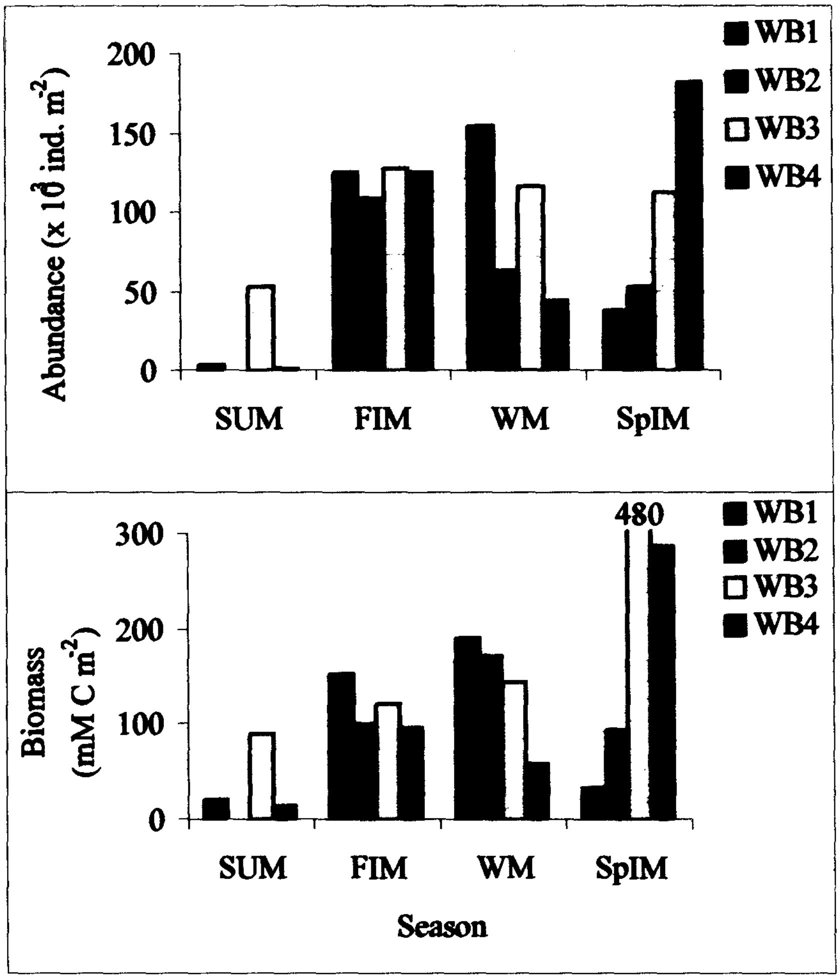


Figure 5.6. Latitudinal variations in the 0-1000 m column integrated mesozooplankton abundance ($10^3$ individuals m$^{-2}$) and biomass in the western Bay during different seasons (SUM: summer monsoon, FIM: fall intermonsoon, WM: winter monsoon; SpIM: spring intermonsoon)

Table 5.3. List of groups found in the western Bay

| Gr. No | Group | Gr. No | Group | Gr. No | Group |
|---|---|---|---|---|---|
| 2 | Amphipoda | | Hippolyte | 19 | Fish eggs |
| 3 | Anthozoa | | Lucifer | 20 | Fish larvae |
| 4 | Appendicularia | | Lucifer mysis | 21 | Foraminiferida |
| 5 | Bivalvia | | Lucifer protozoea | 22 | Gastropoda |
| 7 | Cephalochordata | | Megalopa | 23 | Halobates |
| 8 | Cephalopoda | | Palaemon | 24 | Invertebrate eggs |
| 9 | Chaetognatha | | Phyllosoma larvae | 25 | Isopoda |
| 10 | Cirripedia | | Porcellanid zoea | 26 | Medusae |
| 11 | Cladocera | | Sergestes larvae | 27 | Mysida |
| | Evadna | | Stenopus larvae | 28 | Ostracoda |
| 12 | Crustacean larvae | | Thalassocaris | 29 | Polychaeta |
| 13 | Copepoda | | Unidentified larvae | 30 | Pteropoda |
| 14 | Ctenophora | 16 | Doliolida | 32 | Pyrosomida |
| 15 | Decapoda | 17 | Echinodermata | 33 | Radiolaria |
| | Acetes | 18 | Euphausiacea | 34 | Salpida |
| | Alpheid | | Euphausiid larvae | 35 | Siphonophora |
| | Brachyuran zoea | | Euphausiid protozoea | 37 | Stomatopoda |
| | Callianasa | | Euphausiids | | |

Gr. No: Group Number; As can be noted, Groups 1 (Acantharia), 6(Carinaria), 31 (Pterotrachea) and 36 (Sipuncula) were absent in this transect not detected in any of the samples from the WB. The number of groups varied significantly with seasons and depth but not between stations (Table 5.14; Fig. 5.7).

Twenty groups *viz.* Amphipoda, Appendicularia, Cephalochordata, Chaetognatha, Crustacean larvae, Copepoda, Decapoda, Doliolida, Euphausiiacea, fish eggs, fish larvae, Foraminifera, Gastropoda, invertebrate eggs, Medusae, Ostracoda, Polychaeta, Pteropoda, Salpida and Siphonophora occurred during all seasons (Table 5.4-5.11). Cirripedia was found only during SUM. Pyrosomida that occurred in swarms in the MLD contributed much of the biomass during SUM and a few of its colonies were observed during WM. Bivalvia, Cephalopoda, Isopoda, Mysida and Radiolaria were present during all seasons except SUM. Anthozoa and Ctenophora were observed only during FIM. Stomatopods were observed in FIM and WM. Cladocera were not seen during WM. Halobates was recorded only during SpIM.

The least number of groups were recorded during SUM, and the highest during FIM. As much as nine groups *i.e.* Anthozoa, Bivalvia, Cephalopoda, Ctenophora, Halobates, Isopoda, Mysida, Radiolaria and Stomatopoda were not found during SUM (Table 5.4; 5.5). Only three groups (Cirripedia, Halobates and Pyrosomida; Table 5.6; 5.7) were absent during FIM. During WM, Anthozoa, Cirripedia, Cladocera, Ctenophora and Halobates were not present in samples (Table 5.8; 5.9). During SpIM, six groups (Anthozoa, Cirripedia, Ctenophora, Echinodermata, Pyrosomida and Stomatopoda; Table 5.10; 5.11) were absent at all stations.

As also in the CB, most number of groups were present in the MLD during SUM. During the other three seasons, they also populated the thermocline. The groups in the MLD were not found to have any correlation trend either with temperature, salinity or chl *a* (Table 5.12).The number of groups occurring decreased with increasing depth during most seasons except WM. The lowest number of groups during SUM occurred in the thermocline (range: 1-6) and the strata between 300 and 500 m (range: 1-5) respectively (Fig. 5.7, Table 5.4-5.11). Except for the six groups *i.e.* chaetognaths, copepods, medusae, ostracods, polychaetes and siphonophores, all the other groups were absent in the thermocline at all stations during SUM. Similarly, these groups plus cephalochordates and euphausiids were the only groups present in the 300-500 m stratum during FIM.

Table 5.4. Percent abundance of different groups of mesozooplankton in western Bay during summer monsoon (SUM)

| | | Various depth strata (m) at the stations sampled | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | WB1 | | | | | WB3 | | | |
| Gr. No: | Groups | 0-29 | 29-200 | 200-300 | 300-500 | 500-1000 | 0-14 | 14-200 | 300-500 | 500-1000 |
| 2 | Amphipoda | 0.06 | A | 0.24 | A | A | 0.22 | A | A | 0.17 |
| 4 | Appendicularia | 0.18 | A | 1.03 | A | A | 0.44 | A | A | 0.23 |
| 7 | Cephalochordata | A | A | A | 1.43 | A | 0.07 | A | A | 0.17 |
| 9 | Chaetognatha | A | A | 3.34 | 2.86 | A | 6.16 | 0.12 | 0.84 | 5.27 |
| 10 | Cirripedia | A | A | 3.10 | A | A | 1.32 | A | A | A |
| 11 | Cladocera | A | A | 0.16 | A | A | 0.14 | A | A | A |
| 12 | Crustacean larvae | A | A | 0.08 | A | A | A | A | A | A |
| 13 | Copepoda | 93.53 | 100.00 | 89.28 | 85.71 | 100 | 88.72 | 99.14 | 93.72 | 89.49 |
| 15 | Decapoda | 0.18 | A | 0.16 | A | A | 0.42 | A | A | A |
| | Brachyuran zoea | A | A | A | A | A | 0.14 | A | A | A |
| | Lucifer | A | A | A | A | A | 0.28 | A | A | A |
| | Megalopa | 0.06 | A | A | A | A | A | A | A | A |
| | Sergestes larvae | 0.06 | A | A | A | A | A | A | A | A |
| | Unidentified larvae | 0.06 | A | 0.16 | A | A | A | A | A | A |
| 16 | Doliolida | 0.06 | A | A | A | A | A | A | A | A |
| 17 | Echinodermata | A | A | A | A | A | 0.44 | A | A | A |
| 18 | Euphausiacea | 0.06 | A | 0.08 | A | A | 0.71 | A | 3.35 | 1.50 |
| | Euphausiid protozoea | A | A | A | A | A | 0.14 | A | A | 0.35 |
| | Euphausiids | 0.06 | A | 0.08 | A | A | 0.57 | A | 3.35 | 1.15 |
| 19 | Fish eggs | 0.06 | A | A | A | A | 0.15 | A | A | A |
| 20 | Fish larvae | 0.24 | A | A | A | A | A | A | A | 0.52 |
| 21 | Foraminifera | 0.06 | A | A | A | A | A | A | A | A |
| 24 | Invertebrate eggs | 0.06 | A | A | A | A | A | A | A | A |
| 26 | Medusae | A | A | 0.24 | A | A | 0.37 | 0.12 | A | A |
| 28 | Ostracoda | 3.60 | A | 0.79 | 7.14 | A | 0.64 | 0.24 | 1.26 | 1.89 |
| 29 | Polychaeta | 0.36 | A | 0.48 | 2.86 | A | 0.28 | 0.24 | A | 0.75 |
| 32 | Pyrosomida | A | A | A | A | A | * | A | A | A |
| 35 | Siphonophora | 0.06 | A | 1.03 | A | A | 0.80 | 0.12 | 0.84 | A |
| | Number of groups | 13 | 1 | 13 | 5 | 1 | 16 | 6 | 5 | 10 |
| | Individuals 100 m$^{-3}$ | 6672 | ng | 1007 | ng | 3 | 462080 | 2514 | 1912 | 458 |

'A' denotes absent

*swarms of *Pyrosoma* that could not be counted; ng: negligible

Table 5.4. Contd.

| Gr. No: | Groups | Various depth strata (m) sampled at WB4<br>0-2 | 2-200 | 200-300 | 300-500 | 500-1000 |
|---|---|---|---|---|---|---|
| 4 | Appendicularia | 2.73 | A | 3.65 | A | A |
| 9 | Chaetognatha | 1.87 | A | 3.08 | A | A |
| 10 | Cirripedia | 2.59 | A | A | A | A |
| 12 | Crustacean larvae | 1.29 | A | A | A | A |
| 13 | Copepoda | 82.33 | 100.00 | 85.23 | 100.00 | 100.00 |
| 15 | Decapoda | 0.72 | A | A | A | A |
|  | Lucifer | 0.86 | A | A | A | A |
|  | Unidentified larvae | 0.57 | A | A | A | A |
| 16 | Doliolida | 0.29 | A | 0.24 | A | A |
| 17 | Echinodermata | 0.14 | A | 0.24 | A | A |
| 18 | Euphausiacea | 0.72 | A | A | A | A |
|  | Euphausiids | 0.72 | A | A | A | A |
| 22 | Gastropoda | 0.29 | A | A | A | A |
| 26 | Medusae | 1.01 | A | A | A | A |
| 28 | Ostracoda | 0.86 | A | 2.96 | A | A |
| 29 | Polychaeta | 2.44 | A | 4.36 | A | A |
| 30 | Pteropoda | 0.86 | A | A | A | A |
| 34 | Salpida | 0.14 | A | A | A | A |
| 35 | Siphonophora | 1.01 | A | 0.24 | A | A |
|  | Number of groups | 16 | 1 | 8 | 1 | 1 |
|  | Individuals 100 $m^{-3}$ | 1712 | 80 | 896 | ng | ng |

'A' denotes absent; ng: negligible

Table 5.5. Mesozooplankton groups absent from different depth strata in the western Bay during summer monsoon. Refer to Table 5.3 for the names of individual groups corresponding to the group numbers

| | Groups absent in different depth strata (m) | | | | |
|---|---|---|---|---|---|
| Sampling station | 0-MLD | TT-BT | 200-300 | 300-500 | 500-1000 |
| WB1 | 1, 3, 5-8, 10-12, 14, 17, 22, 23, 25-27, 30-34, 36, 37 | 1-12, 14-37 | 1, 3, 5-8, 14, 16, 17, 19, 25, 27, 30-34, 36, 37 | 1-6, 8, 10-12, 14-27, 30-37 | 1-12, 14-37 |
| WB2 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| WB3 | 1, 3, 5, 6, 8, 12, 14, 16, 18, 20-25, 27, 30-34, 36, 37 | 1-8, 10-12, 14-25, 27, 30-34, 36-37 | NO DATA | 1-8, 10-12, 14-17, 19-27, 29-34, 36, 37 | 1, 3, 5, 6, 8, 10-12, 14-17, 19, 21-27, 30-37 |
| WB4 | 1-3, 5-8, 14, 19, 20, 21, 23-25, 27, 31, 32, 36, 37 | 1-12, 14-37 | 1-3, 5-8, 10-12, 14, 15, 18-27, 30-34, 36, 37 | 1-12, 14-37 | 1-12, 14-37 |

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

ND: No data due to failure of the net to open/close

Table 5.6. Percent abundance of different groups of mesozooplankton in western Bay during fall intermonsoon (FIM)

| | | Various depth strata (m) at the stations sampled | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | WB1 | | | | | WB2 | | | | |
| Gr. No: | Group | 0-30 | 30-200 | 200-300 | 300-500 | 500-1000 | 0-20 | 20-200 | 200-300 | 300-500 | 500-1000 |
| 2 | Amphipoda | 0.12 | 0.02 | A | A | A | 0.15 | 0.12 | A | A | A |
| 3 | Anthozoa | A | 0.30 | A | A | A | A | A | A | A | A |
| 4 | Appendicularia | 2.54 | 1.83 | 0.36 | 1.97 | A | 7.92 | 3.05 | 1.65 | A | 0.56 |
| 5 | Bivalvia | 0.16 | 0.02 | A | A | A | 0.01 | A | A | A | A |
| 7 | Cephalochordata | 0.20 | A | A | A | A | A | 0.05 | A | A | A |
| 8 | Cephalopoda | A | 0.05 | A | A | A | 0.01 | 0.05 | A | A | 0.01 |
| 9 | Chaetognatha | 3.95 | 1.92 | 0.15 | 1.97 | 1.53 | 3.33 | 3.60 | 0.89 | 1.25 | 1.45 |
| 11 | Cladocera | 0.08 | A | A | A | A | 0.97 | A | A | A | A |
| 12 | Crustacean larvae | 0.04 | A | A | A | A | 0.02 | 0.01 | A | A | 0.07 |
| 13 | Copepoda | 88.93 | 89.22 | 33.60 | 90.23 | 87.74 | 67.90 | 78.67 | 72.37 | 95.19 | 88.26 |
| 14 | Ctenophora | A | A | A | A | A | 0.03 | A | A | A | A |
| 15 | Decapoda | 0.20 | 0.02 | A | A | A | 0.30 | 0.09 | A | A | 0.03 |
| | Brachyuran zoea | A | A | A | A | A | A | 0.01 | A | A | 0.01 |
| | Callianasa | 0.04 | A | A | A | A | A | A | A | A | A |
| | Hippolyte | A | A | A | A | A | 0.01 | A | A | A | A |
| | Lucifer | A | A | A | A | A | 0.12 | 0.01 | A | A | A |
| | Lucifer mysis | A | 0.02 | A | A | A | 0.05 | A | A | A | A |
| | Luciferprotozoea | A | A | A | A | A | 0.01 | 0.04 | A | A | A |
| | Megalopa | A | A | A | A | A | A | 0.01 | A | A | 0.01 |
| | Palaemon | 0.04 | A | A | A | A | A | A | A | A | A |
| | Sergestes larvae | 0.04 | A | A | A | A | 0.08 | 0.02 | A | A | A |
| | Stenopus larva | A | A | A | A | A | 0.01 | A | A | A | A |
| | Thalassocaris | 0.08 | A | A | A | A | 0.01 | A | A | A | A |
| 16 | Doliolida | A | 0.23 | 0.07 | A | A | 0.12 | 0.18 | 0.25 | A | 0.11 |
| 18 | Euphausiacea | 0.90 | 0.65 | A | 0.14 | 0.11 | 0.22 | 0.42 | 0.87 | A | 0.34 |
| | Euphausiid larvae | 0.04 | A | A | A | A | 0.01 | 0.05 | A | A | A |
| | Euphausiid protozoea | 0.55 | A | A | 0.14 | A | 0.11 | 0.12 | A | A | 0.14 |
| | Euphausiids | 0.31 | 0.65 | A | A | 0.11 | 0.10 | 0.25 | 0.87 | A | 0.20 |
| 19 | Fish eggs | A | A | A | A | A | 0.03 | 0.12 | A | A | 0.05 |
| 20 | Fish larvae | A | 0.05 | A | 0.07 | A | 0.14 | 0.07 | A | A | 0.01 |
| 21 | Foraminifera | 0.27 | 0.48 | 0.07 | 0.14 | A | 0.30 | 1.25 | 12.47 | 0.43 | 0.27 |
| 22 | Gastropoda | 0.23 | 0.07 | A | 0.42 | A | 0.21 | 0.12 | 0.23 | A | 0.01 |
| 24 | Invertebrate eggs | 0.94 | 1.96 | 65.17 | 1.26 | A | 14.55 | 5.54 | 2.30 | 0.43 | 1.10 |
| 25 | Isopoda | A | A | A | A | A | 0.02 | A | A | A | A |
| 26 | Medusae | 0.08 | 0.02 | A | 0.14 | A | 0.15 | 0.85 | 0.60 | 0.14 | 0.08 |
| 27 | Mysida | 0.04 | A | A | A | A | 0.03 | 0.14 | A | A | 0.05 |
| 28 | Ostracoda | 0.27 | 0.37 | 0.22 | 2.39 | 9.48 | 1.22 | 2.40 | 6.01 | 1.75 | 6.42 |
| 29 | Polychaeta | 0.51 | 0.84 | 0.29 | 0.28 | 1.09 | 0.75 | 1.21 | 1.90 | 1.25 | 0.73 |
| 30 | Pteropoda | 0.04 | 0.16 | A | A | A | 0.08 | 0.16 | 0.05 | A | A |
| 33 | Radiolaria | A | 0.02 | A | A | A | A | A | A | A | 0.06 |
| 34 | Salpida | 0.08 | 0.23 | A | 0.14 | A | 0.20 | 0.06 | A | A | 0.09 |
| 35 | Siphonophora | 0.43 | 1.51 | 0.07 | 0.84 | A | 1.34 | 1.80 | 0.41 | 0.14 | 0.28 |
| 37 | Stomatopoda | A | 0.05 | A | A | A | A | 0.01 | A | A | 0.01 |
| | Number of groups | 20 | 22 | 9 | 13 | 5 | 25 | 23 | 13 | 8 | 21 |
| | Individuals 100 $m^{-3}$ | 136320 | 41237 | 5512 | 2846 | 734 | 99130 | 39124 | 4760 | 794 | 2340 |

‘A’ denotes absent

Table 5.6. Contd.

| | | Various depth strata (m) at the stations sampled | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | WB3 | | | | | WB4 | | | | |
| Gr. No: | Group | 0-20 | 20-200 | 200-300 | 300-500 | 500-1000 | 0-40 | 40-200 | 200-300 | 300-500 | 500-1000 |
| 2 | Amphipoda | 0.16 | 0.04 | 0.02 | 0.03 | 0.04 | 0.02 | 0.14 | 0.06 | 0.12 | 0.29 |
| 3 | Anthozoa | A | 0.50 | A | A | A | 0.04 | 0.05 | A | A | A |
| 4 | Appendicularia | 7.63 | 8.33 | 1.78 | 8.68 | 0.17 | 3.40 | 4.05 | 6.87 | 9.71 | 1.21 |
| 5 | Bivalvia | 0.06 | 0.01 | 0.09 | A | 0.02 | 0.06 | 0.23 | A | A | 0.14 |
| 8 | Cephalopoda | 0.02 | 0.51 | A | 0.01 | A | A | A | A | A | A |
| 9 | Chaetognatha | 2.09 | 6.07 | 2.04 | 1.60 | 0.71 | 1.27 | 1.21 | 1.68 | 2.07 | 1.03 |
| 11 | Cladocera | 1.65 | A | A | A | A | A | A | A | A | A |
| 12 | Crustacean larvae | A | 0.02 | A | A | 0.04 | A | 0.03 | 0.06 | 0.02 | A |
| 13 | Copepoda | 76.61 | 55.32 | 88.90 | 85.14 | 91.34 | 88.72 | 83.10 | 74.28 | 78.07 | 88.82 |
| 14 | Ctenophora | A | A | A | A | A | 0.02 | 0.02 | A | A | A |
| 15 | Decapoda | 0.83 | 1.71 | 0.26 | 0.81 | 0.21 | 1.39 | 0.99 | 2.24 | 5.33 | 0.40 |
| | Alpheid | 0.02 | A | A | 0.02 | A | A | 0.02 | A | A | A |
| | Brachyuran zoea | 0.23 | A | A | A | 0.02 | 0.07 | 0.01 | 0.17 | 0.16 | A |
| | Callianasa | A | A | A | A | A | 0.02 | A | A | A | A |
| | Lucifer | 0.05 | 0.01 | 0.01 | 0.01 | 0.04 | 0.31 | 0.20 | 0.52 | 0.15 | 0.02 |
| | Lucifer mysis | 0.26 | 0.25 | 0.01 | 0.00 | 0.02 | 0.27 | 0.08 | 0.25 | 0.90 | A |
| | Lucifer protozoea | 0.18 | 0.80 | 0.10 | 0.06 | 0.08 | 0.59 | 0.65 | 1.05 | 3.35 | 0.38 |
| | Megalopa | A | A | A | A | A | A | A | 0.03 | A | A |
| | Palaemon | 0.10 | 0.63 | 0.14 | 0.68 | 0.04 | 0.02 | A | 0.17 | 0.76 | A |
| | Porcellanid zoea | A | A | A | A | 0.02 | A | A | A | A | A |
| | Sergestes larvae | A | A | A | 0.03 | A | 0.09 | 0.02 | 0.06 | 0.02 | A |
| | Stenopus larva | A | 0.01 | A | A | A | A | A | A | A | A |
| | Thalassocaris | A | A | A | A | A | 0.03 | 0.01 | A | A | A |
| 16 | Doliolida | 0.31 | 1.25 | 0.10 | 0.02 | 0.04 | 0.02 | 0.27 | 0.19 | 0.09 | A |
| 17 | Echinodermata | A | 0.01 | A | A | A | A | A | A | A | A |
| 18 | Euphausiacea | 0.67 | 2.49 | 0.25 | 0.16 | 0.42 | 1.46 | 1.23 | 0.28 | 0.19 | 0.17 |
| | Euphausiid larvae | 0.03 | A | A | A | A | A | 0.15 | A | A | A |
| | Euphausiid protozoea | 0.20 | A | A | A | A | 0.55 | 0.09 | A | A | A |
| | Euphausiids | 0.43 | 2.49 | 0.25 | 0.16 | 0.42 | 0.90 | 0.98 | 0.28 | 0.19 | 0.17 |
| 19 | Fish eggs | 0.03 | 0.01 | A | A | A | 0.03 | A | A | A | A |
| 20 | Fish larvae | 0.05 | 0.02 | 0.06 | 0.03 | 0.06 | 0.05 | 0.32 | 0.22 | 0.15 | 0.03 |
| 21 | Foraminifera | 0.59 | 1.85 | 0.47 | 0.18 | A | 0.18 | 0.13 | 0.08 | A | 0.64 |
| 22 | Gastropoda | 0.63 | 0.26 | 0.10 | 0.12 | 0.02 | 0.10 | 0.16 | 0.75 | 0.02 | A |
| 24 | Invertebrate eggs | 1.77 | 2.61 | 0.31 | 0.66 | 0.09 | 0.44 | 0.77 | 2.02 | 0.19 | 0.45 |
| 25 | Isopoda | 0.10 | A | A | A | 0.04 | A | A | A | A | A |
| 26 | Medusae | 0.23 | 1.33 | 0.43 | 0.03 | 0.12 | 0.28 | 0.24 | 0.22 | 0.09 | 0.02 |
| 27 | Mysida | 0.10 | A | 0.08 | A | A | 0.09 | 0.02 | 0.06 | 0.06 | 0.03 |
| 28 | Ostracoda | 3.52 | 3.66 | 1.10 | 1.69 | 6.13 | 0.53 | 2.24 | 4.41 | 0.72 | 4.82 |
| 29 | Polychaeta | 1.38 | 6.97 | 1.61 | 0.41 | 0.40 | 1.81 | 2.92 | 4.34 | 1.77 | 1.38 |
| 30 | Pteropoda | 0.06 | 0.03 | A | A | 0.02 | 0.11 | 0.31 | 0.03 | A | A |
| 33 | Radiolaria | A | 0.01 | A | 0.03 | 0.04 | A | 0.19 | 0.28 | 0.20 | 0.02 |
| 34 | Salpida | 0.06 | 0.17 | A | A | A | A | 0.41 | A | A | A |
| 35 | Siphonophora | 1.43 | 6.83 | 2.41 | 0.39 | 0.11 | 0.07 | 0.89 | 1.97 | 1.20 | 0.54 |
| 37 | Stomatopoda | A | A | A | A | A | A | 0.10 | A | A | A |
| | Number of groups | 23 | 24 | 17 | 17 | 19 | 21 | 24 | 19 | 17 | 16 |
| | Individuals 100 $m^{-3}$ | 129110 | 8687 | 44342 | 15843 | 2089 | 131270 | 7851 | 15134 | 13411 | 3590 |

‘A’ denotes absent

Table 5.7. Mesozooplankton groups absent from different depth strata in the western Bay during fall intermonsoon. Refer to Table 5.3 for the names of individual groups corresponding to the group numbers

| | Groups absent in different depth strata (m) | | | | |
|---|---|---|---|---|---|
| Sampling station | 0-MLD | TT-BT | 200-300 | 300-500 | 500-1000 |
| WB1 | 1, 3, 6, 8, 10, 14, 16, 17, 19, 20, 23, 25, 31-33, 36, 37 | 1, 2, 6, 7, 10, 12, 14, 17, 19, 23, 25, 27, 31, 32, 36 | 1-3, 5-8, 10-12, 14, 15, 17-20, 22, 23, 25-27, 30-34, 36, 37 | 1-3, 5-8, 10-12, 14-17, 19, 23, 25, 27, 30-33, 36, 37 | 1-8, 10-12, 14-17, 19-27, 30-37 |
| WB2 | 1, 3, 6, 7, 10, 11, 17, 23, 31-33, 36, 37 | 1, 3, 5, 6, 10-12, 14, 17, 23, 25, 31-33, 36 | 1-3, 5-8, 10-12, 14, 15, 17, 19, 20, 23, 25, 27, 31-34, 36, 37 | 1-8, 10-12, 14-20, 22, 23, 25, 27, 30-34, 36, 37 | 1-3, 5-7, 10, 14, 17, 18, 23, 25, 30, 31, 32, 36 |
| WB3 | 1, 3, 6, 7, 10, 12, 14, 17, 23, 31-33, 36, 37 | 1, 6, 7, 10-12, 14, 23, 27, 31, 32, 36, 37 | 1, 3, 6-8, 10-12, 14, 17, 19, 23, 25, 30-34, 36, 37 | 1, 3, 5-7, 10-12, 14, 17, 19, 23, 25, 27, 30-32, 34, 36, 37 | 1, 3, 6-8, 10, 11, 14, 17, 19, 21, 23, 27, 31, 32, 34, 36-37 |
| WB4 | 1, 6-8, 10-12, 14, 17, 23, 25, 31, 34, 36, 37 | 1, 6-8, 10, 11, 17, 19, 23, 25, 31, 32, 36 | 1, 3, 5-8, 10, 11, 14, 19, 23, 25, 31, 34, 36-37 | 1, 3, 5-8, 10, 11, 14, 17, 19, 21, 23, 25, 30, 31, 32, 34, 36, 37 | 1, 3, 6-8, 10-12, 14, 16, 17, 19, 22, 23, 25, 30, 31, 32, 34, 36-37 |

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

Table 5.8. Percent abundance of different groups of mesozooplankton in western Bay during winter monsoon (WM)

| | | Various depth strata (m) at the stations sampled | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | WB1 | | | | WB2 | | | | |
| Gr. No: | Groups | 0-30 | 30-156 | 156-300 | 300-500 | 0-20 | 20-171 | 171-300 | 300-500 | 500-1000 |
| 2 | Amphipoda | 0.13 | 0.05 | 0.12 | 0.07 | 0.16 | 0.60 | A | 0.10 | A |
| 4 | Appendicularia | 0.83 | 0.33 | 0.13 | 0.34 | 12.39 | 2.93 | 0.37 | 0.54 | 0.31 |
| 5 | Bivalvia | A | A | A | A | A | A | 0.05 | A | 0.22 |
| 7 | Cephalochordata | A | A | A | 0.04 | A | A | A | A | A |
| 9 | Chaetognatha | 2.32 | 1.68 | 3.03 | 4.64 | 4.55 | 9.13 | 2.80 | 2.45 | 1.99 |
| 12 | Crustacean larvae | A | A | A | A | A | 0.09 | A | A | A |
| 13 | Copepoda | 90.72 | 85.43 | 91.00 | 81.81 | 78.52 | 72.56 | 82.41 | 90.08 | 91.29 |
| 15 | Decapoda | 0.05 | 0.09 | 0.13 | 0.19 | 0.48 | 0.63 | A | 0.18 | 0.08 |
| | Brachyuran zoea | 0.03 | A | A | A | A | A | A | A | A |
| | Lucifer | A | A | 0.06 | 0.04 | A | A | A | 0.10 | 0.08 |
| | Lucifer mysis | A | 0.04 | A | 0.11 | 0.26 | A | A | A | A |
| | Megalopa | 0.03 | A | A | A | A | A | A | A | A |
| | Sergestes larvae | A | A | A | A | 0.05 | 0.15 | A | A | A |
| | Thalassocaris | A | A | 0.03 | A | A | A | A | A | A |
| | Unidentified larvae | A | 0.05 | 0.04 | 0.04 | 0.18 | 0.48 | A | 0.08 | A |
| 16 | Doliolida | A | 0.04 | 0.02 | 0.04 | A | 0.06 | A | A | A |
| 18 | Euphausiacea | 0.73 | 2.38 | 0.16 | 0.83 | 0.50 | 0.46 | 0.59 | 1.30 | 0.08 |
| | Euphausiid larvae | 0.15 | A | 0.13 | A | 0.07 | 0.28 | A | 0.08 | A |
| | Euphausiid protozoea | 0.51 | 2.38 | 0.03 | 0.57 | 0.43 | 0.18 | 0.59 | 1.22 | 0.08 |
| | Euphausiids | 0.06 | A | A | 0.26 | A | A | A | A | A |
| 19 | Fish eggs | 0.10 | 0.14 | 0.03 | A | 0.07 | 0.09 | 0.05 | 0.35 | A |
| 20 | Fish larvae | 0.49 | 0.63 | 0.22 | 0.82 | 0.35 | 1.53 | 3.27 | 0.08 | 0.87 |
| 21 | Foraminifera | A | A | A | A | A | 0.07 | A | A | 0.11 |
| 22 | Gastropoda | 0.05 | 0.14 | A | A | 0.15 | 1.87 | 0.13 | 0.08 | 0.11 |
| 25 | Isopoda | 0.10 | 0.23 | 0.58 | 0.07 | A | 0.41 | 0.05 | 0.08 | A |
| 26 | Medusae | A | A | 0.03 | A | A | A | 0.08 | A | A |
| 27 | Mysida | 0.21 | A | 0.11 | 0.07 | 0.07 | 0.44 | A | 0.08 | A |
| 28 | Ostracoda | 2.64 | 8.12 | 2.54 | 10.25 | 0.52 | 4.14 | 8.08 | 3.59 | 3.82 |
| 29 | Polychaeta | 0.41 | 0.34 | 0.78 | 0.60 | 1.29 | 1.29 | 0.19 | 0.18 | 0.22 |
| 30 | Pteropoda | 0.38 | 0.27 | 0.66 | 0.07 | 0.19 | 1.58 | 1.06 | 0.18 | 0.27 |
| 32 | Pyrosomida | 0.05 | A | A | A | 0.11 | 0.07 | 0.05 | 0.17 | A |
| 33 | Radiolaria | A | A | 0.02 | A | A | A | A | A | A |
| 34 | Salpida | 0.54 | 0.14 | 0.02 | 0.11 | 0.44 | 1.18 | 0.72 | 0.44 | 0.47 |
| 35 | Siphonophora | 0.18 | A | 0.39 | 0.04 | 0.20 | 0.81 | 0.08 | 0.10 | 0.16 |
| 37 | Stomatopoda | 0.05 | A | 0.03 | A | A | 0.06 | A | A | A |
| | Number of groups | 18 | 15 | 19 | 16 | 16 | 21 | 16 | 17 | 14 |
| | Individuals 100 $m^{-3}$ | 161827 | 7316 | 34335 | 12472 | 139600 | 17845 | 3122 | 1620 | 434 |

‘A’ denotes absent

Table 5.8. Contd.

| | | Various depth strata (m) at the stations sampled | | | | | |
|---|---|---|---|---|---|---|---|
| | | WB3 | | | | WB4 | |
| Gr. No: | Groups | 0-60 | 60-200 | 200-300 | 300-500 | 0-35 | 35-135 |
| 2 | Amphipoda | 0.20 | 0.20 | 0.13 | 0.15 | 0.69 | 0.42 |
| 4 | Appendicularia | 0.64 | 0.34 | 0.26 | 0.15 | 2.98 | 1.95 |
| 5 | Bivalvia | 0.14 | 0.11 | 0.18 | A | 0.08 | 0.05 |
| 7 | Cephalochordata | A | A | A | A | 1.94 | 0.05 |
| 8 | Cephalopoda | A | A | A | A | 0.01 | A |
| 9 | Chaetognatha | 2.66 | 1.74 | 2.83 | 2.75 | 3.92 | 3.42 |
| 12 | Crustacean larvae | A | 0.07 | A | A | A | A |
| 13 | Copepoda | 88.90 | 86.68 | 86.67 | 72.44 | 68.83 | 85.11 |
| 15 | Decapoda | 0.31 | A | 0.77 | 0.59 | 0.05 | 0.02 |
| | Brachyuran zoea | A | A | 0.09 | A | 0.01 | A |
| | Lucifer | 0.08 | A | 0.18 | 0.37 | A | A |
| | Lucifer mysis | 0.18 | A | 0.23 | 0.07 | A | A |
| | Megalopa | A | A | 0.09 | A | A | A |
| | Palaemon | A | A | A | 0.07 | A | 0.02 |
| | Sergestes larvae | 0.05 | A | 0.09 | 0.07 | A | A |
| | Thalassocaris | A | A | 0.09 | A | 0.04 | A |
| 16 | Doliolida | 0.09 | A | 0.04 | A | 0.04 | 0.05 |
| 17 | Echinodermata | A | 0.02 | A | A | A | 0.05 |
| 18 | Euphausiacea | 0.45 | 0.51 | 0.60 | 0.22 | 0.32 | 0.25 |
| | Euphausiid larvae | A | 0.38 | A | A | 0.08 | 0.05 |
| | Euphausiid protozoea | 0.35 | 0.13 | 0.60 | 0.22 | A | 0.07 |
| | Euphausiids | 0.10 | A | A | A | 0.24 | 0.13 |
| 19 | Fish eggs | A | 0.26 | A | 0.07 | 0.04 | A |
| 20 | Fish larvae | 2.18 | 0.68 | 2.05 | 1.78 | 0.65 | 0.10 |
| 21 | Foraminifera | 0.03 | 0.05 | A | A | 10.94 | 1.51 |
| 22 | Gastropoda | 0.22 | 0.22 | 0.09 | A | 1.21 | 0.05 |
| 24 | Invertebrate eggs | A | A | A | A | 0.68 | 0.53 |
| 25 | Isopoda | 0.03 | 0.16 | 0.68 | A | A | A |
| 26 | Medusae | A | A | A | A | A | 0.10 |
| 27 | Mysida | 0.03 | 0.25 | A | A | A | 0.27 |
| 28 | Ostracoda | 2.16 | 5.59 | 3.32 | 2.38 | 1.38 | 4.42 |
| 29 | Polychaeta | 0.52 | 1.75 | 0.35 | A | 0.48 | 0.62 |
| 30 | Pteropoda | 1.19 | 1.04 | 1.77 | 19.32 | 4.72 | 0.54 |
| 32 | Pyrosomida | 0.05 | 0.02 | A | 0.07 | 0.04 | A |
| 33 | Radiolaria | A | A | 0.09 | A | 0.65 | A |
| 34 | Salpida | 0.03 | A | A | A | A | 0.03 |
| 35 | Siphonophora | 0.12 | 0.26 | 0.09 | A | 0.36 | 0.43 |
| 37 | Stomatopoda | 0.05 | 0.04 | 0.04 | 0.07 | A | A |
| | Number of groups | 20 | 20 | 17 | 12 | 21 | 21 |
| | Individuals 100 $m^{-3}$ | 72891 | 41559 | 5239 | 10768 | 35343 | 31770 |

'A' denotes absent

Table 5.9. Mesozooplankton groups absent from different depth strata in the western Bay during winter monsoon. Refer to Table 5.3 for the names of individual groups corresponding to the group numbers

| | Groups absent in different depth strata (m) | | | | |
|---|---|---|---|---|---|
| Sampling station | 0-MLD | TT-BT | 200-300 | 300-500 | 500-1000 |
| WB1 | 1, 3, 5-8, 10-12, 14, 16, 17, 21, 23, 24, 26, 31, 33, 36 | 1, 3, 5-8, 10-12, 14, 17, 21, 23, 24, 26, 27, 31-33, 35-37 | 1, 3, 5-8, 10-12, 14, 17, 21-24, 31, 32, 36 | 1, 3, 5, 6, 8, 10-12, 14, 17, 19, 21-24, 26, 31-33, 36, 37 | NO DATA |
| WB2 | 1, 3, 5-8, 10-12, 14, 16, 17, 21, 23-26, 31, 33, 36, 37 | 1, 3, 5-8, 10, 11, 14, 17, 23, 24, 26, 31, 33, 36 | 1-3, 6-8, 10-12, 14-17, 21, 23, 24, 27, 31, 33, 36, 37 | 1, 3, 5-8, 10-12, 14, 16, 17, 21, 23, 24, 26, 31, 33, 36, 37 | 1-3, 6-8, 10-12, 14, 16, 17, 19, 23-27, 31-33, 36, 37 |
| WB3 | 1, 3, 6-8, 10-12, 14, 17, 19, 23, 24, 26, 31, 33, 36 | 1, 3, 6, 7, 8, 10, 11, 14-16, 23, 24, 26, 31, 33, 34, 36 | 1, 3, 6-8, 10-12, 14, 17, 19, 21, 23, 24, 26, 27, 31, 32, 34, 36 | 1, 3, 5-8, 10-12, 14, 16, 17, 21-27, 29, 31, 33-36 | NO DATA |
| WB4 | 1, 3, 6, 8, 10-12, 14, 17, 23, 25-27, 31, 34, 36, 37 | 1, 3, 6, 8, 10-12, 14, 19, 23, 25, 31-33, 36, 37 | NO DATA | NO DATA | NO DATA |

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

There was NO DATA in some deeper depths due to shallow water depth

Table 5.10. Percent abundance of different groups of mesozooplankton in western Bay during spring intermonsoon (SpIM)

| | | Various depth strata (m) at the stations sampled | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | WB1 | | | | WB2 | | | |
| Gr. No: | Groups | 0-30 | 30-200 | 200-300 | 300-500 | 0-40 | 40-200 | 200-300 | 300-500 |
| 2 | Amphipoda | 0.33 | 0.36 | A | A | A | 0.24 | A | A |
| 4 | Appendicularia | 0.79 | 0.16 | A | 0.46 | 0.54 | 0.30 | A | A |
| 7 | Cephalochordata | 0.04 | 0.01 | A | A | A | A | A | A |
| 8 | Cephlaopoda | 0.04 | A | A | A | A | A | A | A |
| 9 | Chaetognatha | 9.39 | 3.34 | 0.64 | 4.63 | 2.52 | 1.91 | 1.14 | 3.93 |
| 11 | Cladocera | 0.43 | 0.10 | A | A | 0.08 | A | A | A |
| 12 | Crustacean larvae | 0.23 | A | A | A | A | 0.04 | A | A |
| 13 | Copepoda | 79.95 | 83.57 | 48.70 | 87.50 | 89.78 | 90.95 | 65.11 | 90.58 |
| 15 | Decapoda | 0.07 | 0.01 | 0.02 | A | 0.09 | 0.02 | 0.02 | A |
| | Brachyuran zoea | A | A | A | A | A | 0.02 | A | A |
| | Lucifer | 0.20 | 0.01 | A | A | 0.35 | A | A | A |
| | Lucifer protozoea | 0.36 | 0.08 | A | A | 0.40 | 0.11 | A | A |
| | Phyllosoma larva | A | 0.01 | A | A | A | A | A | A |
| | Sergestes | A | 0.01 | A | A | A | A | A | A |
| | Unidentified larvae | 0.02 | 0.01 | 0.14 | A | 0.03 | 0.02 | 0.20 | A |
| 16 | Doliolida | A | 0.01 | A | A | A | A | A | A |
| 18 | Euphausiacea | 1.66 | 1.13 | 0.81 | A | 1.39 | 1.30 | 2.00 | 0.52 |
| | Euphausiid larva | 0.05 | A | A | A | 0.08 | A | 0.10 | A |
| | Euphausiid protozoea | 1.38 | 0.42 | A | A | 1.13 | 1.11 | A | A |
| | Euphausiids | 0.22 | 0.71 | 0.81 | A | 0.19 | 0.20 | 1.90 | 0.52 |
| 19 | Fish eggs | A | A | A | A | 0.16 | A | A | A |
| 20 | Fish larvae | 0.13 | 0.17 | 0.06 | A | 0.08 | 0.09 | 0.29 | A |
| 21 | Foraminifera | 0.62 | 0.33 | 36.90 | 1.85 | 0.38 | 0.37 | 7.98 | A |
| 22 | Gastropoda | 0.02 | 0.02 | 0.14 | A | A | A | A | A |
| 24 | Invertebrate eggs | 0.55 | 0.82 | 0.12 | 0.46 | 0.88 | A | A | 0.26 |
| 25 | Isopoda | A | 0.03 | A | A | A | A | A | A |
| 26 | Medusae | 0.02 | A | A | A | A | 0.02 | A | A |
| 27 | Mysida | A | A | A | A | 0.03 | A | A | A |
| 28 | Ostracoda | 3.34 | 8.76 | 9.58 | 4.17 | 1.47 | 3.00 | 22.81 | 2.88 |
| 29 | Polychaeta | 1.00 | 0.51 | 0.67 | 0.93 | 0.67 | 0.61 | 0.19 | 1.05 |
| 30 | Pteropoda | 0.66 | 0.20 | 0.25 | A | 0.99 | 0.41 | 0.10 | 0.52 |
| 33 | Radiolaria | A | 0.01 | 0.07 | A | A | 0.33 | A | A |
| 34 | Salpida | 0.13 | 0.09 | 1.91 | A | 0.08 | 0.04 | 0.10 | A |
| 35 | Siphonophora | 0.11 | 0.25 | 0.07 | A | 0.16 | 0.22 | A | 0.26 |
| | Number of groups | 20 | 20 | 14 | 7 | 16 | 16 | 10 | 8 |
| | Individuals 100 m$^{-3}$ | 31013 | 15564 | 3056 | 216 | 37290 | 22995 | 4208 | 764 |

'A' denotes absent

Table 5.10. Contd.

| | | Various depth strata (m) at the stations sampled | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | WB3 | | | | WB4 | | | |
| Gr. No: | Groups | 0-30 | 30-200 | 200-300 | 300-500 | 0-30 | 30-200 | 200-300 | 300-500 |
| 2 | Amphipoda | 0.33 | 0.03 | A | 0.09 | 0.34 | 0.13 | 0.24 | 0.06 |
| 4 | Appendicularia | 6.35 | 2.22 | 3.34 | 5.80 | 2.60 | 0.21 | 0.07 | 0.11 |
| 5 | Bivalvia | 0.11 | 0.09 | 0.44 | 0.09 | 0.04 | 0.21 | 1.07 | 0.22 |
| 7 | Cephalochordata | A | A | A | A | A | A | 0.02 | A |
| 8 | Cephlaopoda | 0.06 | A | A | A | A | 0.02 | 0.02 | A |
| 9 | Chaetognatha | 2.00 | 0.94 | 1.68 | 1.62 | 3.25 | 1.61 | 2.58 | 2.54 |
| 11 | Cladocera | 0.13 | 0.03 | A | 0.05 | 0.29 | 0.01 | A | A |
| 12 | Crustacean larvae | 0.03 | A | 0.11 | A | 0.05 | A | 0.02 | A |
| 13 | Copepoda | 77.62 | 81.03 | 85.77 | 84.50 | 78.81 | 80.24 | 80.51 | 80.96 |
| 15 | Decapoda | 0.16 | 0.05 | 0.01 | 0.05 | 0.11 | 0.05 | 0.04 | 0.01 |
| | Acetes | A | 0.02 | A | A | A | A | A | A |
| | Brachyuran zoea | 0.07 | A | A | A | 0.05 | 0.01 | 0.05 | A |
| | Lucifer | 0.68 | 0.16 | A | 0.18 | 0.51 | 0.04 | 0.10 | A |
| | Lucifer protozoea | 0.35 | 0.13 | A | 0.09 | 0.24 | A | 0.02 | A |
| | Megalopa | A | A | A | A | 0.01 | 0.04 | 0.02 | A |
| | Phyllosoma larvae | A | 0.02 | A | A | A | A | A | 0.06 |
| | Sergestes | A | 0.02 | A | A | A | 0.01 | A | A |
| | Thalassocaris | 0.29 | 0.03 | A | A | A | 0.04 | 0.05 | A |
| | Unidentified larvae | 0.05 | 0.05 | 0.11 | 0.14 | 0.22 | 0.31 | 0.15 | A |
| 16 | Doliolida | 1.82 | 6.40 | 0.21 | 0.50 | 0.01 | 0.24 | 0.34 | 0.66 |
| 18 | Euphausiacea | 1.15 | 0.76 | 0.43 | 0.51 | 1.84 | 2.71 | 1.53 | 0.18 |
| | Euphausiid larvae | A | A | A | A | 0.13 | A | A | A |
| | Euphausiid protozoea | 0.66 | 0.11 | 0.32 | 0.14 | 0.83 | 0.19 | A | 0.06 |
| | Euphausiids | 0.48 | 0.65 | 0.11 | 0.37 | 0.89 | 2.52 | 1.53 | 0.12 |
| 19 | Fish eggs | 0.01 | 0.23 | A | 0.18 | 0.66 | 0.08 | 0.05 | A |
| 20 | Fish larvae | 0.12 | A | A | A | 0.17 | 0.04 | 0.19 | 0.06 |
| 21 | Foraminifera | 0.36 | 0.79 | 0.62 | 0.14 | 1.01 | 0.92 | 0.68 | 2.37 |
| 22 | Gastropoda | A | A | 0.11 | 0.05 | A | 0.01 | A | 0.11 |
| 23 | Halobates | A | A | A | A | A | A | A | 0.01 |
| 24 | Invertebrate eggs | 1.17 | 0.28 | 0.41 | 0.61 | 2.09 | 0.53 | 0.34 | 1.07 |
| 25 | Isopoda | A | A | A | A | A | 0.01 | 0.02 | A |
| 26 | Medusae | 0.31 | 0.18 | 0.21 | 0.05 | 0.20 | 0.21 | 2.02 | 5.31 |
| 27 | Mysida | 0.01 | A | A | A | 0.05 | A | 0.02 | A |
| 28 | Ostracoda | 1.80 | 2.51 | 2.06 | 1.63 | 3.73 | 7.89 | 3.50 | 4.40 |
| 29 | Polychaeta | 0.64 | 0.76 | 1.28 | 0.55 | 0.83 | 1.86 | 2.57 | 0.91 |
| 30 | Pteropoda | 0.27 | 0.13 | 0.55 | 0.23 | 0.49 | 0.07 | 0.12 | 0.50 |
| 33 | Radiolaria | 0.05 | 0.03 | A | A | 0.01 | A | A | A |
| 34 | Salpida | 3.50 | 2.42 | 2.26 | 3.00 | 1.78 | 0.91 | A | 0.12 |
| 35 | Siphonophora | 0.70 | 0.18 | 0.41 | A | 0.66 | 1.42 | 3.67 | 0.22 |
| | Number of groups | 23 | 19 | 17 | 18 | 22 | 22 | 22 | 18 |
| | Individuals 100 $m^{-3}$ | 49486 | 39918 | 1388 | 1606 | 533840 | 8193 | 5134 | 1721 |

'A' denotes absent

Table 5.11. Mesozooplankton groups absent from different depth strata in the western Bay during spring intermonsoon. Refer to Table 5.3 for the names of individual groups corresponding to the group numbers

| Sampling station | Groups in different depth strata (m) | | | |
|---|---|---|---|---|
| | 0-MLD | TT-BT | 200-300 | 300-500 |
| WB1 | 1, 3, 5, 6, 10, 14, 16, 17, 19, 23, 25, 27, 31-33, 36, 37 | 1, 3, 5, 6, 8, 10, 12, 14, 17, 19, 23, 26, 27, 31, 32, 36, 37 | 1-8, 10-12, 14, 16, 17, 23, 25-27, 31, 32, 36, 37 | 1-3, 5-8, 10-12, 14-20, 22, 23, 25-27, 30-37 |
| WB2 | 1-3, 5-8, 10, 12, 14, 16, 17, 22, 23, 25, 26, 31-33, 36, 37 | 1, 3, 5-8, 10, 11, 14, 16, 17, 19, 22-25, 27, 31, 32, 36, 37 | 1-8, 10-12, 14, 16, 17, 19, 22, 23, 25-27, 31-33, 35-37 | 1-8, 10-12, 14-17, 19-23, 25-27, 31-34, 36-37 |
| WB3 | 1, 3, 6, 7, 10, 14, 17, 22, 23, 25, 31, 32, 36, 37 | 1, 3, 6-8, 10, 12, 14, 17, 20, 22, 23, 25, 27, 31, 32, 36, 37 | 1-3, 6-8, 10, 11, 14, 17, 19, 20, 23, 25, 27, 31-33, 36, 37 | 1, 3, 6-8, 10, 12, 14, 17, 20, 23, 25, 27, 31-33, 35-37 |
| WB4 | 1, 3, 6-8, 10, 14, 17, 22, 25, 31, 32, 36, 37 | 1, 3, 6, 7, 10, 12, 14, 17, 23, 27, 31-33, 36, 37 | 1, 3, 6, 10, 11, 14, 17, 22, 23, 31-34, 36, 37 | 1, 3, 6-8, 10-12, 14, 17, 19, 23, 25, 27, 31-33, 36, 37 |

MLD: mixed layer depth; TT: Top of thermocline; BT: Base of thermocline

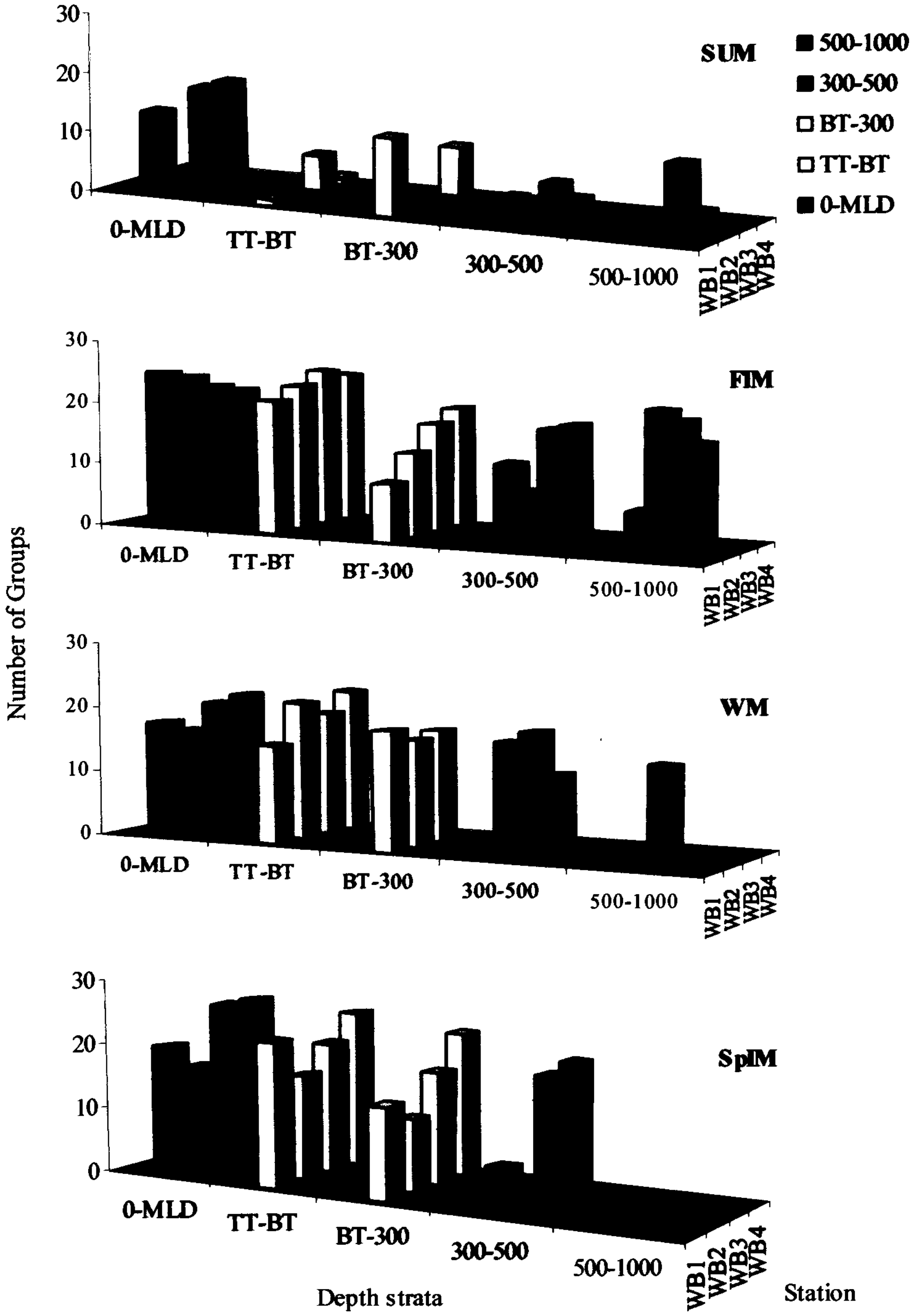


Figure 5.7. Depth-wise variation in the number of groups at each station in the western Bay during different seasons (SUM: summer monsoon, FIM: fall intermonsoon, WM: winter monsoon; SpIM: spring intermonsoon)

Among the 33 groups identified, only two to six of them were found to be dominating numerically (forming ≥2% of the total mesozooplankton abundance; Fig. 5.8) in this transect. Some salient points on their spatio-temporal distribution are listed below. In all seasons, Copepoda was the most predominant group at all stations and depths.

### 5.2.6. Vertical distribution of the dominant groups

During SUM, only two of the 24 groups recorded were dominant (Fig. 5.8). Copepoda ranging from 88 to 99.7% was the most abundant group, especially in the thermocline. The second most major group was Chaetognatha (range: 0.04-2.87%).

During FIM, six groups were dominant (Fig. 5.8). Copepods ranging from 67 to 89 % exhibited a subsurface minimum in the 200-300 m stratum. In this stratum, invertebrate eggs (0.5-17.5%) were most important. Chaetognaths (1.2-3.2%) decreased in percentage with increasing depth. Though polychaetes (1-3%) were observed throughout the water column, they were relatively more abundant in the thermocline. Appendicularians (0.5-5.4%) occurred in higher percentage in the upper 500 m. Ostracods (1.4-6.7%) were more in the deepest stratum.

Copepods ranged from 82 to 91 % among the five groups that dominated during WM (Fig. 5.8). The relative abundance of this group increased with depth. Ostracoda (1.7-5.6%) was the second most-dominant group that was more abundant below MLD. Chaetognath (2-4%) percentage did not vary much with depth. Appendicularia (0.3-4.2%) were dominant in the two uppermost strata. Pteropods increased from surface to the 300- 500 m stratum where they attained a maximum percentage.

During SpIM, copepods ranging from 70 to 85 % at different depths were least abundant in the 200-300 m stratum (Fig. 5.8). In this stratum, Ostracoda (range: 2.6-9.5%) and Foraminifera (0.6-11.5%) increased to their maximum percentages. Chaetognatha (1.5-4.3%) that was highly abundant in the surface was present throughout the upper 500 m.

### 5.2.7. Latitudinal distribution of the dominant groups

Latitudinally, copepods were distributed homogenously at all stations except during WM, where their percentage apparently decreased northwards (Fig. 5.9). Appendicularia, one

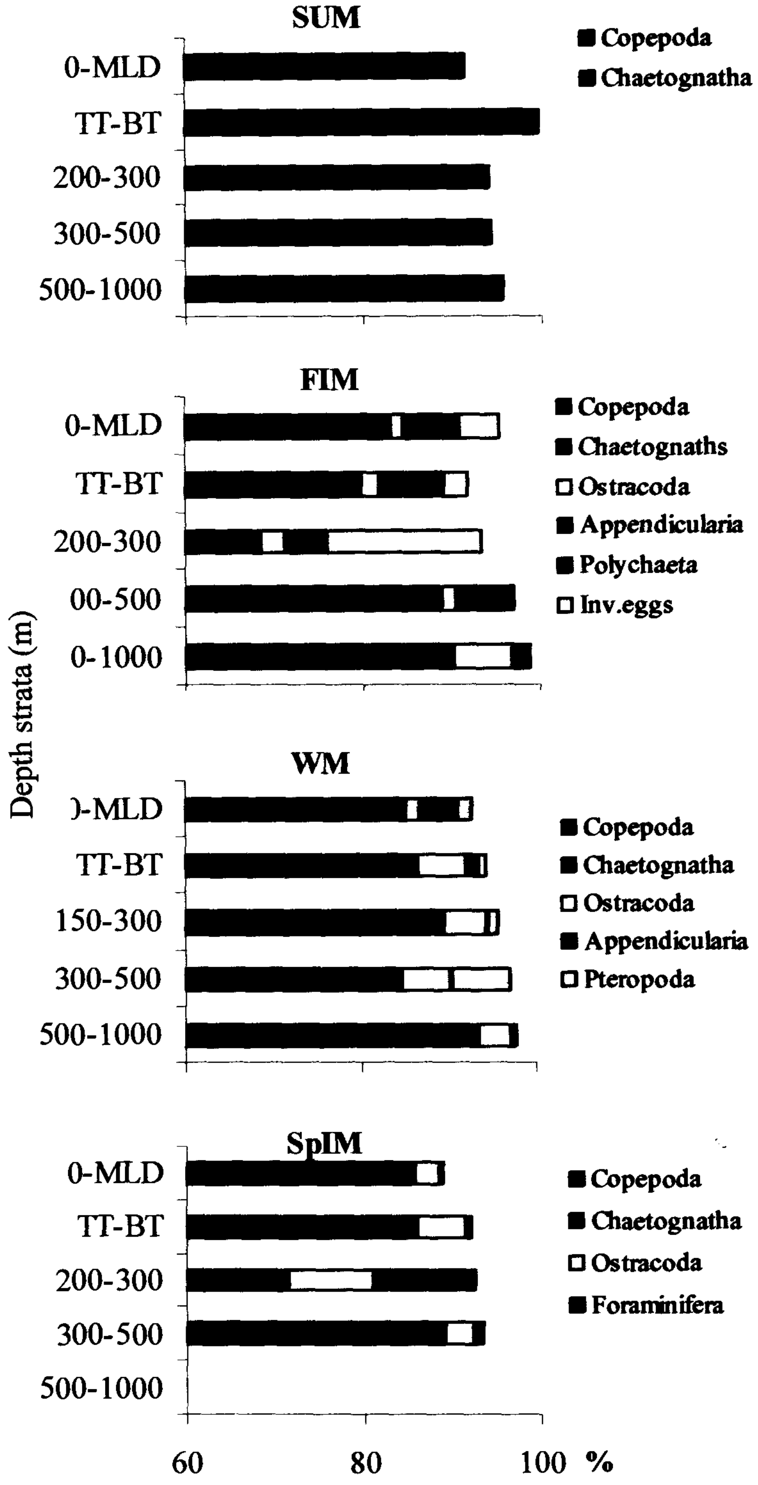


Figure 5.8. Distribution of dominant groups (> 2%) in each stratum in the western Bay during different seasons (SUM: summer monsoon, FIM: fall intermonsoon, WM: winter monsoon; SpIM: spring intermonsoon)

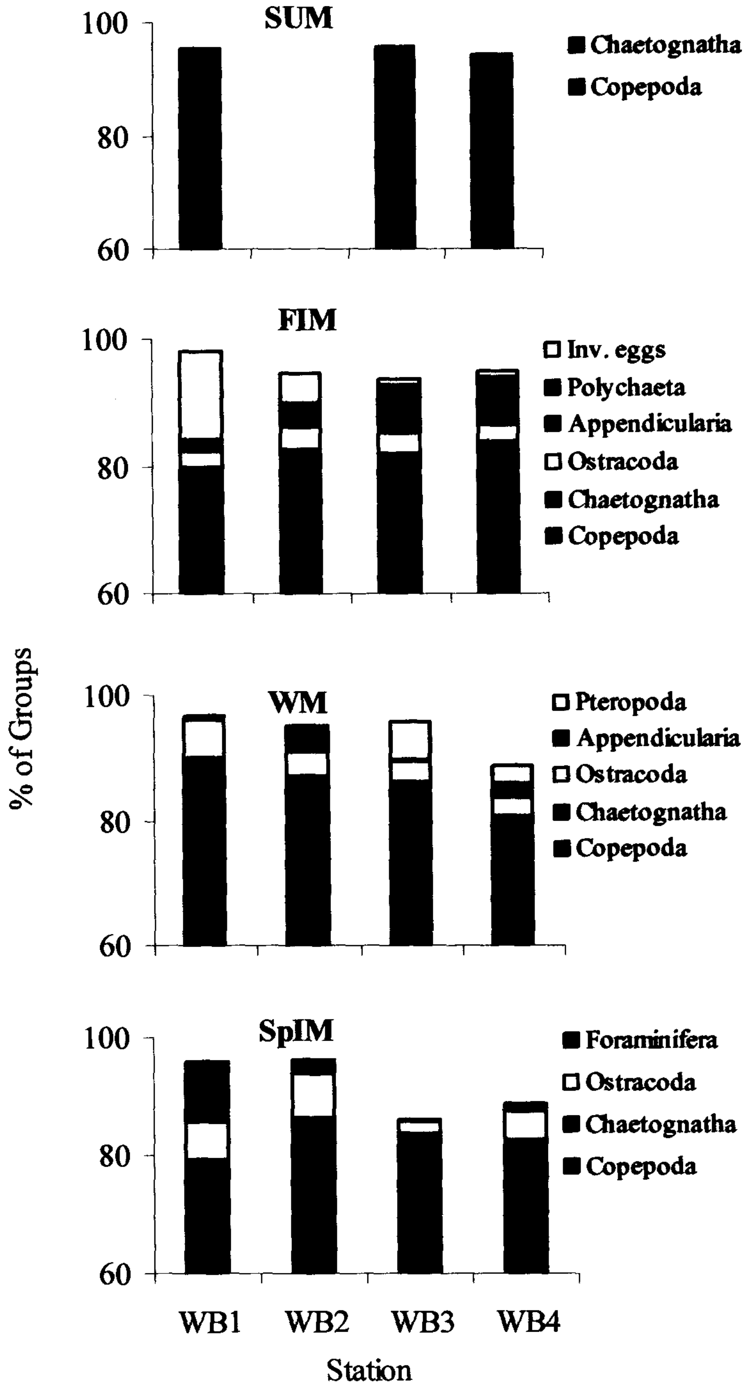


Figure 5.9. Distribution of dominant groups (> 2%) at different stations in the western Bay during different seasons (SUM: summer monsoon, FIM: fall intermonsoon, WM: winter monsoon; SpIM: spring intermonsoon)

Table 5.12. Various statistical (non-parametric tests) analyses to distinguish diel, spatial and temporal differences in mesozooplankton biovolume and abundance in the western Bay of Bengal through non–parametric statistical tests

Wilcoxon Matched Pairs Test between day and night

| | | Biovolume | | | | Abundance | | |
|---|---|---|---|---|---|---|---|---|
| Seasons | N | T | Z | *p* | N | T | Z | *p* |
| SUM | 13 | 23.0 | 1.6 | $p>0.05$ | 10 | 2 | 1.1 | $p>0.05$ |
| FIM | 15 | 43.5 | 0.1 | $p>0.05$ | 15 | 47 | 0.7 | $p>0.05$ |
| WM | 14 | 50.0 | 0.2 | $p>0.05$ | 20 | 47 | 0.7 | $p>0.05$ |
| SpIM | 12 | 12.0 | 1.6 | $p>0.05$ | 10 | 5 | 2.3 | **$p<0.05$** |

Friedman ANOVA to test difference between depths

| | Biovolume | | | | Abundance | | | |
|---|---|---|---|---|---|---|---|---|
| Seasons | Chi Sqr. | N | df | p | Chi Sqr. | N | df | p |
| SUM | 6.0 | 3 | 2 | **$p<0.05$** | 7.7 | 3 | 4 | **$p<0.05$** |
| FIM | 10.9 | 3 | 4 | **$p<0.05$** | 12.6 | 4 | 4 | **$p<0.05$** |
| WM | 3 | 2 | 3 | $p>0.05$ | 11.1 | 4 | 3 | **$p<0.05$** |
| SpIM | 8.1 | 4 | 3 | **$p<0.05$** | 12.8 | 4 | 4 | **$p<0.05$** |

Friedman ANOVA to test the difference between stations

| | Biovolume | | | | Abundance | | | |
|---|---|---|---|---|---|---|---|---|
| Seasons | Chi Sqr. | N | df | *p* | Chi Sqr. | N | df | *p* |
| SUM | 0.4 | 5 | 2 | $p>0.05$ | 4.4 | 5 | 2 | $p>0.05$ |
| FIM | 0.9 | 4 | 3 | $p>0.05$ | 2 | 5 | 3 | $p>0.05$ |
| WM | 5.8 | 4 | 3 | $p>0.05$ | 3.6 | 4 | 3 | $p>0.05$ |
| SpIM | 4.2 | 2 | 3 | $p>0.05$ | 3.8 | 5 | 3 | $p>0.05$ |

Friedman ANOVA to test the difference between seasons

| | Chi Sqr. | N | df | *p* |
|---|---|---|---|---|
| Biovolume | 8.1 | 9 | 3 | **$p<0.05$** |
| Abundance | 14.9 | 12 | 3 | **$p<0.05$** |

Significant results are marked **bold**

Table 5.13. Correlation coefficients between mesozooplankton biovolume, abundance and number of groups (from the mixed layer) and temperature, salinity, chl *a* (average from upper 120 m) in the western Bay of Bengal

| Parameters | Biovolume | Abundance | Groups |
|---|---|---|---|
| **SUM** | | | |
| Temp | 0.064 | 0.003 | **-0.869** |
| Salinity | 0.416 | 0.360 | -0.635 |
| Chl *a* | **-0.758** | **-0.717** | 0.254 |
| **FIM** | | | |
| Temp | -0.631 | -0.574 | -0.180 |
| Salinity | -0.391 | -0.202 | **0.991** |
| Chl *a* | -0.188 | -0.121 | **-0.734** |
| **WM** | | | |
| Temp | **-0.945** | **-0.989** | **0.781** |
| Salinity | **0.878** | **0.964** | **-0.824** |
| Chl *a* | 0.215 | -0.020 | -0.442 |
| **SpIM** | | | |
| Temp | -0.586 | -0.205 | **-0.896** |
| Salinity | **0.851** | 0.576 | **0.815** |
| Chl *a* | 0.404 | 0.004 | 0.613 |

Significant r values at $p<0.05$ are marked **bold**

Table 5.14. Spatio-temporal variation in number of zooplankton groups in the central Bay as determined through one/two way anova in the western Bay of Bengal

| **Groups** | **ANOVA** | |
|---|---|---|
| | Two-way anova | |
| | **SUM** | **FIM** |
| Between depths | $F_{(4, 14)}=5.8$, **$p<0.05$** | $F_{(4, 19)}=6.1$, **$p<0.05$** |
| Between stations | $F_{(2, 14)}=0.8$, $p>0.05$ | $F_{(3, 19)}=1.7$, $p>0.05$ |
| | **WM** | **SpIM** |
| | $F_{(3, 11)}=0.6$, $p>0.05$ | $F_{(3, 15)}=10.6$, **$p<0.01$** |
| | $F_{(2, 11)}=0.1$, $p>0.05$ | $F_{(3, 15)}=12.7$, **$p<0.01$** |
| | One-way anova | |
| Between seasons | $F_{(3, 64)}=15.9$, $p<0.001$ | |

Significant results are marked **bold**

of the dominant groups during FIM and WM, registered higher percentage in the northern Bay during FIM. Pteropods were also more abundant in the northern stations during WM. Chaetognaths did not show any latitudinal trend during any season. In contrast to the above-mentioned groups, invertebrate eggs were proportionately higher in the southern stations, with their highest abundance of 14% at WB1 during FIM. Similar was the case of ostracods during WM and SpIM.

## 5.3. Discussion

### 5.3.1. Variation of Biovolume, Biomass and Abundance

Most of the studies reporting zooplankton biovolumes from the Bay of Bengal (BoB) are from the top 200 m. These are cited in the Table below.

| Region | Sampling period | Biovolume (ml 100 $m^{-3}$) | Reference |
|---|---|---|---|
| Western Bay | SUM | 7.8 to 8.4 | Nair et al. (1977) |
| Western Bay | SUM | 2.5-to 15.4 | Achuthankutty et al. (1980) |
| Western Bay | FIM | 8.9 to 32.2 | Nair et al. (1981) |
| Andaman Sea | WM | 1.8 to 14.4 | Madhupratap et al. (1981) |
| Andaman Sea | SpIM | 1.0 to 13.5 | Madhupratap et al. (1981) |

Results from IIOE for the upper 200 m (Duing 1970), using the Indian Ocean Standard Net suggest that during WM, few spots of > 80 ml per standard haul off Madras, and from 0.1to19.9 ml in the rest of the area were observed in WB. During transitional period *i.e.* March-April, large patches in the WB show values from 10-19.9 ml and the rest, 0.1-9.9 ml. During commencement of SUM, *i.e.* during May-June, biovolume ranged from 10 to 19.9 ml. Values ranging from 20 to 39.9 ml were present south of Andaman Sea. From IIOE studies, it is evident that the BoB becomes highly productive during WM, while the Arabian Sea during SUM (Prasad 1969).

Biovolume (ml 100 $m^{-3}$) was lowest during SUM (10), intermediate during FIM (15.4) and WM (34), and the highest during SpIM (76.4). Results from this study in part agree with the earlier observations. For instance, the average biovolume and carbon biomass in WB during WM is three times more than during SUM. Further, the highest biovolumes were during SpIM. The IIOE studies suggest that Bay is rich in zooplankton especially off Madras and Orissa coasts. Upwelling of weak intensity has been reported in these areas during February-April (La Fond 1954; Varadachari 1961) resulting in high plankton production during April-July (Panikkar and Rao 1973). Subsequent studies (Anand et al. 1968; Murty and Varadachari 1968) have confirmed upwelling in these areas during SpIM and SUM and also intense subsurface upwelling off the mouths of Godavari and Krishna rivers. Sankaranarayanan and Reddy (1968) show evidence for upwelling in coastal areas of northwestern Bay as early as in January. However, no signs of upwelling were evidenced during any of the sampling periods in the WB during this study. Panikkar and Rao (1973) described two peaks in plankton biovolume *i.e.* one during spring and the other during fall in the Gulf of Mannar. On the Southwest coast of India, peak in biomass/abundance is during May, when the SUM induces upwelling early.

Mean biovolumes of zooplankton ranging from 10 to 76.4 ml 100 $m^{-3}$ in the upper 1000 m during the four different seasons of this study are comparable to those observed in the eastern Arabian Sea (Madhupratap et al. 1996 a). However, unlike the results of Madhupratap et al. (1996), results from this study show quite a high variability in biovolumes as well as numerical abundance between seasons. Also, the seasonal averages of zooplankton biovolume relate quite closely to the seasonal distribution of integrated chlorophyll *a* in the upper 120 m, with its concentration increasing from SUM to SpIM (Table 5.15; also in Chapter 3). High chlorophyll *a* and zooplankton abundance are found to co-occur on the offshore and downstream edges of the upwelling area off Peru (Boyd and Smith 1983). At many of the stations, high biovolumes coincided with the occurrence of cold-core eddies, *i.e.* at WB3 during SUM and SpIM. During WM, it was observed at WB1 and around WB2. Similar to the CB, the cyclonic eddies appear to play a significant role in the re-supply of nutrients to the photic zone, which enhances primary production inside them (Falkowski et al. 1991). Muraleedharan et al. (2007) reported biovolume up to 67 ml 100 $m^{-3}$ in the center of a cyclonic eddy and, up to 112 ml 100 $m^{-3}$ in the regions of coastal upwelling. They also observed higher biovolumes in the WB compared to the CB.

Mesozooplankton biovolumes were high in the MLD and decreased rapidly with increasing depth during all seasons except WM. These results are similar to those of Madhu et al. (2003) for the Andaman Sea and, of Padmavati et al. (1998) and Madhupratap et al. (2001) for the Arabian Sea. Rapid decrease in biomass is a universal feature in tropical oceans (Vinogradov 1997). Some zooplankton are known to move through narrow suboxic zones, live anaerobically for short intervals or, reduce metabolism for diapause (Boyd et al. 1980). The critical lower limit for aerobic metabolism in mesozooplankton is about 6μM (Wishner et al. 1990). Since the oxygen concentrations in the subsurface did not fall below 10 μM during WM, up to 10% of the biovolume and ~5% of the numerical abundance could be seen in the 300-500 m stratum, suggesting that zooplankton abundance reduces drastically when oxygen concentrations are at nadir as also observed by Madhupratap et al. (2001). Diel variations with higher biovolumes in the night are reported from the Arabian Sea (Padmavati et al. 1998; Goswami et al. 2002). However, in the Bay and even in the Arabian Sea, it seems to be a manifestation of the oxygen minimum zone.

The deep oxygen minimum zone strongly influenced the vertical distribution of zooplankton in the Arabian Sea (Madhupratap et al. 2001) and Andaman Sea (Madhu et al. 2003). Similar studies conducted in the Arabian Sea and the eastern Pacific also suggest that diel vertical migration (DVM) would be limited by low oxygen, and most zooplankton would remain in the mixed layer both day and night (Wishner et al. 1998; Saltzman and Wishner 1997). Insignificant DVM observed during this study is suggestive of the fact that the existing oxygen minimum levels in the subsurface hinder the vertical migration of mesozooplankton in the BoB.

### 5.3.2. Seasonal variation in community structure

Though the currents reverse with seasons, the sea surface temperature in the WB was always ≥29°C during all seasons except during WM with ~ 26°C. The sea surface salinity, which showed a horizontal gradient, was lower during SUM and FIM ranging from 24 to 34, intermediate during WM and the highest during SpIM. Similar to that in the CB, the thickness of the low oxygen (5-10 μM) zone also varied with seasons. It was the largest during SUM, decreased in thickness during FIM and SpIM and was absent during WM. All the groups reported in this study were reported earlier from the WB (Panikkar and Rao 1973; Achuthankutty et al. 1980; Nair et al. 1981; Rakhesh et al. 2006), Andaman Sea (Madhu et al. 1999; Ik 2007) as well as the eastern Arabian Sea (Padmavati et al. 1998; Madhupratap and Haridas 1990). The standing stocks and groups of zooplankton are known to vary in the northern Indian Ocean according to seasons (Rao 1973, 1979). Zoogeographically, the WB recorded lower number of groups than those in the CB. For instance, four minor/rare groups in CB, *viz.* Acantharia, Carinaria, Pterotrachea and Sipuncula, did not occur in the WB during any of the seasons. The non- occurrence of these groups could be related to patchiness and their numerical rarity in the WB during the study period. Abundance of Carinaria and Pterotrachea was reported to be higher in the WB than the central parts of the Bay (Aravindakshan 1969). Abundance of Acantharia was ascribed directly to primary productivity (Bottazzi and Andreoli 1982 a). Spatially, most Acantharia were found between the tropics and the Equator and, vertically they increased in abundance from the surface to 300 m and then decreased, although juvenile forms were most numerous from 500-900 m. More Acantharia were found in the daytime than at night, and the seasonal period of greatest abundance was spring (Bottazzi and Andreoli 1982 b). It is thus suggested that their size of < 200μm could have caused their exclusion from the samples in this study.

The total number of groups that occurred was 24, 30, 28 and 27 during SUM, FIM, WM and SpIM. As pointed out, the least number of groups occurring during SUM was probably due to the occurrence of a large number of swarms of *Pyrosoma* that contributed most of the biovolume in the samples. The lowest number of groups in the thermocline during SUM and in the 300-500 m layer during FIM (Chapter 3) could have been caused due to drastic decrease in the dissolved oxygen concentration in these zones.

As also reported in many earlier studies including the IIOE, Copepoda was the dominant taxon during all the seasons examined. Chaetognaths, ostracods and invertebrate eggs were the other most dominant group during different seasons for reasons already explained in Chapter 4. It has been observed that during the upwelling period, when phytoplankton is abundant, copepods are sparse in the eastern Arabian Sea.

However, copepods and carnivorous chaetognaths become dominant during the low chlorophyll time, from November to April. Ganapati and Rao (1958) have indicated that only a few chaetognaths and tunicates occur in the WB during the low chl *a* periods between August and December. An abundance of appendicularians and copepods were observed during the high chl *a* period between January and August. Such a difference was not evident in this study. A noteworthy observation of Rao (1973) is that the deeper living chaetognath, *Pterosagitta draco* is found in the surface samples only in February-April when upwelling is prominent in the Bay. It is thus apparent that the essentially marine chaetognath fauna is affected quite adversely by monsoon in the inshore and low-saline waters in the WB.

Ostracods were an important group after copepods in numerical abundance. Unlike the observations during IIOE, there was no notable difference in the ostracod abundance in the WB compared to the CB. Compared to the Bay, the Arabian Sea is richer in ostracod abundance (Panikkar and Rao 1973). As many as 30 species of ostracods were observed in the Arabian Sea during IIOE. Known to inhabit all depths and play a significant role in detrital cycles, they were abundantly seen throughout the 1000 m during the study period. Clear latitudinal zonation patterns were observed during WM and SpIM, with a southward increase in proportion. Such a distribution pattern has also been recently observed in the Southern Ocean with the majority of species occupying the polar seas having circumpolar distributions (Angel and Blachowiak-Samolyk 2007).

Appendicularia, which was abundant mostly in the upper 500 m during FIM and upper 150 m during WM, are thought to avoid very cold and very warm temperatures. These animals occur from the ocean surface to at least 1000 m (Alldredge and Madin 1982). Also known as *sea butterflies*, these marine pelagic gastropods were dominant in the 300-500 m stratum only during WM. Because they may reproduce rapidly, their population dynamics may sometimes closely reflect seasonal or spatial changes in phytoplankton. Foraminifera was one of the major groups during the warm, high-saline period of SpIM, when phytoplankton food was adequate as observed from some higher chl *a* concentration levels. They were found in all strata in the upper 500 m during SpIM. Peak abundances of various pteropods and foraminifers might indicate the presence of local upwelling processes as reported for Bab el Mandeb area (Auras- Schudnagies et al. 1989).

### 5.3.3. Differences between transects

To bring out some of the common and contrasting features in the CB and WB, their physical, chemical and biological characteristics are listed in Table 5.15. In a nutshell, biomass, abundance and composition of zooplankton are influenced by seasonal changes in physico-chemical parameters. These in turn affect the nutrient and chl *a* concentrations. The WB is least productive in terms of zooplankton biovolume and abundance during SUM and most productive during SpIM. In contrast, the CB supported higher biovolumes during both these seasons. However, the number of groups occurring was lower in both these seasons along both transects. WB had higher biovolume and numerical abundances than the CB during all seasons except SUM. The average carbon biomass in both transects was similar during FIM and WM. Compared to the CB however, the carbon biomass was lower during SUM, and higher during SpIM in the WB. In the other two seasons, it was similar in both transects. Also, cyclonic eddies play a crucial role in elevating the zooplankton biomasses in the WB (seasonal average: 42-224 mM C $m^{-2}$) and CB (75-134 mM C $m^{-2}$) to values that even exceeded those reported from the eastern Arabian Sea (75–83 mM C $m^{-2}$) and nearly matched those in the central Arabian Sea (73-158 mM C $m^{-2}$). From the fewer groups *i.e.* only 33 that were present in the WB compared to 37 in the CB, it is discernible that group diversity increases from coastal to open waters in the Bay. Copepods, chaetognaths, ostracods, appendicularians, polychaetes, invertebrate eggs and foraminifera were the major groups common in both transects during different seasons. However, certain differences did prevail in the dominance of a few groups. For instance, medusae and Euphausiacea were dominant only in CB and, Pteropoda in the WB.

### 5.3.4. Salient biological features of the dominant groups in the Bay of Bengal

The following is a brief description of the main biological features of the dominant groups recorded in the BoB. This is included to provide an insight into the possible roles these mesozooplankton groups play in the trophic structure of the BoB.

Table 5.15. Ranges of physical, chemical and biological parameters in the central and western Bay of Bengal

| | CB | | | | WB | | | |
|---|---|---|---|---|---|---|---|---|
| Parameters | SUM | FIM | WM | SpIM | SUM | FIM | WM | SpIM |
| SST (°C) | 28.4-29 | 28.4-29.1 | 26.8-28.7 | 29.3-30.5 | 28.6-29.4 | 29.8-30.6 | 26.5-27.1 | 29.1-30.5 |
| SSS (psu) | 27.7-33.3 | 28.1-33.9 | 32.2-33.3 | 32.6-33.3 | 29.6-33.9 | 20.7-34.0 | 32.0-33.3 | 33.3-33.9 |
| Chl *a* (mg $m^{-3}$) | 9.0-11.5 | 13.8-23.4 | 17.3-22.2 | 13.4-18.26 | 11.7-18.7 | 11.3-18.7 | 16.7-26.7 | 11.18-42.92 |
| DO (μM) | 3-201 | 3-206 | 5.1-220.9 | 3.5-200 | 3-194 | 3-219 | 5.2-231 | 5.6-194 |
| Biovolume (ml 100 $m^{-3}$) | 0.2-404 | ng-120 | 0.3-75 | ng-230 | 0.2-120 | ng-115 | 1.0-142 | 1.0-533 |
| Biomass (mM C $m^{-2}$; 1000 m) | 41-111 | 79-190 | 71-225 | 24-197 | 14-90 | 96-154 | 58-190 | 35-480 |
| Abundance (x $10^3$ 100 $m^{-3}$) | 0.1-35.8 | 0.2-356 | 0.4-308 | 0.1-248 | 0.5-462 | 0.7-136 | 0.4-162 | 0.2-534 |
| Number of groups (range) | 4-14 | 9-25 | 9-24 | 4-25 | 1-16 | 9-25 | 14-21 | 7-25 |
| Major groups (>2%) | | | | | | | | |
| Copepoda | 75-90 | 74-90 | 74-93 | 78-85 | 88.2-99.7 | 67.3-89 | 81-91 | 70-86 |
| Chaetognatha | 2.6-9.3 | 1.6-5.7 | 1.4-7.6 | 1.9-4 | 0.04-3.2 | 1.2-3.2 | 2.0-4.0 | 1.5-4.3 |
| Euphausiacea | 0.2-6 | 0.6-3.8 | | | | | | |
| Ostracoda | 0.6-4 | 1.6-4.8 | 2.8-7.2 | 2.7-6.6 | | 1.4-6.7 | 1.7-5.6 | 2.6-9.5 |
| Polychaeta | 0.1-3.9 | | | | | 0.9-3.0 | | |
| Appendicularia | | 0.3-7 | | | | 0.5-5.4 | 0.3-4.2 | |
| Medusae | | | 0-7 | | | | | |
| Foraminifera | | 0.8-2.6 | | 0.6-3.1 | | | | 0.6-11.6 |
| Invertebrate eggs | | | | 1.2-6.5 | | 0.6-17.5 | | |
| Pteropoda | | | | | | | 0.3-6.5 | |

Ng: negligible

It is well understood that occurrence and relative abundance of zooplankton assemblages is governed by hydrographical characteristics of the region (Fager and McGowan 1963; Ashjian and Wishner 1993). With diverse forms and varied roles, they are important in the marine food web. Since it was not the aim of this study (except copepods) to undertake detailed taxonomic analyses of all the groups, it would be out of scope of this discussion to provide an opinion on the possible species of carnivores or, other groups except copepods.

*Pyrosoma*, the holoplanktonic colonial tunicates are known to be restricted to warmer waters (Van Soest 1981). Their trophic function in the ocean, as well as their ecology and physiology are extremely poorly known (Perissinotto et al. 2007). Harbison (1998) has shown that, in oceanic ecosystems, they are actually a very important prey item in the diet of many marine animals, vertebrates in particular. Harbison (1998) lists 62 fish and 3 turtle species worldwide that devour pyrosomes as a significant food source. Amongst the invertebrates, at least one species of sapphirinid copepod (Harbison 1998), two genera of hyperiid amphipods (Tregouboff and Rose 1957) and another two of penaeid shrimps (Monticelli and Lo Bianco 1901, Lindley et al. 2001) have been found inside *Pyrosoma* colonies.

Chaetognatha are extremely abundant in the sea and, constitute an important part of the marine plankton. Their vertical distribution is known to show a strong association with water masses (Ulloa et al. 2000). Occasionally mesopelagic species like *Sagitta decipiens* and *Eukrohnia hamata* are found in surface waters during coastal upwelling events (Bieri 1959; Fagetti 1968). All of them except *Spadella* sp. are planktonic with majority of these species being oceanic. These arrow worms are mostly holoplanktonic carnivores preying on copepods and other small zooplankton. They have mechanosensory hair fans along the body, which are capable of detecting prey in the form of water borne vibrations; however the range of prey detection is limited only to 2-3 mm (Horridge and Boulton 1967; Feigenbaum and Reeve 1977). The use of a tetrodotoxin (TTX) venom, found in at least six species of chaetognaths greatly enhances their success rate of prey capture and may be essential for the ingestion process to begin when the prey item is large or spiniferous (Thuesen et al. 1988). They found that in general, larger chaetognath species tended to possess higher quantities of toxin. The widespread abundance of planktonic chaetognaths in the pelagic and neritic waters of the world suggests that they may act as a vector in the distribution of TTX producing bacteria through marine food webs. Cannibalism was evident in all species studied by Batistic et al. (2003) in the Mediterranean. Around 30 species of chaetognaths have been recorded from the Indian Ocean. *Sagitta enflata* is the dominant species and, *S. bombayensis* is considered to be endemic. In general, chaetognath fauna of the Indian Ocean resembles that of the Pacific.

Appendicularians are marine filter-feeders that live and consume particulate food inside an elaborate mucoid house (Fenaux 1986). They form an important constituent of food for carnivorous zooplankton (King et al. 1980) and fish (Shelbourne 1962; Ryland 1964; Last 1978 a, b). When epipelagic appendicularians are numerous, they can consume the total daily production of phytoplankton (Alldredge 1981). A single individual produces as many as 5-16 houses a day depending on food and temperature conditions (Taguchi 1982; Gorsky et al. 1984; Fenaux 1985). Such particle-laden material constitutes one kind of marine snow aggregate, a substratum on which active microbial communities develop (Davoll and Silver 1986; Caron et al. 1986). Due to an elaborate apparatus for feeding, the weight-specific filtering rates and growth rates of appendicularians are higher and generation times shorter than those of copepods (Fenaux 1976; Paffenhofer 1976; Alldredge 1981). In a nutshell, appendicularians also have greater potentials as secondary producers. However their role in carbon transformation and transport to the deep water is not yet well understood (Barham 1979; Galt 1979; Youngbluth 1984).

Planktonic especially halocyprid ostracods are an important, but poorly studied component of open ocean plankton communities. They inhabit all depths and play a significant role in detrital cycles. Numerically, they are often the second or third most abundant group in mesoplankton samples and play a significant role in the recycling of marine snow and fecal pellets within thermocline waters. Their species occupying the polar seas were observed to have circumpolar distributions (Angel and Blachowiak-Samolyk 2007). The species that are predominantly temperate with occasional records in polar waters have either circumpolar distributions or are restricted to either the Atlantic or the Indo-Pacific Oceans. The tropical *Cypria tigris* has a wide distribution in the Indian Ocean region (Rao 1973).

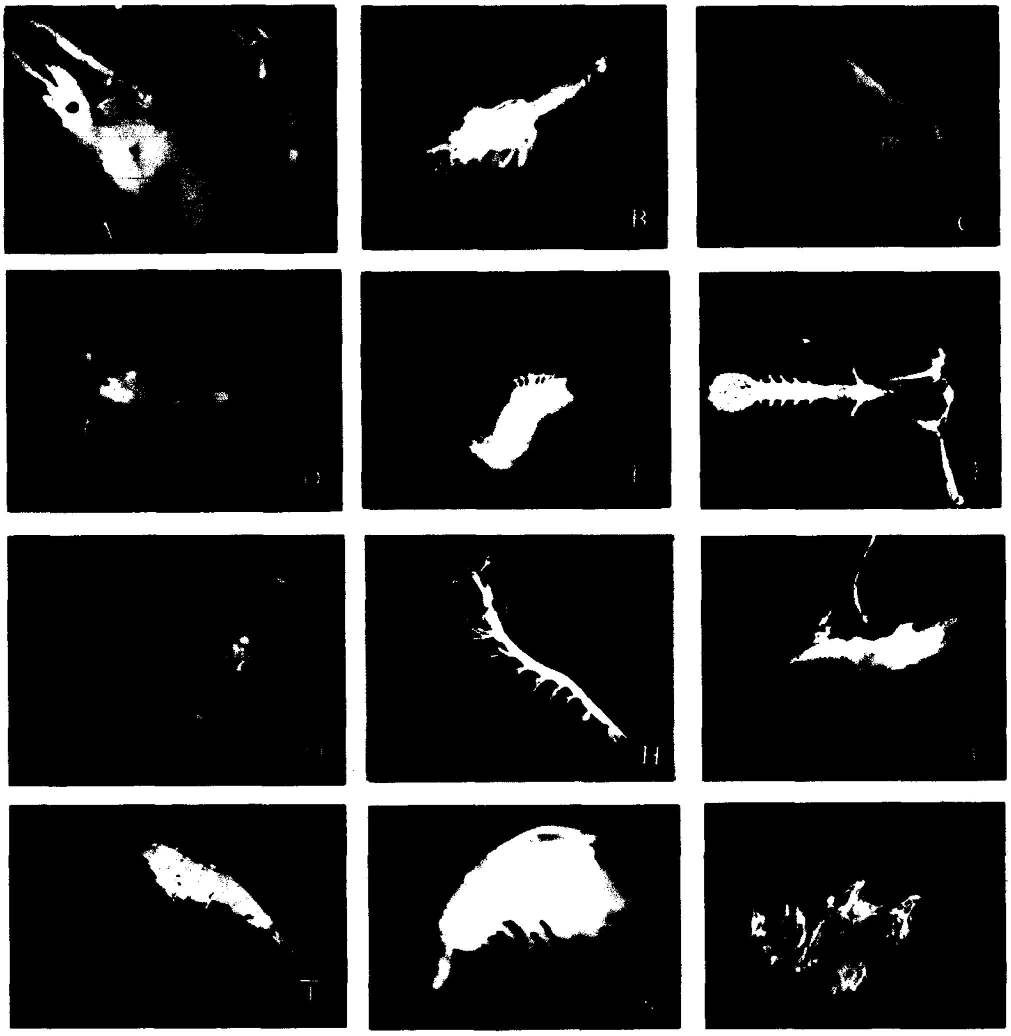
Euthecosomatous pteropods are widespread in the world oceans secreting aragonitic tests. After their death, together with the skeletal remains of other calcareous planktonic organisms, they contribute to the calcareous ooze on the sea floor (Herman 1968). When pteropods constitute a high percentage of the ooze, the deposit is called pteropod ooze (Herman 1998). Certain species of pteropods are believed to have great potential as bathymetric indicators due to the restricted depth ranges of certain species and to rapid settling velocities, which should lead to deposition close to their habitat (Herman and Rosenberg 1969).

Foraminifera, the single-celled amoeboid protists are abundant all over the ocean with ~40 planktonic species. In tropical euphotic waters, where trophic resources are highly competitive and sunlight is plentiful, several families of foraminifera harbor a host of unicellular photoautotrophs such as dinoflagellates, diatoms, green algae, red algae and even chrysophytes and prymnesiophytes. They derive carbohydrates (energy) from their symbionts. Owing to the diversity of endosymbionts or their photopigments, the symbiont bearing foraminifera are successful to utilize a wider range of the light spectrum and water depths. Other species mostly being omnivorous consume foods ranging from dissolved organic molecules, bacteria, diatoms and other single celled phytoplankton, to small animals such as copepods. They move and catch their food with a network of thin extensions of the cytoplasm called reticulopodia.

Scyphomedusae represent a conspicuous component of the plankton, especially during the summer months (Brodeur et al. 2002). They devour on a wide spectrum of zooplankton prey and can have a strong impact on zooplankton standing stocks (Omori et al. 1995; Ishii and Tanaka 2001; Brodeur et al. 2002). Their mass occurrence has been found to reduce local stocks of copepods (Hulsizer 1976).

In the Bay, the herbivorous copepods, foraminifers and appendicularians; the carnivorous chaetognaths and, the omnivorous ostracods and pteropods prevailed during most seasons. It can thus be proposed that these groups of mesozooplankton populating the MLD consume most of the primary and microbial (bacterial and microzooplankton) production in the surface layers of the BOB. This is also implicit from the close seasonal coupling of their biovolume with chlorophyll concentration in the MLD.

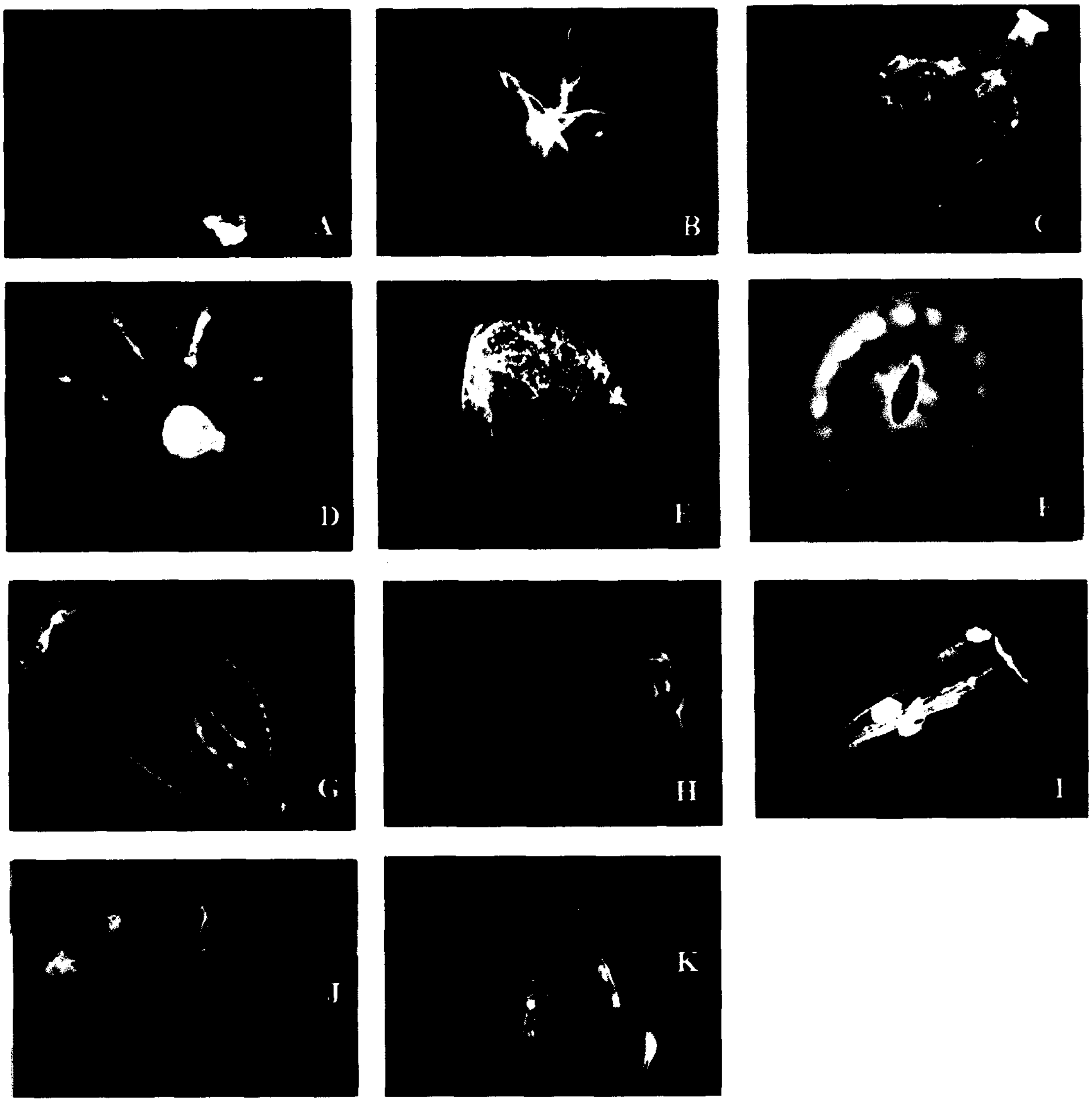
# Plate 1



Different crustacean zooplankton groups from the Bay of Bengal

Key:
A: Mysid; B: Mysid; C: Euphausiid; D: Thalassocaris; E: Pasiphaeid; F: Stomatopod;
G: Megalopa; H: Lucifer; I: Isopod; J-L: Amphipods

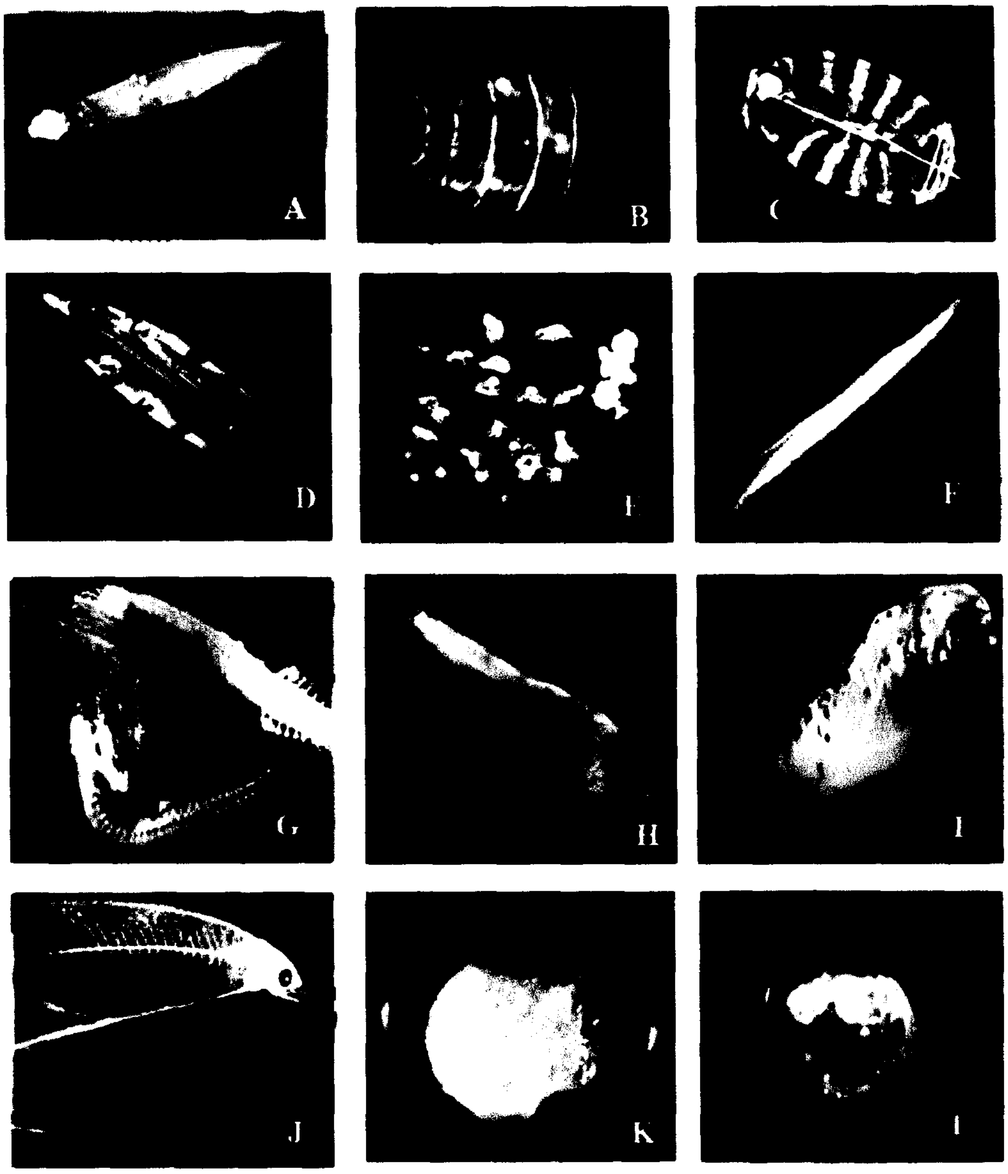
# Plate 2



Various cnidarian zooplankton identified from the Bay of Bengal

Key:
A-F: Medusae, G-K: Siphonophores

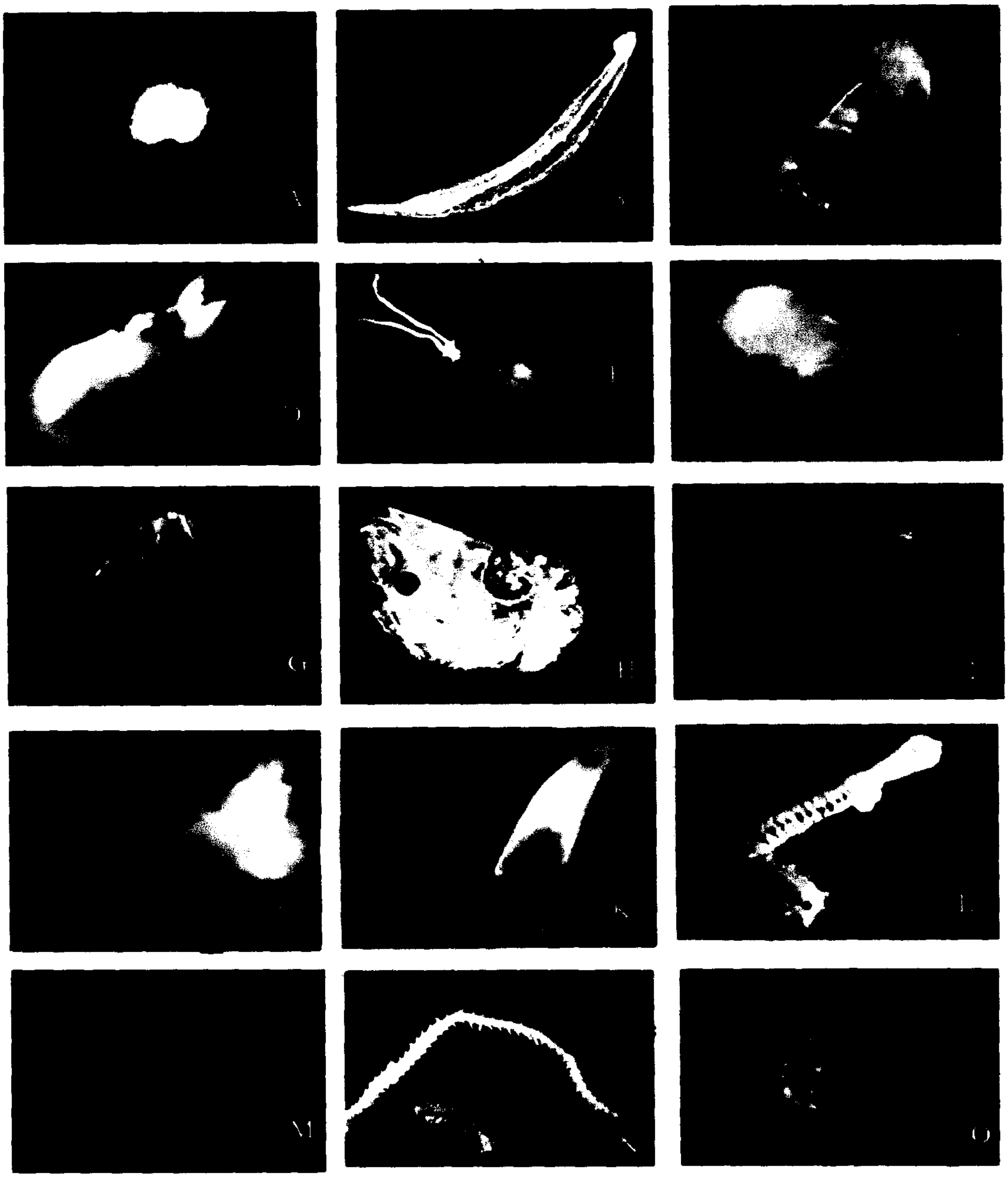
# Plate 3



Various Chordates identified from mesozooplankton samples in the Bay

Key:
A: Appendicularia; B: Doliolum, C, D: Salps, E: *Pyrosoma* colony;
F: Amphioxus; G-J: Fish larvae; K, L: Fish eggs

# Plate 4



Various mesozooplankton groups in the Bay

Key:
A: Foraminifera: B: Chaetognath: C: Gastropod; D. E: Cephalopod larvae:
F: Ostracod: G: Echinoderm larvae: H: Carinaria: I: Halobates; J. K: Pteropod;
L-O: Polychaetes

# Chapter 6

# Chapter 6

## *Copepoda in Central Bay of Bengal*

Copepods, the very diverse aquatic crustaceans, are the most numerous metazoans (Hardy 1970) in aquatic ecosystems. Their habitats range from freshwater to super hypersaline conditions, from subterranean caves to water collected on leaves or leaf litter on the ground and from streams, rivers, and lakes to the sediment layer in the open ocean. Their habitats also range from the aquatic bodies in the highest mountains (Loffler 1968) to the deepest ocean trenches (Wolff 1960), and from the cold polar ice-water interface to the hot active hydrothermal vents (Tsurumi and Tunnicliffe 2003).

The subclass Copepoda comprises 10 Orders: Calanoida, Cyclopoida, Gelyelloida, Harpacticoida, Misophrioida, Monstrilloida, Mormonilloida, Platycopioida, Poecilostomatoida and Siphonostomatoida (Boxshall and Hasley 2004) covering approximately 210 described families, 2,280 genera and over 14,000 species. More than 11000 of these known species live in the sea (Bowman and Abele 1982; Humes 1994). As they form the biggest biomass in the oceans, they are also called as the *insects of the sea*. They may be free-living, symbiotic, or internal or external parasites on almost every phylum of aquatic animals. Evolved presumably in the post-Precambrian (Sharov 1966; Boxshall 1983, Huys and Boxshall 1991), they are typically small and fragile. The copepods do not fossilize well; the first true fossils were of harpacticoids and cyclopoids and were reported by Palmer (1960, 1969) in North and South America. One of these forms was identified as *Cletocamptus* Schmankewitsch species. The most spectacular fossil copepod is undoubtedly *Kabatarina pattersoni* Cressey and Boxshall, a fish parasite from the Lower Cretaceous (Cressey and Patterson 1973; Cressey and Boxshall 1989).

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. Morphological and other biological features are described briefly in the following paragraphs.

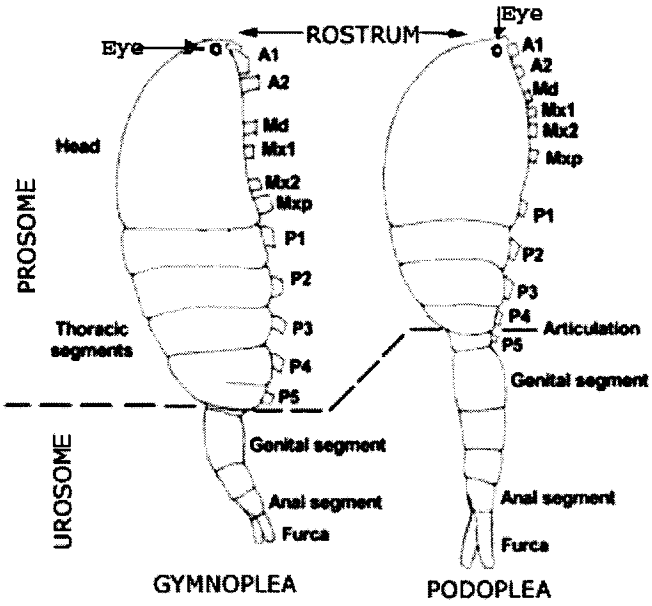


**Figure 6.1. Schematic diagram of typical copepods showing different morphological features (http://www.luciopesce.net/copepods/intro.htm)**

**Morphology**: There are two basic plans of body organization or tagmosis in copepods, gymnoplean and podoplean, differentiated by the position of the major body articulation. In the gymnoplean plan, this is behind the fifth pedigerous somite whereas in the podoplean plan (Harpacticoida) it is between the fourth and fifth pedigerous somites. The major articulation divides the body into an anterior prosome and a posterior urosome (Figure 6.1). Theoretically, the body comprises of 16 segments. The prosome is further divided into two sub-regions. It consists of the anterior cephalosome (head) comprising of six somites, and thorax (metasome). The first thoracic somite bears the maxillipeds. All copepods have their first thoracic somite fully incorporated into the cephalosome. The head has a central naupliar eye and a pair of uniramous antennules (A1) that are generally very long and comprise up to 27 segments. The antennae (A2), mandible (Md) and maxilla 1(Mx1; maxillule) are biramous whereas the maxilla 2 (Mx2) and maxillipeds (Mxp) are uniramous without exopod. Each of the second to sixth thoracic somites bears a pair of biramous swimming legs (P1 to P5). These legs are often reduced and, sometimes missing, especially in parasitic forms. The fifth leg is often modified, by reduction or loss of the endopod or by fusion of the endopod to the basis. The fifth leg is absent in some species. The sixth pair of pereopods is reduced and included into the genital apparatus that is present on the seventh thoracic somite in both sexes. The posterior urosome consists of the abdomen. The four abdominal somites are limbless, although the anal somite bears terminally paired caudal rami of seven setae each (Huys and Boxshall 1991).

**Size:** Copepods are typically small with size of 1-2 mm. In the marine planktonic forms, total body length is usually between 0.5 and 5.0 mm, although the full range is from about 0.2 mm (some species of *Oncaea* Philippi) to about 28 mm (a species of *Valdiviella* Steuer; Huys and Boxshall 1991). Adult males of *Sphaeronellopsis monothrix*, a parasite of marine ostracods are the smallest copepods attaining length of 0.11 mm (Bowman and Kornicker 1967). However *Pennella balaenopterae*, an ectoparasite of fin whale, measuring 28±3 cm is the largest copepod in the world (Cicek et al. 2007).

**Locomotion:** Their long and feathered antennae are ideal for drifting in the free water. Some species show daily migrations, ascending to the surface layer during the night and descending to several hundred meters depth during daytime. These tiny creatures (1-2 mm length) reach a speed of up to 90 meters per hour (this is ~ 45000 body lengths per hour and would equal a speed of 81 km/h for a human of 1.80 m height; Enright 1977). The movement of the mouth appendages provides the propulsion and for faster movements, the swimming legs are used (Alcaraz and Strickler 1998; Durbaum and Kunnemann; http://www.uni-oldenburg.de/zoomorphology/Biologyintro.htm).

**Nutrition:** Planktonic copepods are mainly suspension feeders on phytoplankton and/or bacteria; the food items being collected by the second maxillae. As such, copepods are therefore selective filter feeders (Frost 1972, 1974; Wilson 1973). Water current is generated by the appendages over the stationary second maxillae, which actively captures the food particles. Calanoida are typical particle feeders (Gauld 1966). As soon as food receptors detect the approach of a suitable algal cell, the maxillae are opened. Water with the cell is sucked into the chamber between the maxillae. When the chamber is closed the water is pressed out again. The algal cells are trapped between the bristles of the maxillae. In this chamber, particles of 5-μm diameter can be retained. Many harpacticoids feed on algae or microbes that cover the substrate. Most predatory copepods can be found in the Calanoida and Cyclopoida (Gauld 1966). Some of the latter are able to tear pieces out of the body of their victims (small fishes) with their strong mandibles.

**Life cycle:** The life cycle includes up to six naupliar and five copepodid stages prior to the adult. The male copepods are commonly smaller than the females and appear in lower abundance then the latter. Locating a mate is the most difficult task for planktonic copepods in oligotrophic environments (Buskey 1998). Reproductive success can be found in swarming copepods such as *Dioithona oculata*, which swarm in densities of tens of copepods per ml (Ambler et al. 1991; Buskey et al. 1996). Usually, copepods swarm at dawn and disperse at dusk (Buskey 1998). It has been evidenced that in planktonic copepods, the male searches for the female (Katona 1973; Blades 1977; Uchima and Murano 1988; Ambler et al. 1996). The virgin females are usually preferred (Snell and Carmona 1994). They may use distance-pheromones (Katona 1973; Griffiths and Frost 1976) and contact-pheromones (Snell and Morris 1993; Snell and Carmona 1994) or even mechanosensory information in mate recognition (Strickler and Bal 1973; Yen et al. 1995).

During copulation, the male grasps the female with its first antennae (Figure 6.2), sperm is transferred by the male through spermatophores that are placed on the female and glued by means of special cement (Strickler 1998). The spermatophores discharge the sperm via paired copulatory pores into paired seminal receptacles within the genital somite of the female where they are stored. Some female copepods are reportedly observed with multiple spermatophore attachments (Katona 1975; Hopkins and Machin 1977) suggesting that multiple mating has occurred. It has been found that the female *Oithona davisae* needs to be mated only once to remain fertile during the rest of its adult life (Uchima 1985). However, female members of the family Centropagidae require frequent re-mating to stay fertile (Ohtsuka and Huys 2001). Inter-species

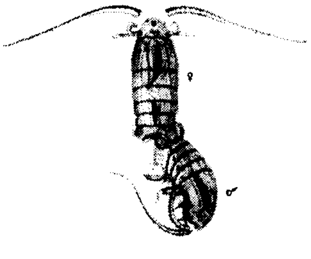


**Figure 6.2. Copepod mating (Jurine 1820)**

breeding, found in some experiments is not well studied (Katona 1973; Jacoby and Youngbluth 1983; Maly 1984).

A few hours or days after copulation, egg-sacks are formed in females. Eggs typically carried in paired egg sacs outside the body under the abdomen are usually embedded into a mass of secretions. 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. Calanoids shed their eggs singly into the water. Depending on size and life style, a few to several dozen eggs develop inside their protective cover. Some parasites produce several thousand eggs. Studies in the Atlantic and Indian waters have shown fecundity in planktonic copepods ranging from 80-130 eggs.female$^{-1}$ clutch$^{-1}$ (Sazhina 1980, 1982, 1985). It was also found that most of these species bear their eggs-sacs with small number of large eggs (20-25) or great number of small eggs (50-150 eggs.female$^{-1}$. clutch$^{-1}$). Reproduction of copepods is associated with temperature, size of females and food (Marshall and Orr 1955; McLaren 1978; Durbin et al. 1983).

The females nourish the eggs and after a few days the larvae hatch and the egg sack is cast off. The production of non-hatching eggs is often ascribed to insufficiency of food (Ban et al. 1997; Miralto et al. 1999), or to production of resting eggs (Castellani and Lucas 2003). It is also possible that the eggs are unfertilized (Ianora et al. 1989) and the females unmated since virgin copepod females may produce sterile eggs (Parrish and Wilson 1978; Uchima 1985). Sazhina (1987) reported that up to 20-30 % of copepods, out of all species available were found to reproduce in productive and coastal zones, while only 10 % pertained to oligotrophic zones. The duration of clutch development was rather short in surface waters of high temperature (25-30°C). While the species laying eggs into water showed a lower duration (0.5-2 days), the development time of eggs in egg sacs was found to be 3-6 days.

**Larval stages:** The first larvae of copepods are called nauplii (Figure 6.3). They are very small (sometimes 20 μm) and like the adults, are found in very different habitats. Usually copepods pass six naupliar stages, which are separated by moulting. The first stages have only three pairs of appendages that are responsible for locomotion and feeding. The older nauplii already show buds of further mouth appendages and swimming legs.

Figure 6.3: Copepod nauplii (Durbaum and Kunnemann)

The sixth naupliar stage moults into the first copepodid. With the increasing number of body segments more appendages become functional. After the fifth moult, adulthood is reached and reproduction can take place. The development may take from less than one week to as long as one year. Life span of a copepod ranges from six months to one year. (http://www.fao.org/DOCREP/003/W3732E/w3732e0t.htm)

**Diapause:** Under unfavorable conditions some copepod species can produce thick-shelled dormant eggs or resting eggs. Such cysts can withstand desiccation and also provide means for dispersal when these are carried to other places by birds or other animals. In higher latitudes, a diapause stage is present in the development of the copepods so as to survive adverse environmental conditions, such as freezing. Diapause usually taking place between the copepodite stage II and adult females, are recognized by an empty alimentary tract, the presence of numerous orange oil globules in the tissue and an organic, cyst-like covering. The major diapause habitat is the sediment, although a minor part of the diapausing individuals may stay in the planktonic fraction, the so-called "active diapause" (Dussart and Defaye 2001; http://www.uni-oldenburg.de/zoomorphology/Biology.html).

**Significance of copepods in marine ecosystems:** Planktonic copepods, calanoids in particular, are the main consumers of diatoms. Copepods in general, can be credited as the biological entities linking microscopic algal cells to juvenile fish to whales in the marine food chain. Notably, this group constitutes the biggest source of protein in the oceans (http://www.uni-oldenburg.de/zoomorphology/Biology.html.). The sheer abundance of this most diverse group in marine plankton secures them a vital role in the marine economy. Most of the commercially harvested fishes and even the whales in the northern hemisphere directly feed on them. Due to their widespread distribution throughout the world oceans, they largely contribute to its secondary productivity, and to carbon sink. Through their extensive diel and seasonal vertical migrations, they also make some matter from the euphotic layer available to deeper layers (Longhurst and Williams 1992). Their fecal pellets contribute greatly to the marine snow and therefore accelerate the downward flux of organic matter from surface waters.

Advancing the understanding of the distribution of marine copepod communities in oceanic/ coastal regions has been one of the focuses of the ICES (International Council for Exploration of Seas), JGOFS (Joint Global Ocean Flux Study) and GLOBEC (Global Ocean Ecosystem Dynamics). Studies on copepods from many oceanic regions like the tropical Pacific (Grice 1961; Longhurst 1967, 1985; Vinogradov and Shushkina 1976; Dessier and Donguy 1985; Roman et al. 1995), Subarctic Pacific (Miller 1993; Mackas et al. 1993; Shih and Chiu 1998;Yamaguchi et al. 2002), the Sargasso Sea (Deevey and Brooks 1971, 1977; Roman et al. 1993), the North Atlantic (Hulsemann and Grice 1963; Deevey 1964; Morales et al. 1991; Hays et al. 1997; Berasategui et al. 2005) and the Arabian Sea (Smith 1998; 2000; Madhupratap et al. 2000) have been carried out.

The copepod assemblages in the oceanic environments are very diverse, for instance, Hayward and McGowan (1979) found over 200 copepod species in the North Pacific gyre. Sameoto (1986) reported 118 species in the eastern tropical Pacific and, Webber and Roff (1995) recorded 69 species at an oceanic site off Jamaica. More recently, Berasategui et al. (2005) observed 35 species of copepods in 23 genera and 13 families in the upper 50 m of the southwestern Atlantic. Along a transect extending from 60°N to 41°N over the mid Atlantic ridge, a total of 68 genera and 117 species were identified from the upper 2500 m (Gaard et al. 2008). They found 57 genera of calanoid copepods dominating the generic richness. Also, there was a clear equator-ward increase in the number of genera.

The Indian Ocean harbors the greatest copepod diversity (http://copepodes.obs-banyuls.fr/en). In the Arabian Sea, up to 98 species of only calanoid copepods were identified by Padmavati et al. (1998). Similarly, 86 calanoid species were identified in the central Arabian Sea (Madhupratap et al. 2001).

After the IIOE (International Indian Ocean Expedition), the Bay of Bengal has remained relatively unexplored. Further, in addition to being sparsely sampled during IIOE, data on copepod species abundance was limited to the upper 200 m. A few other studies carried out thereafter were mostly from the coastal areas (Achuthankutty et al.1980; Nair et al. 1981; Rakhesh et al. 2006). The main aim was to advance our knowledge on the abundance and distribution of copepods in the oceanic regions of the Bay of Bengal. It was also aimed to understand the seasonal variability in existence of copepod species at various depths in the upper 1000 m.

## 6.1. Materials and Methods

As described in Chapter 4, zooplankton samples were collected from five strata at five stations from the central Bay of Bengal (CB) using a multiple plankton closing net. After biovolume measurements, zooplankton samples were preserved in 4% formaldehyde-seawater solution. In the laboratory, the plankton samples were sorted out group-wise. From the copepods, all adult specimens were identified up to generic and up to species level in most cases. To confirm the species of calanoids, the 5th leg of many individual specimens were dissected out whenever felt necessary. The unidentifiable copepodites and nauplii were included in total copepod counts. Statistical analyses have been carried out as mentioned in Chapter 4.

Many standard identification keys were referred to for taxonomic confirmation (Tanaka 1956; Kasturirangan 1963; Owre and Foyo 1967; Bradford and Jillett 1980; Bradford-Grieve 1994). Also integrated taxonomic information system (ITIS; http://www.itis.gov) was used for confirmation of currently used species names.

### 6.1.1. Diversity indices

Diversity index is a mathematical measure of species diversity in a community. Diversity indices provide more information about community composition than simply species richness (*i.e.* the number of species present); they also take the relative abundances of different species into account.

The Shannon diversity index (Omori and Ikeda 1984) for copepod species was calculated for comparing the species diversity among copepod communities at various depths and locations in the Bay, using the formula:

$H' = - {}_{i=1}{}^{S}\Sigma\, Pi \log_2 Pi$

where, $S$= total number of species and

$Pi$ = proportion of the numbers of individuals of species $i$ to the total number of individuals ($Pi = ni/N$).
$H'$ accounts for both abundance and evenness of the species present. Its maximum value for fixed species richness is therefore $ln(S)$. Therefore, $H'$ increases dramatically with increasing numbers of species.

Species Evenness ($J'$) was calculated according to Pielou (1966):
$J' = H' / \mathrm{Log}_2 S$
Where, $H'$ is the Shannon diversity index and, $S$= total number of species. Evenness is the ratio of observed diversity to maximum diversity ($\mathrm{Log}_2 S$). The latter is achieved when most species in a collection are equally abundant (Margalef 1951; Pielou 1966). Evenness assumes a value between 0 and 1, with 1 being complete evenness.

Species Richness ($d$; Margalef 1951) is defined as the number of species recorded from a region. Higher the number of species, higher will be the richness. It is an indirect method of calculating diversity. It was determined by the formula:
$d = (S-1)/\log_n N$
$d$ does not use information on species proportions. According to it, when total abundance is larger, species will be less evenly distributed, which is often the case in natural communities.

## 6.2. Results

### 6.2.1. Abundance

Copepod abundance (Fig. 6.1) varied respectively from 35 to 86796 (average, 8773 individuals 100 $m^{-3}$), 136 to 103253 (23643 ind. 100 $m^{-3}$), 321 and 273588 (21150 ind. 100 $m^{-3}$) and 68 to 202080 (22246 ind. 100 $m^{-3}$) during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM). There was significant difference ($p<0.05$) in the abundance between the stations during SUM, FIM and WM in the CB (Table 6.1). During the former two seasons, abundance was higher in the mixed layer depth (MLD) at CB1 and CB5. During WM and SpIM however, it was highest only at CB5 and CB3 respectively. However, the abundance decreased significantly with increasing depth during all seasons. The seasonal variation in copepod abundance was significant but the diel variation was not (Table 6.1). Cluster analysis

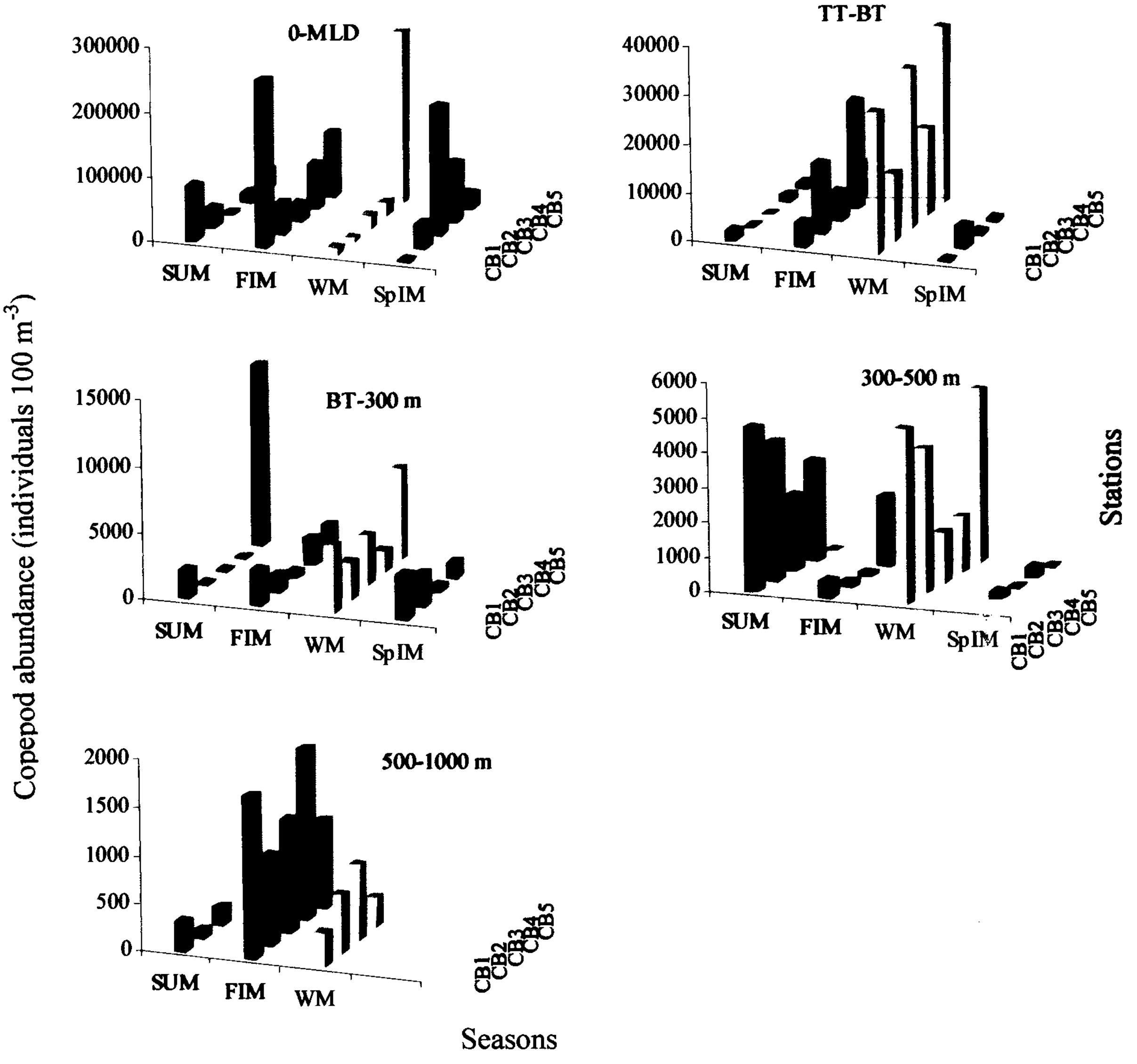


Figure 6.1. Spatio-temporal variation in copepod abundance at different depths in the central Bay of Bengal. SUM: Summer monsoon, FIM: fall intermonsoon, WM: winter monsoon and SpIM: spring intermonsoon. Scales are different for each graph

Table 6.1. Diel, spatial and seasonal difference in copepod abundance in the central Bay of Bengal during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM) as deciphered through non-parametric tests

| Wilcoxon Matched Pairs Test between day and night | | | | |
|---|---|---|---|---|
| Seasons | N | T | Z | $p$ |
| SUM | 25 | 130 | 0.57 | $p > 0.05$ |
| FIM | 18 | 67 | 0.81 | $p > 0.05$ |
| WM | 25 | 119 | 0.89 | $p > 0.05$ |
| SpIM | | ND | | |

| | Friedman ANOVA | | | |
|---|---|---|---|---|
| Seasons | Chi Sqr. | N | df | $p$ |
| | Between stations | | | |
| SUM | 8.8 | 4 | 4 | **$p = 0.05$** |
| FIM | 8.32 | 5 | 4 | **$p = 0.05$** |
| WM | 10.6 | 4 | 4 | **$p < 0.05$** |
| SpIM | 4.2 | 3 | 3 | $p > 0.05$ |
| | Between depths | | | |
| SUM | 13.4 | 4 | 4 | **$p < 0.05$** |
| FIM | 18.08 | 5 | 4 | **$p < 0.05$** |
| WM | 14.8 | 4 | 4 | **$p < 0.05$** |
| SpIM | 5.8 | 3 | 3 | $p > 0.05$ |
| | Between Seasons | | | |
| | 15.63 | 17 | 3 | **$p < 0.05$** |

Significant results are marked **bold**

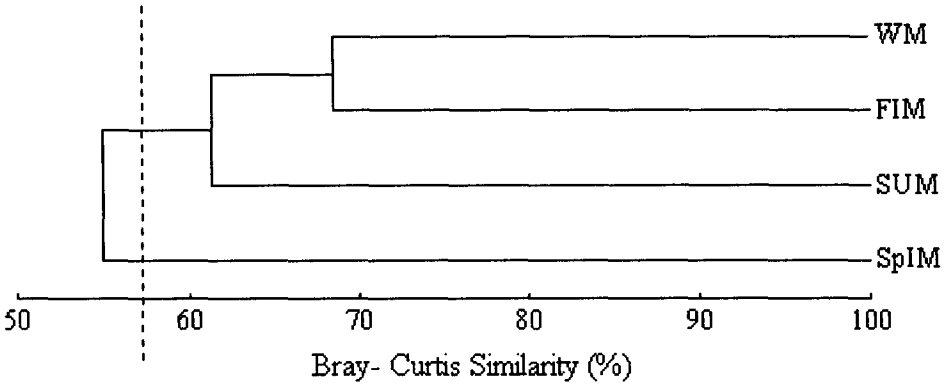


Figure 6.2. Cluster dendrogram based on Bray- Curtis similarity coefficients, depicting similarity in copepod abundance between seasons in the central Bay.
SUM: Summer monsoon, FIM: fall intermonsoon, WM: winter monsoon and SpIM: spring intermonsoon

revealed that the copepod abundance was spatially similar during SUM, FIM and WM, differing from that during SpIM (Fig. 6.2).

### 6.2.2. Orders

Five orders *viz.* Calanoida, Cyclopoida, Harpacticoida, Mormonilloida and Poecilostomatoida were identified during all seasons in the CB (Fig. 6.3; Tables 6.2 -6.6). Overall, Calanoida was always the most dominant order (49.4%), followed by Poecilostomatoida (26.2%), Mormonilloida (9.1%), Cyclopoida (7.6%) and Harpacticoida (3.8%). For the ease of comparison, seasonal variations in the abundance of individuals from different families under these orders are described below.

*Calanoida:* Members of Calanoida ranging from 33 to 61 % of total copepods during SUM was higher in the subsurface (200-300 m) and the deepest layer (Fig. 6.3). It also attained a subsurface maximum in the 300-500 m stratum during FIM (44-79 %) and 150-500 m stratum during WM (18-63 %). During SpIM however, it (35-59%) decreased from the surface to the 200-300 m stratum.

In this transect, 25 calanoid families were recorded (Tables 6.2 -6.6). The individual species belonging to the families Metridinidae (average 8.7%) and Eucalanidae (7.5%) were the largest during SUM, followed by Paracalanidae (15.6%), Lucicutiidae (10.3%) and Augaptilidae (9.0%) during FIM, Metridinidae (13%) during WM and Clausocalanidae (10.2%) and Metridinidae (9.3%) during SpIM.

*Cyclopoida:* This order (3.5-13%) comprising exclusively of Oithonidae was abundant in the 200-300 m layer during SUM. It was found in the upper 300 m and especially the thermocline during FIM (0.4-11.3%). It was abundant above 500 m during WM (2.6-15%), and was most abundant again in the thermocline (5-19%) during SpIM.

*Harpacticoida:* Observed at all depths, this order ranging from 2.3 to 9.5% was most abundant during SUM. In the other three seasons, it was present throughout the water column in minor concentrations ranging from 2.3 to 3.9 %. Species in the families Clyemnestridae and Miraciidae were generally abundant among the five families recorded under this order.

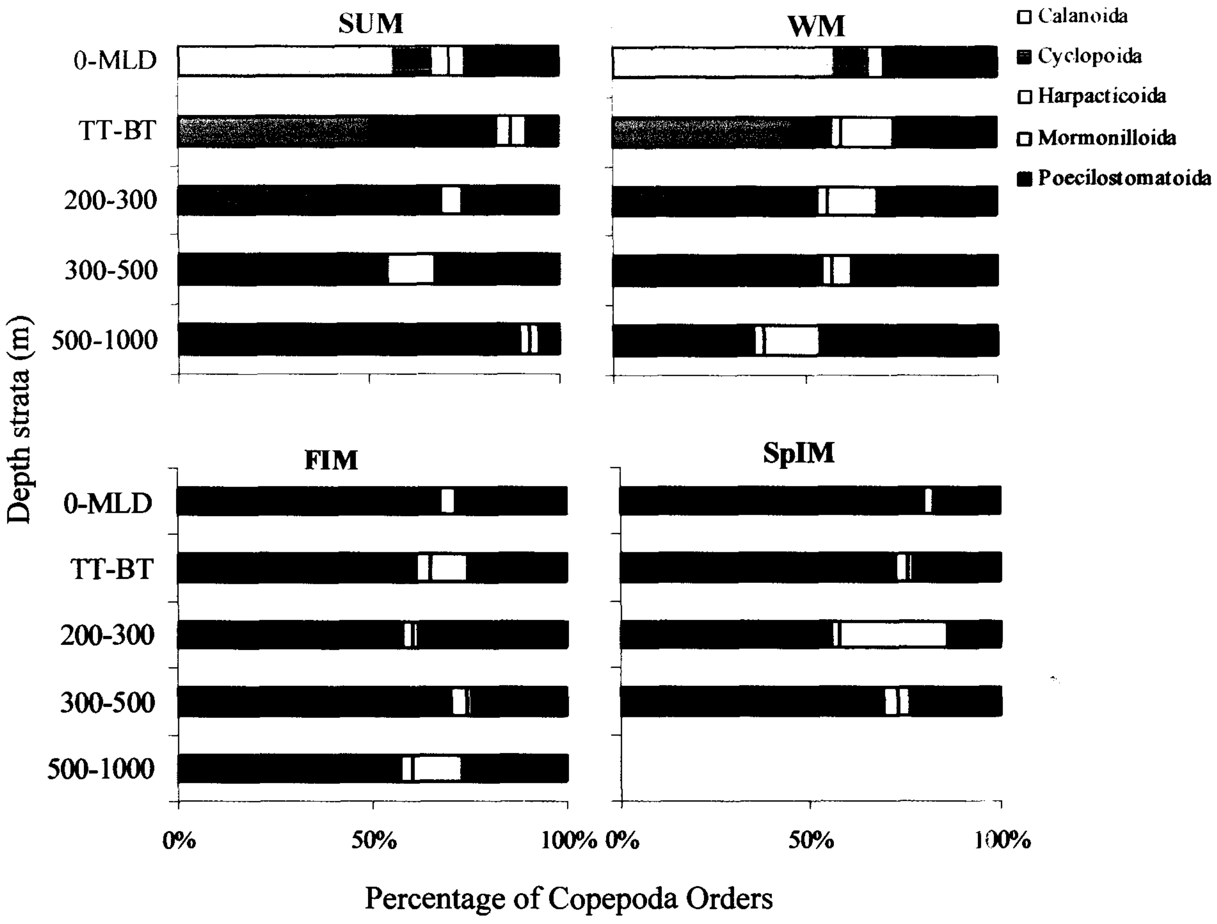


Figure 6.3. Vertical distribution of Copepoda orders at different depths during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM) in the central Bay of Bengal

*Mormonilloida:* Mormonilloida represented by single family Mormonillidae was mostly abundant below MLD during all seasons (SUM 3.1-31.0; FIM: 0.04-8.7; WM: 0.2-21.4; SpIM: 2.0-30.9%).

*Poecilostomatoida:* Poecilostomatoida ranging from 15.3 to 47.5% was abundant in the surface, decreased subsurface showing a secondary peak in the 300-500 m layer during SUM. Similarly, it relatively increased below subsurface minima at 300-500 m during FIM (6.0 to 41.1%), 150-300 m during WM (15.3-52.9%) and thermocline during SpIM (14.1-26.7%). Though six families were recorded, only two *viz.* Oncaeidae and Corycaeidae were the most dominant.

### 6.2.3. Families

From the 37 families (Tables 6.2-6.6) that were recorded from the CB during the study, members of only eight families (Clausocalanidae, Eucalanidae, Lucicutiidae, Metridinidae, Paracalanidae, Oithonidae, Mormonillidae and Oncaeidae) contributed ≥5 %. Another eight families (Aetideidae, Augaptilidae, Euchaetidae, Scolecithrichidae, Heterorhabdidae, Clytemnestridae, Miraciidae and Corycaeidae) were minor, occurring between one and five percent. The percentage contribution of the remaining 21 families (Acartiidae, Arietellidae, Calanidae, Candaciidae, Centropagidae, Fosshageniidae, Mecynoceridae, Megacalanidae, Nullosetigeridae, Phaennidae, Pontellidae, Rhincalanidae, Spinocalanidae, Temoridae, Tharybidae, Aegisthidae, Ectinosomatidae, Euterpinidae, Clausidiidae, Lubbockidae and Sapphirinidae) was <1% of total copepods.

In the mixed layer, the number of families occurring was 29, 25, 27 and 28 during SUM, FIM, WM and SpIM respectively (Table 6.2). Members of Oncaeidae (15-40%), Corycaeidae (8.5-9.4%) and Paracalanidae (6.8-38.9%) were preponderant during all seasons. Clausocalanidae (8.6-23.5%) and Oithonidae (7-12.5%) were dominant during most seasons except FIM. Comprising six and five percent of the total abundance, Miraciidae and Eucalanidae were most abundant only during SUM and FIM respectively. Similarly, members of Metridinidae and Lucicutiidae contributed to 5.8% and 7.7% respectively only during SpIM. Arietellidae, Megacalanidae, Aegisthidae, Clausiidae and Lubbockidae were absent from the MLD during all seasons.

In the thermocline, the number of families reduced during SUM compared to that in the MLD (SUM: 22, FIM: 27, WM: 31, SpIM: 25; Table 6.3). Representatives of the families Oncaeidae (11-22%) and Metridinidae (7-11%) were in high abundance during all seasons. Members of Paracalanidae (9.5-21%) and Oithonidae (11.3-19.2%) were preponderant during most seasons except SUM. Mormonillidae (6-31%) and Eucalanidae (4.8-9.4%) were dominant in most seasons except during FIM and WM respectively. Peaks of Lucicutiidae (10.3%) and Clausocalanidae (12.1%) in this stratum were found during FIM and WM only. Two families, Megacalanidae and Clausiidae were absent during all seasons from this stratum.

In the 200-300 m stratum too the number of families varied with seasons (SUM: 22, FIM: 29, WM: 28, SpIM: 20; Table 6.4). Cohorts of four families *viz.* Oncaeidae (12.0-25.6%), Oithonidae (4.7-12.7%), Metridinidae (11-39.2%) and Eucalanidae (5.1-14.1%) dominated during all the seasons in this stratum. The dominant family Euchaetidae accounted for 10.7% of the total abundance only during SUM. Both Paracalanidae (9.3 and 14.2%) and Lucicutiidae (6.1 and 8.4%) were relatively abundant during SUM and FIM. Similarly, representatives of Mormonillidae (7.4 and 31%) were dominant during WM and SpIM in particular. Members of families Arietellidae, Megacalanidae, Nullosetigeridae, Phaennidae and Temoridae were absent from this stratum during all seasons.

In the stratum between 300 and 500 m, the highest number of families was recorded during WM (SUM: 25, FIM: 24, WM: 31; Table 6.5). Members of Oncaeidae (5.7-40.6%), Mormonillidae (7.1-8.7%), Metridinidae (8.4-9.6%) and Lucicutiidae (5.3-19.9%) were highly abundant during all the sampled seasons. Representatives of Miraciidae, Augaptilidae and Eucalanidae attained their highest abundance during SUM (6.2%), FIM (33%) and WM (14.6%) respectively. Oithonidae accounted for 5% of the abundance during SUM and WM. Families such as Megacalanidae, Nullosetigeridae, Tharybidae, Euterpinidae and Clausiidae were absent from this stratum during all seasons.

In the deepest stratum sampled during this study, the numbers of families present were 27, 26 and 26 in SUM, FIM and WM respectively (Table 6.6). The dominant family Oncaeidae (18.7-51.7%) was preponderant during all seasons in this stratum. Members of

Table 6.2. Seasonal variations in abundance (individuals 100 $m^{-3}$) and percentage (%) of different copepod species in the mixed layer depth in central Bay of Bengal

| | SUM | | FIM | | WM | | SpIM | |
|---|---|---|---|---|---|---|---|---|
| Species | Abundance | % | Abundance | % | Abundance | % | Abundance | % |
| **CALANOIDA** | | | | | | | | |
| **Acartiidae** | | | | | | | | |
| *Acartia amboinensis* | 88.16 | 0.26 | A | - | A | - | A | - |
| *A. danae* | A | - | 130.12 | 0.13 | A | - | A | - |
| *A. erythraea* | 71.90 | 0.21 | A | - | A | - | A | - |
| *A. negligens* | A | - | 214.33 | 0.21 | 270.83 | 0.40 | 164.57 | 0.51 |
| *A. spinicauda* | A | - | 27.89 | 0.03 | A | - | A | - |
| *Acartiella sewelli* | A | - | 245.80 | 0.24 | A | - | A | - |
| **Aetideidae** | | | | | | | | |
| *Aetideus acutus* | 388.79 | 1.13 | A | - | A | - | A | - |
| *Euchirella amoena* | A | - | 101.32 | 0.10 | A | - | A | - |
| *E. galeata* | 8.34 | 0.02 | A | - | A | - | A | - |
| *E. indica* | 28.82 | 0.08 | A | - | 21.23 | 0.03 | 83.00 | 0.26 |
| *E. rostromagna* | 33.37 | 0.10 | A | - | A | - | A | - |
| *E. speciosa* | 44.08 | 0.13 | A | - | A | - | A | - |
| *E. truncata* | A | - | A | - | 25.13 | 0.04 | A | - |
| *Euchirella* sp. | A | - | A | - | A | - | 87.16 | 0.27 |
| *Gaidius pungens* | 44.08 | 0.13 | A | - | 246.66 | 0.37 | A | - |
| **Augaptilidae** | | | | | | | | |
| *Centraugaptilus horridus* | 16.69 | 0.05 | A | - | A | - | A | - |
| *Haloptilus longicornis* | 201.34 | 0.58 | 65.06 | 0.06 | 46.35 | 0.07 | 2.08 | 0.01 |
| *H. mucronatus* | A | - | 14.01 | 0.01 | A | - | A | - |
| *H. spiniceps* | 44.08 | 0.13 | A | - | A | - | A | - |
| *Pseudhaloptilus pacificus* | A | - | 65.06 | 0.06 | A | - | A | - |
| **Calanidae** | | | | | | | | |
| *Canthocalanus pauper* | 160.05 | 0.46 | 83.68 | 0.08 | 453.70 | 0.68 | 202.96 | 0.63 |
| *Mesocalanus tenuicornis* | A | - | 42.04 | 0.04 | A | - | A | - |
| *Nannocalanus minor* | A | - | 74.73 | 0.07 | A | - | A | - |
| *Undinula vulgaris* | 14.41 | 0.04 | 738.42 | 0.72 | 1372.79 | 2.05 | 515.97 | 1.60 |
| **Candaciidae** | | | | | | | | |
| *Candacia bispinosa* | A | - | A | - | A | - | 2.60 | 0.01 |
| *Candacia bradyi* | 14.41 | 0.04 | 14.01 | 0.01 | 802.85 | 1.20 | 100.65 | 0.31 |
| *C. catula* | A | - | 47.48 | 0.05 | A | - | A | - |
| *C. discaudata* | 44.08 | 0.13 | 74.73 | 0.07 | 11.94 | 0.02 | A | - |
| *C. pachydactyla* | 44.08 | 0.13 | A | - | A | - | 13.03 | 0.04 |
| *Candacia* sp. | A | - | 108.20 | 0.11 | A | - | 227.28 | 0.71 |
| *Paracandacia truncata* | A | - | 199.85 | 0.19 | A | - | 1.04 | 0.00 |
| *P. simplex* | A | - | A | - | A | - | A | - |
| **Centropagidae** | | | | | | | | |
| *Centropages alcocki* | A | - | 191.76 | 0.19 | A | - | A | - |
| *C. calaninus* | A | - | A | - | 366.90 | 0.55 | 15.11 | 0.05 |
| *C. dorsispinatus* | A | - | A | - | 8.22 | 0.01 | A | - |
| *C. furcatus* | 109.75 | 0.32 | 130.12 | 0.13 | 201.23 | 0.30 | 347.63 | 1.08 |
| *C. gracilis* | A | - | 81.93 | 0.08 | A | - | 39.49 | 0.12 |
| *C. orsinii* | A | - | 765.29 | 0.74 | A | - | A | - |
| *Centropages* sp. | 27.82 | 0.08 | 849.74 | 0.83 | A | - | A | - |
| **Clausocalanidae** | | | | | | | | |
| *Clausocalanus arcuicornis* | 981.26 | 2.85 | 2093.99 | 2.04 | 6415.77 | 9.58 | 6956.63 | 21.60 |
| *C. furcatus* | 1586.81 | 4.61 | 1094.62 | 1.06 | 2087.69 | 3.12 | 599.48 | 1.86 |
| *C. pergens* | 352.62 | 1.02 | 266.24 | 0.26 | A | - | A | - |
| *Drepanopsis orbus* | 44.08 | 0.13 | A | - | A | - | A | - |
| **Eucalanidae** | | | | | | | | |
| *Eucalanus crassus* | 27.82 | 0.08 | 1372.61 | 1.33 | 25.13 | 0.04 | A | - |
| *E. subcrassus* | 132.23 | 0.38 | 327.24 | 0.32 | 25.13 | 0.04 | A | - |
| *E. elongatus* | 298.97 | 0.87 | A | - | A | - | 85.59 | 0.27 |
| *E. monachus* | 503.60 | 1.46 | 3037.20 | 2.95 | 592.14 | 0.88 | 421.49 | 1.31 |
| *E. mucronatus* | A | - | 130.12 | 0.13 | A | - | 13.03 | 0.04 |
| *E. pseudattenuatus* | 16.69 | 0.05 | A | - | A | - | A | - |
| *Eucalanus* sp. | 301.12 | 0.87 | 338.75 | 0.33 | A | - | 187.80 | 0.58 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Pareucalanus attenuatus* | 64.99 | 0.19 | A | - | 336.88 | 0.50 | 419.54 | 1.30 |
| **Euchaetidae** | | | | | | | | |
| *Euchaeta concinna* | 27.82 | 0.08 | A | - | 139.78 | 0.21 | A | - |
| *E. indica* | 88.16 | 0.26 | 1372.15 | 1.33 | 31.95 | 0.05 | 13.03 | 0.04 |
| *E. marina* | 190.72 | 0.55 | 540.79 | 0.53 | 770.53 | 1.15 | 666.60 | 2.07 |
| *E. media* | A | - | A | - | A | - | A | - |
| *E. plana* | A | - | 27.89 | 0.03 | A | - | A | - |
| *Euchaeta* sp. | 109.75 | 0.32 | 95.95 | 0.09 | 253.54 | 0.38 | A | - |
| **Fosshageniidae** | | | | | | | | |
| *Temoropia mayumbaensis* | 55.64 | 0.16 | A | - | A | - | 168.59 | 0.52 |
| **Heterorhabdidae** | | | | | | | | |
| *Heterorhabdus abyssalis* | 16.69 | 0.05 | A | - | A | - | A | - |
| *H. pacificus* | 14.41 | 0.04 | A | - | A | - | A | - |
| *H. papilliger* | 11.22 | 0.03 | A | - | 36.32 | 0.05 | A | - |
| *H. spinifrons* | 2.88 | 0.01 | A | - | A | - | A | - |
| *Heterostylites major* | A | - | A | - | A | - | 2.59 | 0.01 |
| **Lucicutiidae** | | | | | | | | |
| *Lucicutia bicornuta* | 16.69 | 0.05 | A | - | A | - | A | - |
| *L. flavicornis* | 632.06 | 1.83 | 943.72 | 0.92 | 720.92 | 1.08 | 2380.27 | 7.39 |
| *L. maxima* | 131.30 | 0.38 | A | - | 6.88 | 0.01 | A | - |
| *L. ovalis* | 194.64 | 0.56 | A | - | A | - | 101.66 | 0.32 |
| **Mecynoceridae** | | | | | | | | |
| *Mecynocera clausii* | 44.08 | 0.13 | 489.49 | 0.48 | 34.98 | 0.05 | 39.49 | 0.12 |
| **Metridinidae** | | | | | | | | |
| *Gaussia princeps* | 8.34 | 0.02 | A | - | A | - | 5.17 | 0.02 |
| *Metridia brevicauda* | 39.44 | 0.11 | A | - | A | - | 2.59 | 0.01 |
| *Metridia* sp. | 44.08 | 0.13 | A | - | A | - | A | - |
| *Pleuromamma abdominalis* | A | - | 16.59 | 0.02 | 45.80 | 0.07 | A | - |
| *P. gracilis* | 154.99 | 0.45 | A | - | 91.30 | 0.14 | 259.90 | 0.81 |
| *P. indica* | 866.34 | 2.51 | 1251.95 | 1.22 | 956.98 | 1.43 | 1598.42 | 4.96 |
| *P. quadrangulata* | 8.34 | 0.02 | 33.47 | 0.03 | A | - | A | - |
| *P. robusta* | A | - | 134.51 | 0.13 | 45.80 | 0.07 | A | - |
| *P. xiphias* | A | - | A | - | 15.10 | 0.02 | 2.59 | 0.01 |
| *Pleuromamma* sp. | A | - | A | - | 91.60 | 0.14 | A | - |
| **Nullosetigeridae** | | | | | | | | |
| *Nullosetigera bidentata* | 250.38 | 0.73 | A | - | A | - | A | - |
| **Paracalanidae** | | | | | | | | |
| *Acrocalanus gibber* | 132.23 | 0.38 | 262.32 | 0.26 | A | - | 257.50 | 0.80 |
| *A. gracilis* | 377.91 | 1.10 | 1345.45 | 1.31 | 246.66 | 0.37 | 489.96 | 1.52 |
| *A. longicornis* | A | - | 2807.40 | 2.73 | 1608.64 | 2.40 | 564.22 | 1.75 |
| *A. monachus* | A | - | A | - | 23.88 | 0.04 | A | - |
| *Calocalanus pavo* | 63.65 | 0.18 | 1848.87 | 1.80 | 1542.97 | 2.30 | 979.91 | 3.04 |
| *C. plumulosus* | A | - | A | - | 158.60 | 0.24 | 85.59 | 0.27 |
| *Paracalanus indicus* | 969.72 | 2.81 | 26244.18 | 25.52 | 4757.19 | 7.10 | 613.62 | 1.91 |
| *P. aculeatus* | 55.64 | 0.16 | 3931.57 | 3.82 | 60.80 | 0.09 | A | - |
| *P. crassirostris* | A | - | 3386.11 | 3.29 | A | - | A | - |
| *P. parvus* | 741.90 | 2.15 | 163.87 | 0.16 | 2197.19 | 3.28 | A | - |
| **Phaennidae** | | | | | | | | |
| *Amallophora conifer* | 27.82 | 0.08 | A | - | A | - | A | - |
| *Xanthocalanus pectinatus* | 36.16 | 0.10 | A | - | A | - | A | - |
| **Pontellidae** | | | | | | | | |
| *Calanopia aurivilli* | A | - | 101.32 | 0.10 | A | - | A | - |
| *C. elliptica* | 27.82 | 0.08 | 881.95 | 0.86 | A | - | A | - |
| *C. minor* | A | - | A | - | 45.80 | 0.07 | A | - |
| *Labidocera acuta* | 55.64 | 0.16 | A | - | 386.44 | 0.58 | 83.00 | 0.26 |
| *L. pavo* | A | - | A | - | 48.86 | 0.07 | 2.59 | 0.01 |
| *Pontellina plumata* | A | - | 28.03 | 0.03 | 85.18 | 0.13 | 168.08 | 0.52 |
| **Rhincalanidae** | | | | | | | | |
| *Rhincalanus cornutus* | 88.16 | 0.26 | A | - | A | - | A | - |
| *R. nasutus* | 25.03 | 0.07 | A | - | A | - | A | - |
| *R. rostrifrons* | 96.50 | 0.28 | 65.06 | 0.06 | 4.25 | 0.01 | A | - |
| **Scolecitrichidae** | | | | | | | | |
| *Amallothrix gracilis* | A | - | A | - | A | - | 168.59 | 0.52 |
| *Lophothrix frontalis* | 14.41 | 0.04 | A | - | A | - | 1.04 | 0.00 |
| *Scaphocalanus elongatus* | A | - | A | - | A | - | 2.08 | 0.01 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Scolecithricella bradyi* | A | - | A | - | A | - | 257.50 | 0.80 |
| *Scolecithricella* sp. | A | - | A | - | A | - | 275.07 | 0.85 |
| *Scolecithrichopsis ctenopus* | 27.82 | 0.08 | A | - | A | - | 83.78 | 0.26 |
| *Scolecithrix bradyi* | A | - | A | - | A | - | 39.49 | 0.12 |
| *S. danae* | 39.44 | 0.11 | 1141.01 | 1.11 | 542.64 | 0.81 | 42.08 | 0.13 |
| **Spinocalanidae** | | | | | | | | |
| *Monacilla gracilis* | A | - | A | - | 25.13 | 0.04 | A | - |
| *M. typica* | 69.11 | 0.20 | A | - | A | - | A | - |
| *Spinocalanus spinosus* | A | - | A | - | A | - | A | - |
| **Temoridae** | | | | | | | | |
| *Temora turbinata* | A | - | 346.84 | 0.34 | A | - | A | - |
| *T. discaudata* | A | - | 129.21 | 0.13 | 293.01 | 0.44 | 2.59 | 0.01 |
| *T. stylifera* | A | - | 101.32 | 0.10 | 666.26 | 0.99 | A | - |
| **Tharybidae** | | | | | | | | |
| *Undinella brevipes* | 52.42 | 0.15 | A | - | A | - | A | - |
| *U. spinifer* | 44.08 | 0.13 | A | - | A | - | A | - |
| **CYCLOPOIDA** | | | | | | | | |
| **Oithonidae** | | | | | | | | |
| *Oithona brevicornis* | 153.83 | 0.45 | 255.20 | 0.25 | 514.54 | 0.77 | A | - |
| *O. plumifera* | 433.36 | 1.26 | 658.29 | 0.64 | 1605.16 | 2.40 | 783.52 | 2.43 |
| *O. similis* | 1392.24 | 4.04 | 3103.10 | 3.02 | 6236.92 | 9.31 | 1549.39 | 4.81 |
| *O. spinirostris* | 308.55 | 0.90 | 218.86 | 0.21 | A | - | A | - |
| *Oithona* sp. | 83.46 | 0.24 | 224.20 | 0.22 | A | - | A | - |
| **HARPACTICOIDA** | | | | | | | | |
| **Clytemnestridae** | | | | | | | | |
| *Clytemnestra scutellata* | 763.37 | 2.22 | 324.39 | 0.32 | 203.68 | 0.30 | A | - |
| **Ectinosomatidae** | | | | | | | | |
| *Microsetella rosea* | A | - | A | - | 246.66 | 0.37 | 13.03 | 0.04 |
| **Euterpinidae** | | | | | | | | |
| *Euterpina acutifrons* | A | - | 202.64 | 0.20 | 386.44 | 0.58 | A | - |
| **Miraciidae** | | | | | | | | |
| *Macrosetella gracilis* | 2124.26 | 6.17 | 928.01 | 0.90 | 762.04 | 1.14 | 270.53 | 0.84 |
| *Miracia efferata* | A | - | 14.01 | 0.01 | 334.29 | 0.50 | 2.08 | 0.01 |
| *Oculosetella gracilis* | A | - | 65.06 | 0.06 | A | - | A | - |
| **MORMONILLOIDA** | | | | | | | | |
| **Mormonillidae** | | | | | | | | |
| *Mormonilla minor* | 810.19 | 2.35 | 44.49 | 0.04 | 116.76 | 0.17 | 640.08 | 1.99 |
| *M. phasma* | 271.71 | 0.79 | A | - | A | - | A | - |
| **POECILOSTOMATOIDA** | | | | | | | | |
| **Corycaeidae** | | | | | | | | |
| *Corycaeus catus* | 1308.15 | 3.80 | 2710.68 | 2.64 | 3522.39 | 5.26 | 1532.52 | 4.76 |
| *C. danae* | 1368.47 | 3.97 | 5822.05 | 5.66 | 1649.01 | 2.46 | 176.90 | 0.55 |
| *C. longistylis* | A | - | 264.40 | 0.26 | 46.35 | 0.07 | A | - |
| *C. speciosus* | 176.31 | 0.51 | 610.96 | 0.59 | 609.88 | 0.91 | 908.99 | 2.82 |
| *C. typicus* | A | - | 28.03 | 0.03 | A | - | 302.16 | 0.94 |
| *Corycaeus* sp. | 44.08 | 0.13 | A | - | 246.66 | 0.37 | 93.90 | 0.29 |
| *Farranula carinata* | 44.08 | 0.13 | 163.87 | 0.16 | 24.66 | 0.04 | A | - |
| **Oncaeidae** | | | | | | | | |
| *Conaea gracilis* | 406.55 | 1.18 | A | - | 75.10 | 0.11 | A | - |
| *Oncaea mediterranea* | A | - | A | - | 853.72 | 1.27 | 660.12 | 2.05 |
| *O. notopus* | A | - | A | - | 116.32 | 0.17 | A | - |
| *O. venusta* | 12637.47 | 36.68 | 23280.88 | 22.64 | 13287.60 | 19.84 | 4215.53 | 13.09 |
| *Triconia conifera* | 27.82 | 0.08 | 377.83 | 0.37 | 93.82 | 0.14 | A | - |
| **Sapphirinidae** | | | | | | | | |
| *Copilia longistylis* | A | - | 44.49 | 0.04 | A | - | A | - |
| *C. mirabilis* | A | - | A | - | A | - | A | - |
| *C. quadrata* | 263.59 | 0.77 | 108.20 | 0.11 | 513.78 | 0.77 | 114.18 | 0.35 |
| *Sapphirina auronitens* | 27.82 | 0.08 | 101.32 | 0.10 | 296.91 | 0.44 | 94.94 | 0.29 |
| *S. metallina* | A | - | 74.73 | 0.07 | A | - | A | - |
| *S. nigromaculata* | A | - | A | - | 31.95 | 0.05 | 13.03 | 0.04 |
| *S. opalina* | A | - | A | - | 21.23 | 0.03 | A | - |
| *S. ovatolanceolata* | 52.42 | 0.15 | A | - | A | - | 2.59 | 0.01 |
| *Sapphirina* sp. | A | - | 16.59 | 0.02 | 45.65 | 0.07 | 83.00 | 0.26 |
| Unidentified | 224.46 | 0.65 | 2250.79 | 2.19 | 5874.15 | 8.77 | 436.54 | 1.36 |
| Total individuals 100 $m^{-3}$ | 34453 | | 102850 | | 66961 | | 32200 | |

Table 6.3. Seasonal variations in abundance (individuals 100 $m^{-3}$) and percentage (%) of different copepod species in the thermocline in central Bay of Bengal

| Species | SUM | | FIM | | WM | | SpIM | |
|---|---|---|---|---|---|---|---|---|
| | Abundance | % | Abundance | % | Abundance | % | Abundance | % |
| **CALANOIDA** | | | | | | | | |
| **Acartiidae** | | | | | | | | |
| *Acartia danae* | A | - | 14.32 | 0.13 | A | - | A | - |
| *A. negligens* | A | - | A | - | 26.31 | 0.10 | 3.98 | 0.23 |
| *A. southwelli* | A | - | 0.96 | 0.01 | A | - | A | - |
| **Aetideidae** | | | | | | | | |
| *Aetideus acutus* | 3.46 | 0.30 | 0.96 | 0.01 | 45.52 | 0.17 | A | - |
| *A. armatus* | A | - | A | - | 17.83 | 0.07 | 3.56 | 0.21 |
| *Aetideus* sp. | A | - | 0.53 | 0.00 | A | - | A | - |
| *Chiridiella* sp. | A | - | 18.42 | 0.16 | A | A | A | - |
| *Euchirella amoena* | A | - | 18.42 | 0.16 | 0.86 | 0.00 | A | - |
| *E. bella* | A | - | 0.96 | 0.01 | A | - | A | - |
| *E. bitumida* | 1.34 | 0.12 | A | - | A | - | A | - |
| *E. indica* | 1.73 | 0.15 | A | - | 1.55 | 0.01 | A | - |
| *E. messinensis* | A | A | A | - | 28.56 | 0.11 | A | - |
| *E. similis* | 4.01 | 0.35 | A | - | A | - | A | - |
| *E. speciosa* | 1.34 | 0.12 | A | - | A | - | A | - |
| *E. venusta* | 0.67 | 0.06 | A | - | A | - | A | - |
| *Euchirella* sp. | 2.73 | 0.24 | A | - | 101.23 | 0.38 | 7.65 | 0.45 |
| *Pseudochirella mawsoni* | A | - | A | - | 26.31 | 0.10 | A | - |
| *Gaetanus miles* | A | - | 0.96 | 0.01 | A | - | A | - |
| *G. minor* | A | - | A | - | 0.52 | 0.00 | A | - |
| *Gaidius pungens* | 1.73 | 0.15 | A | - | A | - | A | - |
| *Undeuchaeta major* | A | - | A | - | 25.17 | 0.09 | A | - |
| *U. plumosa* | A | - | 221.06 | 1.95 | A | - | A | - |
| **Arietellidae** | | | | | | | | |
| *Arietellus giesbrechtii* | A | - | A | - | 0.86 | 0.00 | A | - |
| **Augaptilidae** | | | | | | | | |
| *Augaptilus* sp. | A | - | 55.27 | 0.49 | A | - | A | - |
| *Centraugaptilus horridus* | A | - | A | - | 0.71 | 0.00 | A | - |
| *Centraugaptilus* sp. | A | - | A | - | 16.97 | 0.06 | A | - |
| *Euaugaptilus facilis* | A | - | A | - | A | - | 3.56 | 0.21 |
| *Haloptilus acutifrons* | A | - | 18.42 | 0.16 | A | - | 3.49 | 0.20 |
| *H. longicornis* | 2.24 | 0.19 | 0.96 | 0.01 | 165.85 | 0.63 | 23.11 | 1.36 |
| *H. ornatus* | 1.34 | 0.12 | A | - | A | - | A | - |
| *H. spiniceps* | A | - | A | - | 21.09 | 0.08 | A | - |
| *Pseudhaloptilus abbreviatus* | A | - | 3.15 | 0.03 | A | - | A | - |
| *P. pacificus* | A | - | 0.96 | 0.01 | A | - | A | - |
| **Calanidae** | | | | | | | | |
| *Canthocalanus pauper* | A | - | 14.38 | 0.13 | 162.27 | 0.61 | 7.65 | 0.45 |
| *Cosmocalanus darwinii* | A | - | 14.03 | 0.12 | A | - | A | - |
| *Mesocalanus tenuicornis* | A | - | 10.75 | 0.09 | A | - | A | - |
| *Nannocalanus minor* | A | - | 19.18 | 0.17 | A | - | A | - |
| *Undinula vulgaris* | 9.81 | 0.85 | 33.19 | 0.29 | 307.71 | 1.16 | 19.62 | 1.15 |
| **Candaciidae** | | | | | | | | |
| *Candacia bispinosa* | A | - | A | - | 0.86 | 0.00 | A | - |
| *C. bradyi* | 0.20 | 0.02 | 26.03 | 0.23 | 254.80 | 0.96 | A | - |
| *C. catula* | A | - | 20.70 | 0.18 | A | - | A | - |
| *C. discaudata* | A | - | 0.53 | 0.00 | 18.69 | 0.07 | A | - |
| *C. pachydactyla* | 0.33 | 0.03 | 7.01 | 0.06 | 29.41 | 0.11 | A | - |
| *Candacia* sp. | 0.33 | 0.03 | A | - | 21.42 | 0.08 | 3.98 | 0.23 |
| *Paracandacia truncata* | A | - | 30.22 | 0.27 | A | - | 19.37 | 1.14 |
| *P. simplex* | A | - | 0.53 | 0.00 | A | - | A | - |
| **Centropagidae** | | | | | | | | |
| *Centropages calaninus* | A | - | 7.16 | 0.06 | 61.18 | 0.23 | A | - |
| *C. furcatus* | A | - | 29.05 | 0.26 | 18.69 | 0.07 | 7.65 | 0.45 |
| *C. orsinii* | A | - | 7.16 | 0.06 | A | - | A | - |
| *Centropages* sp. | A | - | 1.91 | 0.02 | A | - | A | - |
| **Clausocalanidae** | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Clausocalanus arcuicornis* | 19.62 | 1.70 | 274.76 | 2.43 | 1831.50 | 6.91 | 65.32 | 3.83 |
| *C. furcatus* | A | - | 3.15 | 0.03 | 1377.92 | 5.20 | 6.96 | 0.41 |
| *C. pergens* | 13.92 | 1.20 | 47.49 | 0.42 | A | - | A | - |
| *Clausocalanus* sp. | 9.32 | 0.81 | A | - | A | - | A | - |
| *Drepanopsis frigidus* | A | - | 18.42 | 0.16 | A | - | A | - |
| **Eucalanidae** | | | | | | | | |
| *Eucalanus crassus* | A | - | 123.55 | 1.09 | A | - | 3.56 | 0.21 |
| *E. subcrassus* | A | - | 1.48 | 0.01 | 32.63 | 0.12 | A | - |
| *E. elongatus* | 91.59 | 7.92 | 51.40 | 0.45 | 68.75 | 0.26 | 39.58 | 2.32 |
| *E. monachus* | 13.49 | 1.17 | 796.56 | 7.04 | 136.98 | 0.52 | A | - |
| *E. mucronatus* | A | - | 23.50 | 0.21 | 121.59 | 0.46 | 19.37 | 1.14 |
| *Eucalanus* sp. | A | - | 44.38 | 0.39 | 40.69 | 0.15 | A | - |
| *Pareucalanus attenuatus* | 1.73 | 0.15 | 25.18 | 0.22 | 154.44 | 0.58 | 19.37 | 1.14 |
| **Euchaetidae** | | | | | | | | |
| *Euchaeta concinna* | A | - | 7.02 | 0.06 | 78.24 | 0.30 | A | - |
| *E. indica* | 1.73 | 0.15 | 22.32 | 0.20 | 58.86 | 0.22 | A | - |
| *E. marina* | 6.91 | 0.60 | 49.55 | 0.44 | 396.91 | 1.50 | 19.37 | 1.14 |
| *Euchaeta* sp. | 9.81 | 0.85 | A | - | 25.17 | 0.09 | 3.98 | 0.23 |
| **Fosshageniidae** | | | | | | | | |
| *Temoropia mayumbaensis* | A | - | A | - | 209.38 | 0.79 | 10.52 | 0.62 |
| **Heterorhabdidae** | | | | | | | | |
| *Heterorhabdus papilliger* | 0.29 | 0.02 | 30.22 | 0.27 | A | - | 6.96 | 0.41 |
| *H. spinifrons* | A | - | A | - | A | - | 23.18 | 1.36 |
| *H. vipera* | A | - | A | - | 20.34 | 0.08 | A | - |
| *Heterorhabdus* sp. | 1.05 | 0.09 | A | - | 22.97 | 0.09 | 11.15 | 0.65 |
| *Heterostylites longicornis* | A | - | A | - | A | - | 11.45 | 0.67 |
| *H. major* | A | - | A | - | A | - | 15.43 | 0.90 |
| **Lucicutiidae** | | | | | | | | |
| *Lucicutia flavicornis* | 17.02 | 1.47 | 1135.15 | 10.03 | 879.04 | 3.32 | 39.03 | 2.29 |
| *L. lucida* | A | - | 5.88 | 0.05 | A | - | A | - |
| *L. magna* | A | - | 2.10 | 0.02 | A | - | A | - |
| *L. maxima* | 0.48 | 0.04 | 18.42 | 0.16 | 1.55 | 0.01 | 2.98 | 0.17 |
| *L. ovalis* | 15.22 | 1.32 | A | - | 18.69 | 0.07 | A | - |
| **Mecynoceridae** | | | | | | | | |
| *Mecynocera clausii* | A | - | 79.39 | 0.70 | 224.82 | 0.85 | 2.98 | 0.17 |
| **Metridinidae** | | | | | | | | |
| *Gaussia princeps* | 0.20 | 0.02 | A | - | 0.52 | - | 0.50 | 0.03 |
| *Metridia brevicauda* | 5.18 | 0.45 | A | - | 12.38 | 0.05 | 3.56 | 0.21 |
| *Pleuromamma abdominalis* | A | - | 21.50 | 0.19 | A | - | A | - |
| *P. gracilis* | 32.88 | 2.84 | 0.53 | 0.00 | 174.65 | 0.66 | 12.51 | 0.73 |
| *P. indica* | 69.47 | 6.01 | 855.12 | 7.56 | 1370.16 | 5.17 | 152.70 | 8.95 |
| *P. quadrangulata* | A | - | 14.03 | 0.12 | A | - | A | - |
| *P. robusta* | A | - | 43.73 | 0.39 | A | - | 6.54 | 0.38 |
| *P. xiphias* | 3.46 | 0.30 | 0.96 | 0.01 | 62.50 | 0.24 | A | - |
| *Pleuromamma* sp. | A | - | 2.74 | 0.02 | 269.52 | 1.02 | 11.93 | 0.70 |
| **Nullosetigeridae** | | | | | | | | |
| *Nullosetigera* sp. | 0.33 | 0.03 | A | - | A | - | A | - |
| **Paracalanidae** | | | | | | | | |
| *Bestiolina similis* | A | - | A | - | 28.56 | 0.11 | A | - |
| *Acrocalanus gibber* | A | - | 18.70 | 0.17 | 28.56 | 0.11 | 19.37 | 1.14 |
| *A. gracilis* | A | - | 53.31 | 0.47 | 26.31 | 0.10 | 80.98 | 4.75 |
| *A. longicornis* | A | - | 95.22 | 0.84 | 151.55 | 0.57 | A | - |
| *A. monachus* | A | - | 10.96 | 0.10 | A | - | A | - |
| *Calocalanus longispinus* | 0.29 | 0.02 | A | - | A | - | A | - |
| *C. pavo* | 0.33 | 0.03 | 49.69 | 0.44 | 292.98 | 1.11 | 3.49 | 0.20 |
| *C. plumulosus* | A | - | 22.66 | 0.20 | 227.66 | 0.86 | A | - |
| *Paracalanus indicus* | 40.96 | 3.54 | 1608.21 | 14.21 | 1374.46 | 5.19 | 66.51 | 3.90 |
| *P. aculeatus* | A | - | 264.13 | 2.33 | 185.37 | 0.70 | A | - |
| *P. crassirostris* | A | - | 235.95 | 2.08 | A | - | A | - |
| *P. parvus* | 1.73 | 0.15 | 9.44 | 0.08 | 207.02 | 0.78 | A | - |
| **Phaennidae** | | | | | | | | |
| *Amallophora conifer* | A | - | A | - | 19.38 | 0.07 | A | - |
| *A. oculata* | A | - | A | - | 85.68 | 0.32 | A | - |
| **Pontellidae** | | | | | | | | |
| *Calanopia aurivilli* | A | - | 2.74 | 0.02 | A | - | A | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *C. elliptica* | A | - | 14.70 | 0.13 | A | - | A | - |
| *C. minor* | A | - | A | - | 45.53 | 0.17 | A | - |
| *Pontellina plumata* | 0.29 | 0.02 | 1.89 | 0.02 | 1.71 | 0.01 | 19.62 | 1.15 |
| **Rhincalanidae** | | | | | | | | |
| *Rhincalanus cornutus* | 19.34 | 1.67 | A | - | 56.82 | 0.21 | 3.56 | 0.21 |
| *R. nasutus* | 1.73 | 0.15 | 5.48 | 0.05 | A | - | 3.56 | 0.21 |
| *R. rostrifrons* | 3.46 | 0.30 | 12.64 | 0.11 | 59.81 | 0.23 | A | - |
| **Scolecitrichidae** | | | | | | | | |
| *Amallothrix arcuata* | A | - | A | - | 32.63 | 0.12 | A | - |
| *A. gracilis* | A | - | A | - | 118.55 | 0.45 | 2.98 | 0.17 |
| *Lophothrix frontalis* | A | - | A | - | A | - | 10.55 | 0.62 |
| *Scaphocalanus echinatus* | A | - | 14.03 | 0.12 | 1.55 | 0.01 | A | - |
| *S. elongatus* | A | - | A | A | 26.31 | 0.10 | A | - |
| *S. longifurca* | A | - | 7.02 | 0.06 | A | - | A | - |
| *S. magnus* | A | - | A | - | A | - | 0.50 | 0.03 |
| *Scaphocalanus* sp. | A | - | A | - | A | - | 3.49 | 0.20 |
| *Scolecithrichopsis ctenopus* | A | - | 19.15 | 0.17 | 57.80 | 0.22 | A | - |
| *Scolecithrix bradyi* | A | - | 0.53 | 0.00 | 0.86 | 0.00 | A | - |
| *S. danae* | A | - | 281.82 | 2.49 | 43.29 | 0.16 | A | - |
| *Scolecithrix* sp. | A | - | 7.16 | 0.06 | A | - | A | - |
| *Scottocalanus dauglishi* | A | - | 10.75 | 0.09 | A | - | A | - |
| *S. helenae* | A | - | 10.75 | 0.09 | A | - | A | - |
| *S. rotundatus* | A | - | A | - | 0.52 | 0.00 | A | - |
| **Spinocalanidae** | | | | | | | | |
| *Monacilla gracilis* | A | - | A | - | 52.97 | 0.20 | A | - |
| *M. tenera* | A | - | 1.89 | 0.02 | A | - | A | - |
| *M. typica* | A | - | 7.55 | 0.07 | A | - | A | - |
| *Spinocalanus magnus* | A | - | A | - | 32.63 | 0.12 | A | - |
| **Temoridae** | | | | | | | | |
| *Temora discaudata* | A | - | 1.89 | 0.02 | A | - | A | - |
| **Tharybidae** | | | | | | | | |
| *Undinella brevipes* | 1.73 | 0.15 | A | - | A | - | A | - |
| **CYCLOPOIDA** | | | | | | | | |
| **Oithonidae** | | | | | | | | |
| *Oithona brevicornis* | A | - | 8.22 | 0.07 | 50.35 | 0.19 | A | - |
| *O. plumifera* | A | - | 56.50 | 0.50 | 19.38 | 0.07 | 39.24 | 2.30 |
| *O. setigera* | A | - | A | - | A | - | 19.62 | 1.15 |
| *O. similis* | 40.12 | 3.47 | 857.70 | 7.58 | 3887.09 | 14.66 | 268.57 | 15.75 |
| *O. spinirostris* | A | - | 234.35 | 2.07 | 28.56 | 0.11 | A | - |
| *Oithona* sp. | A | - | 116.61 | 1.03 | A | - | A | - |
| **HARPACTICOIDA** | | | | | | | | |
| **Aegisthidae** | | | | | | | | |
| *Aegisthus mucronatus* | A | - | A | - | 1.55 | 0.01 | A | - |
| **Clytemnestridae** | | | | | | | | |
| *Clytemnestra scutellata* | 49.05 | 4.24 | A | - | 54.68 | 0.21 | A | - |
| **Ectinosomatidae** | | | | | | | | |
| *Microsetella norveigica* | A | - | A | - | 28.56 | 0.11 | A | - |
| *M. rosea* | A | - | 0.53 | 0.00 | 92.44 | 0.35 | 7.65 | 0.45 |
| **Euterpinidae** | | | | | | | | |
| *Euterpina acutifrons* | A | - | 7.01 | 0.06 | A | - | A | - |
| **Miraciidae** | | | | | | | | |
| *Macrosetella gracilis* | 19.46 | 1.68 | 58.66 | 0.52 | 83.01 | 0.31 | 3.98 | 0.23 |
| *Miracia efferata* | A | - | A | - | 20.34 | 0.08 | A | - |
| *Oculosetella gracilis* | A | - | A | - | 26.31 | 0.10 | A | - |
| **MORMONILLOIDA** | | | | | | | | |
| **Mormonillidae** | | | | | | | | |
| *Mormonilla minor* | 357.59 | 30.93 | 276.39 | 2.44 | 1589.60 | 6.00 | 164.83 | 9.67 |
| *M. phasma* | 1.19 | 0.10 | A | - | A | - | A | - |
| **POECILOSTOMATOIDA** | | | | | | | | |
| **Corycaeidae** | | | | | | | | |
| *Corycaeus asiaticus* | A | - | 28.87 | 0.26 | A | - | A | - |
| *C. catus* | 3.46 | 0.30 | 12.83 | 0.11 | 413.75 | 1.56 | 15.43 | 0.90 |
| *C. danae* | 3.46 | 0.30 | 179.31 | 1.58 | 501.87 | 1.89 | 19.37 | 1.14 |
| *C. longistylis* | A | - | 47.23 | 0.42 | A | - | A | - |
| *C. speciosus* | 1.00 | 0.09 | 30.51 | 0.27 | 177.44 | 0.67 | 3.98 | 0.23 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *C. typicus* | A | - | A | - | A | - | 7.47 | 0.44 |
| *Corycaeus* sp. | A | - | 75.12 | 0.66 | A | - | 3.49 | 0.20 |
| *Farranula carinata* | A | - | 2.74 | 0.02 | 33.95 | 0.13 | A | - |
| **Lubbockidae** | | | | | | | | |
| *Lubbockia aculeata* | A | - | A | - | 1.37 | 0.01 | 2.98 | 0.17 |
| *L. squillimana* | A | - | A | - | 28.56 | 0.11 | A | - |
| **Oncaeidae** | | | | | | | | |
| *Conaea gracilis* | 5.57 | 0.48 | A | - | 111.91 | 0.42 | 23.77 | 1.39 |
| *Oncaea mediterranea* | A | - | A | - | 340.52 | 1.28 | 11.94 | 0.70 |
| *O. notopus* | A | - | A | - | 105.34 | 0.40 | A | - |
| *O. venusta* | 249.57 | 21.59 | 2004.44 | 17.71 | 4381.95 | 16.53 | 142.09 | 8.33 |
| *Triconia conifera* | 0.23 | 0.02 | 67.12 | 0.59 | 145.34 | 0.55 | 10.61 | 0.62 |
| **Sapphirinidae** | | | | | | | | |
| *Copilia quadrata* | 1.73 | 0.15 | 7.01 | 0.06 | 119.75 | 0.45 | A | - |
| *C. vitrea* | A | - | A | - | 20.34 | 0.08 | A | - |
| *Sapphirina intestinata* | A | - | 9.75 | 0.09 | A | - | A | - |
| *S. nigromaculata* | A | - | A | - | 65.25 | 0.25 | A | - |
| *S. ovatolanceolata* | A | - | A | - | 75.64 | 0.29 | A | - |
| *Sapphirina* sp. | A | - | A | - | 84.03 | 0.32 | A | - |
| Unidentified | 11.73 | 1.02 | 183.29 | 1.62 | 1941.91 | 7.33 | 152.49 | 8.94 |
| Total individuals 100 $m^{-3}$ | 1156 | | 11318 | | 26508 | | 1705 | |

Table 6.4. Seasonal variations in abundance (individuals 100 $m^{-3}$) and percentage (%) of different copepod species in the base of the thermocline-300 m stratum in central Bay of Bengal

| Species | SUM | | FIM | | WM | | SpIM | |
|---|---|---|---|---|---|---|---|---|
| | Abundance | % | Abundance | % | Abundance | % | Abundance | % |
| **CALANOIDA** | | | | | | | | |
| **Acartiidae** | | | | | | | | |
| *Acartia negligens* | A | - | A | - | A | - | 20.02 | 1.04 |
| **Aetideidae** | | | | | | | | |
| *Aetideus acutus* | 1.60 | 0.05 | 6.86 | 0.38 | A | - | A | - |
| *A. armatus* | A | - | 0.75 | 0.04 | 0.66 | 0.02 | 5.35 | 0.28 |
| *Euchirella amoena* | A | - | 3.27 | 0.18 | 5.63 | 0.14 | A | - |
| *E. bella* | 1.60 | 0.05 | A | - | A | - | A | - |
| *E. bitumida* | A | - | A | - | A | - | 12.69 | 0.66 |
| *E. curticauda* | A | - | A | - | 0.53 | 0.01 | A | - |
| *E. galeata* | A | - | 9.32 | 0.52 | A | - | A | - |
| *E. indica* | 59.32 | 1.76 | A | - | 19.17 | 0.46 | A | - |
| *E. messinensis* | 1.60 | 0.05 | A | - | A | - | A | - |
| *E. rostrata* | 1.60 | 0.05 | A | - | A | - | A | - |
| *E. venusta* | A | - | A | - | 2.29 | 0.06 | A | - |
| *Euchirella* sp. | 1.30 | 0.04 | A | A | 8.14 | 0.20 | A | A |
| *Gaetanus arminger* | A | - | 0.75 | 0.04 | A | - | A | - |
| *G. kruppii* | A | - | A | - | A | - | 13.18 | 0.69 |
| *G. miles* | A | - | 9.38 | 0.52 | 2.05 | 0.05 | A | - |
| *Undeuchaeta* sp. | A | - | 0.20 | 0.01 | A | - | A | - |
| **Augaptilidae** | | | | | | | | |
| *Augaptilus glacialis* | 0.50 | 0.01 | A | - | A | - | A | - |
| *Centraugaptilus horridus* | 50.58 | 1.50 | A | - | A | - | A | - |
| *Euaugaptilus bullifer* | 1.60 | 0.05 | 86.28 | 4.80 | A | - | A | - |
| *E. facilis* | A | - | A | - | A | - | 6.69 | 0.35 |
| *E. longimanus* | 1.60 | 0.05 | A | - | A | - | A | - |
| *E. oblongus* | 1.60 | 0.05 | A | - | A | - | A | - |
| *Haloptilus acutifrons* | 29.48 | 0.88 | A | - | A | - | 22.69 | 1.18 |
| *H. longicornis* | A | - | 1.01 | 0.06 | 21.18 | 0.51 | 22.69 | 1.18 |
| *H. ornatus* | A | - | A | - | 4.00 | 0.10 | A | - |
| *H. spiniceps* | 0.65 | 0.02 | A | - | 20.38 | 0.49 | A | - |
| **Calanidae** | | | | | | | | |
| *Canthocalanus pauper* | A | - | A | - | 9.91 | 0.24 | A | - |
| *Mesocalanus tenuicornis* | A | - | 5.97 | 0.33 | A | - | A | - |
| *Undinula vulgaris* | 55.75 | 1.66 | 6.86 | 0.38 | 40.22 | 0.97 | A | - |
| **Candaciidae** | | | | | | | | |
| *Candacia bradyi* | A | - | A | - | 6.46 | 0.16 | A | - |
| *C. catula* | A | - | 1.01 | 0.06 | A | - | A | - |
| *C. discaudata* | A | - | A | - | 0.53 | 0.01 | A | - |
| *C. pachydactyla* | A | - | A | - | 16.88 | 0.41 | A | - |
| *Candacia* sp. | A | - | A | - | A | - | 12.69 | 0.66 |
| *Paracandacia truncata* | 0.65 | 0.02 | 71.34 | 3.97 | A | - | A | - |
| *P. simplex* | A | - | 0.75 | 0.04 | A | - | A | - |
| **Centropagidae** | | | | | | | | |
| *Centropages calaninus* | A | - | 5.97 | 0.33 | 0.53 | 0.01 | A | - |
| *C. dorsispinatus* | A | - | 6.86 | 0.38 | A | - | A | - |
| *Centropages* sp. | A | - | 6.86 | 0.38 | 6.46 | 0.16 | A | - |
| **Clausocalanidae** | | | | | | | | |
| *Clausocalanus arcuicornis* | 27.88 | 0.83 | 16.63 | 0.92 | 104.36 | 2.51 | 55.40 | 2.89 |
| *C. furcatus* | 27.88 | 0.83 | 21.16 | 1.18 | 51.20 | 1.23 | A | - |
| *C. pergens* | 27.88 | 0.83 | A | - | A | - | A | - |
| **Eucalanidae** | | | | | | | | |
| *Eucalanus crassus* | 1.60 | 0.05 | 28.30 | 1.57 | 3.50 | 0.08 | 68.78 | 3.59 |
| *E. subcrassus* | A | - | 7.45 | 0.41 | A | - | A | - |
| *E. elongatus* | 17.72 | 0.53 | 29.08 | 1.62 | 101.79 | 2.45 | 62.73 | 3.27 |
| *E. monachus* | 256.56 | 7.62 | 114.48 | 6.36 | 35.01 | 0.84 | A | - |
| *E. mucronatus* | 1.60 | 0.05 | 20.28 | 1.13 | 60.46 | 1.46 | 10.01 | 0.52 |
| *E. pseudattenuatus* | A | - | 7.62 | 0.42 | A | - | A | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Eucalanus* sp. | A | - | 40.34 | 2.24 | 4.00 | 0.10 | A | - |
| *Pareucalanus attenuatus* | A | - | 6.86 | 0.38 | 7.00 | 0.17 | A | - |
| **Euchaetidae** | | | | | | | | |
| *Euchaeta concinna* | A | - | 2.99 | 0.17 | 16.88 | 0.41 | A | - |
| *E. indica* | A | - | 1.01 | 0.06 | A | - | A | - |
| *E. marina* | 164.68 | 4.89 | 2.22 | 0.12 | 13.41 | 0.32 | A | - |
| *E. media* | A | - | 1.50 | 0.08 | A | - | A | - |
| *E. plana* | A | - | A | - | A | - | A | - |
| *Euchaeta* sp. | 194.99 | 5.79 | 1.01 | 0.06 | 50.64 | 1.22 | A | - |
| **Fosshageniidae** | | | | | | | | |
| *Temoropia mayumbaensis* | A | - | A | - | 118.91 | 2.86 | 5.35 | 0.28 |
| **Heterorhabdidae** | | | | | | | | |
| *Heterorhabdus abyssalis* | A | - | 1.01 | 0.06 | A | - | A | - |
| *H. papilliger* | 1.60 | 0.05 | 12.20 | 0.68 | 40.55 | 0.98 | A | - |
| *H. spinifrons* | A | - | A | - | A | - | 5.35 | 0.28 |
| *H. vipera* | 0.65 | 0.02 | A | - | A | - | A | - |
| *Heterorhabdus* sp. | 1.45 | 0.04 | A | - | 33.08 | 0.80 | A | - |
| *Paraheterorhabdus robustus* | 1.60 | 0.05 | A | - | A | - | A | - |
| *Heterostylites longicornis* | A | - | A | - | 13.99 | 0.34 | A | - |
| *H. major* | A | - | A | - | A | - | A | - |
| **Lucicutiidae** | | | | | | | | |
| *Lucicutia flavicornis* | 188.36 | 5.59 | 142.62 | 7.93 | 131.50 | 3.17 | 12.69 | 0.66 |
| *L. lucida* | A | - | A | - | 3.50 | 0.08 | A | - |
| *L. magna* | 1.60 | 0.05 | A | - | A | - | A | - |
| *L. maxima* | 15.40 | 0.46 | 7.84 | 0.44 | A | - | 25.37 | 1.32 |
| **Mecynoceridae** | | | | | | | | |
| *Mecynocera clausii* | A | - | 1.47 | 0.08 | 3.50 | 0.08 | A | - |
| **Metridinidae** | | | | | | | | |
| *Gaussia princeps* | A | - | A | - | 2.05 | 0.05 | 13.18 | 0.69 |
| *Metridia brevicauda* | 5.57 | 0.17 | A | - | 42.52 | 1.02 | 56.10 | 2.93 |
| *M. cuticauda* | A | - | A | - | A | - | 10.01 | 0.52 |
| *M. pacifica* | 1.60 | 0.05 | A | - | A | - | A | - |
| *M. princeps* | 26.89 | 0.80 | A | - | A | - | 25.37 | 1.32 |
| *Metridia* sp. | A | - | 10.85 | 0.60 | 2.29 | 0.06 | A | - |
| *Pleuromamma abdominalis* | A | - | 38.23 | 2.12 | A | - | A | - |
| *P. gracilis* | 79.87 | 2.37 | 10.83 | 0.60 | 170.57 | 4.11 | 18.04 | 0.94 |
| *P. indica* | 384.51 | 11.42 | 166.83 | 9.27 | 1306.09 | 31.46 | 48.07 | 2.51 |
| *P. quadrangulata* | A | - | 0.75 | 0.04 | A | - | 10.01 | 0.52 |
| *P. robusta* | 16.06 | 0.48 | 2.95 | 0.16 | 95.67 | 2.30 | 18.04 | 0.94 |
| *P. xiphias* | A | - | 7.48 | 0.42 | 1.91 | 0.05 | 11.91 | 0.62 |
| *Pleuromamma* sp. | 2.75 | 0.08 | A | - | 5.63 | 0.14 | A | - |
| **Paracalanidae** | | | | | | | | |
| *Acrocalanus gibber* | 83.63 | 2.48 | A | - | 20.48 | 0.49 | A | - |
| *A. gracilis* | 27.88 | 0.83 | 25.29 | 1.41 | A | - | A | - |
| *A. longicornis* | A | - | 58.61 | 3.26 | 33.76 | 0.81 | A | - |
| *Calocalanus pavo* | A | - | 5.79 | 0.32 | 20.95 | 0.50 | A | - |
| *C. plumulosus* | A | - | A | - | 21.00 | 0.51 | 10.01 | 0.52 |
| *Paracalanus indicus* | 167.26 | 4.97 | 138.40 | 7.69 | 14.54 | 0.35 | 10.01 | 0.52 |
| *P. aculeatus* | A | - | 27.17 | 1.51 | 2.28 | 0.05 | A | - |
| *P. parvus* | 34.28 | 1.02 | A | - | A | - | A | - |
| **Pontellidae** | | | | | | | | |
| *Calanopia elliptica* | A | - | 6.86 | 0.38 | A | - | A | - |
| *C. minor* | A | - | A | - | 6.46 | 0.16 | A | - |
| *Pontellina plumata* | 0.50 | 0.01 | 33.86 | 1.88 | A | - | A | - |
| **Rhincalanidae** | | | | | | | | |
| *Rhincalanus cornutus* | 4.80 | 0.14 | 2.99 | 0.17 | 6.77 | 0.16 | 50.74 | 2.65 |
| *R. nasutus* | 3.70 | 0.11 | 3.01 | 0.17 | A | - | 15.36 | 0.80 |
| *R. rostrifrons* | 52.68 | 1.56 | 3.01 | 0.17 | 16.38 | 0.39 | A | - |
| **Scolecitrichidae** | | | | | | | | |
| *Amallothrix gracilis* | A | - | A | - | 14.48 | 0.35 | A | - |
| *Lophothrix frontalis* | 11.63 | 0.35 | A | - | 6.00 | 0.14 | 18.04 | 0.94 |
| *Scaphocalanus echinatus* | A | - | 1.50 | 0.08 | A | - | A | - |
| *S. longifurca* | 2.10 | 0.06 | A | - | A | - | A | - |
| *Scolecithricella* sp. | 139.38 | 4.14 | A | - | 19.82 | 0.48 | A | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Scolecithrichopsis ctenopus* | A | - | 4.77 | 0.27 | A | - | A | - |
| *Scolecithrix danae* | 55.75 | 1.66 | 15.09 | 0.84 | A | - | A | - |
| *Scottocalanus helenae* | 1.60 | 0.05 | 1.76 | 0.10 | A | - | A | - |
| **Spinocalanidae** | | | | | | | | |
| *Monacilla gracilis* | A | - | 27.45 | 1.53 | 2.28 | 0.05 | 20.02 | 1.04 |
| *M. tenera* | 5.16 | 0.15 | A | - | A | - | A | - |
| *Spinocalanus magnus* | A | - | A | - | 3.50 | 0.08 | A | - |
| *S. spinosus* | 1.60 | 0.05 | A | - | A | - | A | - |
| **Tharybidae** | | | | | | | | |
| *Undinella spinifer* | A | - | 6.86 | 0.38 | A | - | A | - |
| **CYCLOPOIDA** | | | | | | | | |
| **Oithonidae** | | | | | | | | |
| *Oithona brevicornis* | A | - | 0.75 | 0.04 | 17.65 | 0.43 | A | - |
| *O. plumifera* | 60.56 | 1.80 | 8.92 | 0.50 | 16.88 | 0.41 | A | - |
| *O. similis* | 337.43 | 10.02 | 30.83 | 1.71 | 240.16 | 5.78 | 90.78 | 4.74 |
| *O. spinirostris* | 28.49 | 0.85 | 36.37 | 2.02 | 8.00 | 0.19 | A | - |
| *Oithona* sp. | A | - | 26.06 | 1.45 | A | - | A | - |
| **HARPACTICOIDA** | | | | | | | | |
| **Aegisthidae** | | | | | | | | |
| *Aegisthus mucronatus* | A | - | 2.99 | 0.17 | 1.46 | 0.04 | 12.69 | 0.66 |
| **Clytemnestridae** | | | | | | | | |
| *Clytemnestra scutellata* | A | - | 0.75 | 0.04 | 7.36 | 0.18 | A | - |
| **Ectinosomatidae** | | | | | | | | |
| *Microsetella rosea* | 0.50 | 0.01 | 1.01 | 0.06 | A | - | A | - |
| **Euterpinidae** | | | | | | | | |
| *Euterpina acutifrons* | A | - | 7.84 | 0.44 | A | - | A | - |
| **Miraciidae** | | | | | | | | |
| *Macrosetella gracilis* | 1.81 | 0.05 | 6.67 | 0.37 | 5.79 | 0.14 | A | - |
| *Miracia efferata* | A | - | A | - | A | - | A | - |
| *Oculosetella gracilis* | A | - | A | - | 2.29 | 0.06 | A | - |
| **MORMONILLOIDA** | | | | | | | | |
| **Mormonillidae** | | | | | | | | |
| *Mormonilla minor* | 102.06 | 3.03 | 30.00 | 1.67 | 306.64 | 7.39 | 594.12 | 30.99 |
| *M. phasma* | 41.30 | 1.23 | A | - | A | - | A | - |
| **POECILOSTOMATOIDA** | | | | | | | | |
| **Corycaeidae** | | | | | | | | |
| *Corycaeus catus* | 55.75 | 1.66 | 6.86 | 0.38 | 27.34 | 0.66 | 10.01 | 0.52 |
| *C. danae* | 28.38 | 0.84 | 29.35 | 1.63 | 25.99 | 0.63 | A | - |
| *C. longistylis* | A | - | A | - | 1.25 | 0.03 | A | - |
| *C. speciosus* | A | - | A | - | 16.93 | 0.41 | A | - |
| *Corycaeus* sp. | A | - | 13.78 | 0.77 | 3.54 | 0.09 | A | - |
| **Clausidiidae** | | | | | | | | |
| *Sapphirella tropica* | A | - | A | - | 3.50 | 0.08 | A | - |
| **Lubbockidae** | | | | | | | | |
| *Lubbockia aculeata* | A | - | A | - | 1.25 | 0.03 | A | - |
| *L. squillimana* | A | - | 5.97 | 0.33 | 0.66 | 0.02 | A | - |
| *Lubbockia* sp. | A | - | 9.85 | 0.55 | A | - | A | - |
| **Oncaeidae** | | | | | | | | |
| *Conaea gracilis* | 40.84 | 1.21 | A | - | 108.84 | 2.62 | 234.39 | 12.23 |
| *Oncaea mediterranea* | A | - | A | - | 103.95 | 2.50 | A | - |
| *O. notopus* | A | - | A | - | 59.72 | 1.44 | A | - |
| *O. venusta* | 353.67 | 10.50 | 216.41 | 12.03 | 148.15 | 3.57 | 246.38 | 12.85 |
| *Oncaea* sp. | A | - | A | - | 44.22 | 1.07 | A | - |
| *Triconia conifera* | 8.36 | 0.25 | 8.25 | 0.46 | 79.85 | 1.92 | 10.71 | 0.56 |
| **Sapphirinidae** | | | | | | | | |
| *Sapphirina auronitens* | A | - | A | - | 2.29 | 0.06 | A | - |
| *S. intestinata* | A | - | 4.08 | 0.23 | A | - | A | - |
| *Sapphirina* sp. | 27.88 | 0.83 | A | - | 9.91 | 0.24 | 10.01 | 0.52 |
| Unidentified | 55.75 | 1.66 | 61.74 | 3.43 | 134.71 | 3.24 | 12.69 | 0.66 |
| Total individuals 100 $m^{-3}$ | 3367 | | 1799 | | 4152 | | 1917 | |

Miraciidae (6%) and Spinocalanidae (7.2%) registered their highest percentage in this stratum only during SUM. Similarly, Augaptilidae (6.4%) and Metridinidae (7.6%) showed higher abundant in this stratum only during FIM. Eucalanidae (11.2 and 5.8%) and Lucicutiidae (13.4 and 12.1%) contributed to relatively higher abundances during SUM and FIM respectively. Mormonillidae also accounted for 6.4 and 12.4% of the total during SUM and WM respectively. Clausiidae was the only family that was absent during all seasons from this stratum.

### 6.2.4. Genera and species

A total of 83 genera were identified during the study (Tables 6.2-6.6). The numbers of genera found in MLD, TT-BT, BT-300 m, 300-500 m and 500-1000 m were, 63, 71, 61, 62 and 62 respectively. Not only did the total number of genera in the water column vary seasonally (SUM: 64, FIM: 66, WM: 70 and SpIM: 50) but they varied also in each sampled strata. The highest number of genera in the thermocline was due to the presence of many deep-water genera such as *Chiridiella*, *Pseudochirella*, *Gaetanus*, *Undeuchaeta*, *Arietellus*, *Augaptilus*, *Scottocalanus*, *Aegisthus* and *Lubbockia* that occurred only below MLD and two other genera *viz. Bestiolina* and *Cosmocalanus* that were exclusively present in this stratum.

The most dominant genera were *Oncaea* (17%), *Mormonilla* (9.0%), *Pleuromamma* (8.6%), *Oithona* (7.6%), *Clausocalanus* (6.0%), *Lucicutia* (6.0%), *Eucalanus* (5.5%) and *Paracalanus* (5.5%) accounting for 68% of the total abundance in the 1000 m water column in the CB (Table 7.9; Chapter 7).

From the total of 251 species that were identified in the CB, 69 species occurred during all the seasons. From these, only two *viz. Oithona similis* and *Oncaea venusta* were preponderant at all depths and stations. Varying distinctly with depths, the number of species occurring was 150, 169, 145, 170 and 145 in MLD, TT-BT, BT-300 m, 300-500 m and 500-1000 m respectively. In the topmost stratum, the largest number of species of *Sapphirina* and *Corycaeus* were observed. Similarly, the largest number of species of Aetideidae, Augaptilidae, Scolecithrichidae and Spinocalanidae were observed in the 300-500 m stratum. While some species never surfaced in any of the seasons, species such as *Conaea gracilis* were found to increase in abundance with depth.

Table 6.5. Seasonal variations in abundance (individuals 100 m$^{-3}$) and percentage (%) of different copepod species in the 300-500 m stratum in central Bay of Bengal

| | SUM | | FIM | | WM | |
|---|---|---|---|---|---|---|
| Species | Abundance | % | Abundance | % | Abundance | % |
| **CALANOIDA** | | | | | | |
| **Acartiidae** | | | | | | |
| *Acartia negligens* | 28.31 | 1.01 | 0.25 | 0.03 | 6.35 | 0.18 |
| *A. southwelli* | A | - | 5.64 | 0.61 | A | - |
| **Aetideidae** | | | | | | |
| *Aetideus acutus* | A | - | A | - | 2.79 | 0.08 |
| *A. armatus* | A | - | A | - | 17.76 | 0.51 |
| *A. bradyi* | A | - | A | - | 8.02 | 0.23 |
| *Aetideus* sp. | A | - | A | - | 17.76 | 0.51 |
| *Chiridiella* sp. | A | - | A | - | 4.20 | 0.12 |
| *Euchirella amoena* | A | - | 0.60 | 0.07 | A | - |
| *E. bitumida* | A | - | A | - | 8.47 | 0.24 |
| *E. galeata* | A | - | 0.27 | 0.03 | 11.38 | 0.33 |
| *E. indica* | 15.78 | 0.56 | A | - | 2.79 | 0.08 |
| *E. maxima* | A | - | 0.10 | 0.01 | A | - |
| *E. rostrata* | A | - | 5.64 | 0.61 | A | - |
| *E. rostromagna* | A | - | A | - | 10.86 | 0.31 |
| *E. speciosa* | A | - | A | - | 1.48 | 0.04 |
| *E. venusta* | A | - | A | - | 3.33 | 0.10 |
| *Euchirella* sp. | 6.98 | 0.25 | 3.20 | 0.35 | 6.44 | 0.19 |
| *Gaetanus arminger* | A | - | 2.12 | 0.23 | A | - |
| *G. kruppii* | A | - | 2.15 | 0.23 | 1.09 | 0.03 |
| *G. miles* | 6.98 | 0.25 | 5.64 | 0.61 | 5.47 | 0.16 |
| *G. minor* | 10.28 | 0.37 | A | - | 0.74 | 0.02 |
| *G. pileatus* | 4.00 | 0.14 | A | - | A | - |
| *Undeuchaeta* sp. | A | - | 0.35 | 0.04 | A | - |
| **Arietellidae** | | | | | | |
| *Arietellus setosus* | A | - | A | - | 0.89 | 0.03 |
| **Augaptilidae** | | | | | | |
| *Augaptilus* sp. | A | - | A | - | 2.44 | 0.07 |
| *Centraugaptilus rattrayi* | A | - | A | - | 0.40 | 0.01 |
| *C. horridus* | 3.43 | 0.12 | A | - | A | - |
| *Euaugaptilus bullifer* | A | - | 282.42 | 30.66 | A | - |
| *E. hecticus* | A | - | A | - | 2.44 | 0.07 |
| *E. laticeps* | A | - | A | - | 17.76 | 0.51 |
| *E. magnus* | A | - | 0.71 | 0.08 | A | - |
| *E. mixtus* | A | - | 1.42 | 0.15 | A | - |
| *E. nodifrons* | A | - | A | - | 1.48 | 0.04 |
| *E. oblongus* | 1.71 | 0.06 | 11.33 | 1.23 | A | - |
| *E. rigidus* | A | - | 1.42 | 0.15 | A | - |
| *Haloptilus acutifrons* | A | - | A | - | 10.86 | 0.31 |
| *H. longicornis* | 8.20 | 0.29 | 0.71 | 0.08 | 9.02 | 0.26 |
| *H. spiniceps* | 2.10 | 0.07 | A | - | A | - |
| *Pseudhaloptilus abbreviatus* | A | - | 5.92 | 0.64 | A | - |
| *P. eurygnathus* | 1.71 | 0.06 | A | - | A | - |
| *P. pacificus* | 1.71 | 0.06 | A | - | A | - |
| **Calanidae** | | | | | | |
| *Undinula vulgaris* | 6.98 | 0.25 | A | - | 12.64 | 0.36 |
| **Candaciidae** | | | | | | |
| *Candacia bradyi* | 8.69 | 0.31 | A | - | 25.10 | 0.72 |
| *C. catula* | A | - | A | - | 6.29 | 0.18 |
| *C. discaudata* | A | - | A | - | 6.35 | 0.18 |
| *C. pachydactyla* | A | - | 0.25 | 0.03 | A | - |
| *Candacia* sp. | A | - | 0.71 | 0.08 | 10.86 | 0.31 |
| *Paracandacia truncata* | 1.71 | 0.06 | 0.25 | 0.03 | A | - |
| *P. simplex* | A | - | A | - | A | - |
| **Centropagidae** | | | | | | |
| *Centropages calaninus* | 6.98 | 0.25 | A | - | 6.29 | 0.18 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *C. dorsispinatus* | A | - | 5.17 | 0.56 | A | - |
| *C. furcatus* | 0.24 | 0.01 | A | - | A | - |
| *C. gracilis* | A | - | 1.07 | 0.12 | A | - |
| **Clausocalanidae** | | | | | | |
| *Clausocalanus arcuicornis* | 47.41 | 1.69 | 22.42 | 2.43 | 66.15 | 1.90 |
| *C. furcatus* | 6.98 | 0.25 | 0.84 | 0.09 | 20.31 | 0.58 |
| *C. pergens* | 4.20 | 0.15 | 0.17 | 0.02 | A | - |
| **Eucalanidae** | | | | | | |
| *Eucalanus crassus* | 6.85 | 0.24 | 0.50 | 0.05 | 6.35 | 0.18 |
| *E. subcrassus* | A | - | 0.10 | 0.01 | A | - |
| *E. elongatus* | 74.90 | 2.66 | 6.26 | 0.68 | 384.01 | 11.03 |
| *E. monachus* | 22.27 | 0.79 | 0.10 | 0.01 | 18.98 | 0.55 |
| *E. mucronatus* | 7.86 | 0.28 | 7.81 | 0.85 | 92.36 | 2.65 |
| *E. pseudattenuatus* | 15.42 | 0.55 | 1.07 | 0.12 | A | - |
| *Eucalanus* sp. | 5.53 | 0.20 | 0.25 | 0.03 | A | - |
| *Pareucalanus attenuatus* | 3.43 | 0.12 | 0.10 | 0.01 | 6.35 | 0.18 |
| **Euchaetidae** | | | | | | |
| *Euchaeta concinna* | A | - | 0.10 | 0.01 | A | - |
| *E. indica* | A | - | 1.18 | 0.13 | A | - |
| *E. marina* | 18.24 | 0.65 | 2.41 | 0.26 | 4.91 | 0.14 |
| *E. media* | A | - | A | - | A | - |
| *E. plana* | 6.98 | 0.25 | 0.10 | 0.01 | A | - |
| *Euchaeta* sp. | 15.67 | 0.56 | 0.10 | 0.01 | 8.77 | 0.25 |
| *Pareuchaeta malayensis* | A | - | 1.07 | 0.12 | A | - |
| **Fosshageniidae** | | | | | | |
| *Temoropia mayumbaensis* | A | - | A | - | 41.10 | 1.18 |
| **Heterorhabdidae** | | | | | | |
| *Disseta palumboi* | A | - | A | - | 0.45 | 0.01 |
| *Heterorhabdus abyssalis* | A | - | 6.37 | 0.69 | 6.87 | 0.20 |
| *H. fistulosus* | A | - | A | - | A | - |
| *H. pacificus* | A | - | 0.10 | 0.01 | 4.20 | 0.12 |
| *H. papilliger* | 26.29 | 0.93 | 45.70 | 4.96 | 31.39 | 0.90 |
| *H. spinifrons* | 12.29 | 0.44 | A | - | 6.29 | 0.18 |
| *H. subspinifrons* | A | - | A | - | 0.20 | 0.01 |
| *H. vipera* | 2.10 | 0.07 | A | - | 4.84 | 0.14 |
| *Heterorhabdus* sp. | 4.23 | 0.15 | A | - | 21.96 | 0.63 |
| *Heterostylites longicornis* | 0.40 | 0.01 | A | - | 4.20 | 0.12 |
| **Lucicutiidae** | | | | | | |
| *Lucicutia flavicornis* | 119.67 | 4.25 | 134.37 | 14.59 | 107.79 | 3.10 |
| *L. longispina* | 1.71 | 0.06 | A | - | A | - |
| *L. maxima* | 50.67 | 1.80 | 48.59 | 5.28 | 74.96 | 2.15 |
| *L. ovalis* | 15.54 | 0.55 | A | - | A | - |
| **Mecynoceridae** | | | | | | |
| *Mecynocera clausii* | A | - | 5.17 | 0.56 | 6.29 | 0.18 |
| **Metridinidae** | | | | | | |
| *Gaussia princeps* | A | - | 12.85 | 1.40 | 1.34 | 0.04 |
| *Metridia brevicauda* | 6.85 | 0.24 | 1.52 | 0.17 | 94.94 | 2.73 |
| *M. cuticauda* | 11.99 | 0.43 | A | - | A | - |
| *M. pacifica* | 3.43 | 0.12 | A | - | A | - |
| *M. princeps* | 3.43 | 0.12 | A | - | 0.74 | 0.02 |
| *Metridia* sp. | A | - | 5.98 | 0.65 | A | - |
| *Pleuromamma abdominalis* | A | - | 3.54 | 0.38 | A | - |
| *P. gracilis* | 9.40 | 0.33 | 1.90 | 0.21 | 121.65 | 3.49 |
| *P. indica* | 233.67 | 8.31 | 40.66 | 4.41 | 153.84 | 4.42 |
| *P. quadrangulata* | A | - | 6.14 | 0.67 | 17.76 | 0.51 |
| *P. robusta* | A | - | 0.81 | 0.09 | 55.64 | 1.60 |
| *P. xiphias* | 1.71 | 0.06 | 2.65 | 0.29 | 25.89 | 0.74 |
| *Pleuromamma* sp. | A | - | 1.00 | 0.11 | 5.65 | 0.16 |
| **Paracalanidae** | | | | | | |
| *Acrocalanus gibber* | 20.93 | 0.74 | 5.67 | 0.62 | 12.69 | 0.36 |
| *A. gracilis* | 7.77 | 0.28 | 0.10 | 0.01 | A | - |
| *A. longicornis* | 0.40 | 0.01 | A | - | 6.35 | 0.18 |
| *A. monachus* | 6.98 | 0.25 | A | - | A | - |
| *Calocalanus pavo* | A | - | 0.50 | 0.05 | 55.28 | 1.59 |
| *C. pavoninus* | 6.98 | 0.25 | A | - | A | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| *C. plumulosus* | A | - | A | - | 36.19 | 1.04 |
| *Paracalanus indicus* | 21.57 | 0.77 | 14.32 | 1.55 | 12.69 | 0.36 |
| *P. aculeatus* | 0.40 | 0.01 | 2.96 | 0.32 | 8.59 | 0.25 |
| *P. crassirostris* | A | - | A | - | A | - |
| *P. parvus* | 6.98 | 0.25 | A | - | A | - |
| **Phaennidae** | | | | | | |
| *Xanthocalanus* sp. | A | - | A | - | 2.44 | 0.07 |
| **Pontellidae** | | | | | | |
| *Calanopia elliptica* | A | - | 1.57 | 0.17 | 20.55 | 0.59 |
| *Pontellina plumata* | 13.96 | 0.50 | 1.96 | 0.21 | A | - |
| **Rhincalanidae** | | | | | | |
| *Rhincalanus cornutus* | 1.71 | 0.06 | 1.07 | 0.12 | 8.59 | 0.25 |
| *R. nasutus* | 10.40 | 0.37 | 0.50 | 0.05 | 8.09 | 0.23 |
| *R. rostrifrons* | A | - | A | - | 25.90 | 0.74 |
| **Scolecitrichidae** | | | | | | |
| *Amallothrix gracilis* | 6.98 | 0.25 | A | - | 2.24 | 0.06 |
| *Pseudoamallothrix emarginata* | A | - | A | - | 0.40 | 0.01 |
| *Lophothrix frontalis* | 24.67 | 0.88 | 0.50 | 0.05 | 60.80 | 1.75 |
| *L. humilifrons* | A | - | A | - | 8.14 | 0.23 |
| *Scaphocalanus echinatus* | 2.10 | 0.07 | 0.50 | 0.05 | A | - |
| *S. longifurca* | A | - | A | - | 2.79 | 0.08 |
| *S. magnus* | 2.10 | 0.07 | A | - | A | - |
| *Scaphocalanus* sp. | 4.83 | 0.17 | 0.55 | 0.06 | 2.79 | 0.08 |
| *Scolecithricella abyssalis* | A | - | 0.31 | 0.03 | A | - |
| *S. dentata* | A | - | 1.07 | 0.12 | A | - |
| *Scolecithricella* sp. | A | - | 0.21 | 0.02 | 26.85 | 0.77 |
| *Scolecithrichopsis ctenopus* | A | - | 1.28 | 0.14 | 6.35 | 0.18 |
| *Scolecithrix danae* | A | - | 2.80 | 0.30 | 18.93 | 0.54 |
| *S. nicobarica* | 6.98 | 0.25 | A | - | A | - |
| *Scolecithrix* sp. | A | - | 11.33 | 1.23 | 2.24 | 0.06 |
| *Scottocalanus helenae* | A | - | 12.94 | 1.40 | 3.72 | 0.11 |
| **Spinocalanidae** | | | | | | |
| *Monacilla gracilis* | 1.19 | 0.04 | A | - | 78.66 | 2.26 |
| *M. tenera* | 36.87 | 1.31 | A | - | 65.78 | 1.89 |
| *M. typica* | 2.21 | 0.08 | 0.06 | 0.01 | A | - |
| *Spinocalanus magnus* | 0.40 | 0.01 | A | - | A | - |
| *Spinocalanus* sp. | A | - | A | - | 2.44 | 0.07 |
| **Temoridae** | | | | | | |
| *Temora turbinata* | 6.98 | 0.25 | A | - | A | - |
| *T. stylifera* | A | - | 0.71 | 0.08 | A | - |
| **CYCLOPOIDA** | | | | | | |
| **Oithonidae** | | | | | | |
| *Oithona brevicornis* | 6.98 | 0.25 | A | - | A | - |
| *O. plumifera* | 6.98 | 0.25 | 0.10 | 0.01 | 17.16 | 0.49 |
| *O. setigera* | 2.10 | 0.07 | A | - | 5.65 | 0.16 |
| *O. similis* | 130.00 | 4.62 | 3.33 | 0.36 | 150.02 | 4.31 |
| *O. spinirostris* | 6.98 | 0.25 | 0.63 | 0.07 | A | - |
| **HARPACTICOIDA** | | | | | | |
| **Aegisthidae** | | | | | | |
| *Aegisthus mucronatus* | A | - | A | - | 10.58 | 0.30 |
| **Clytemnestridae** | | | | | | |
| *Clytemnestra scutellata* | A | - | A | - | 10.55 | 0.30 |
| **Ectinosomatidae** | | | | | | |
| *Microsetella rosea* | A | - | 0.10 | 0.01 | 20.55 | 0.59 |
| **Miraciidae** | | | | | | |
| *Macrosetella gracilis* | 174.60 | 6.21 | 1.19 | 0.13 | 33.03 | 0.95 |
| *Miracia efferata* | A | - | A | - | 6.35 | 0.18 |
| **MORMONILLOIDA** | | | | | | |
| **Mormonillidae** | | | | | | |
| *Mormonilla minor* | 184.23 | 6.55 | 80.25 | 8.71 | 246.03 | 7.07 |
| **POECILOSTOMATOIDA** | | | | | | |
| **Corycaeidae** | | | | | | |
| *Corycaeus catus* | 14.75 | 0.52 | A | - | 25.33 | 0.73 |
| *C. danae* | 58.04 | 2.06 | 2.06 | 0.22 | 24.36 | 0.70 |
| *C. longistylis* | A | - | 0.25 | 0.03 | 6.35 | 0.18 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| *C. speciosus* | 7.37 | 0.26 | A | - | 12.69 | 0.36 |
| *Corycaeus* sp. | A | - | 0.21 | 0.02 | A | - |
| *Farranula carinata* | A | - | A | - | 18.88 | 0.54 |
| **Lubbockidae** |  |  |  |  |  |  |
| *Lubbockia aculeata* | A | - | A | - | 0.74 | 0.02 |
| **Oncaeidae** |  |  |  |  |  |  |
| *Conaea gracilis* | 118.78 | 4.22 | A | - | 139.82 | 4.02 |
| *Oncaea mediterranea* | A | - | A | - | 54.68 | 1.57 |
| *O. notopus* | A | - | A | - | 8.59 | 0.25 |
| *O. venusta* | 1023.28 | 36.37 | 52.15 | 5.66 | 324.03 | 9.31 |
| *Triconia conifera* | A | - | 0.56 | 0.06 | 49.89 | 1.43 |
| **Sapphirinidae** |  |  |  |  |  |  |
| *Copilia quadrata* | 7.37 | 0.26 | A | - | 10.86 | 0.31 |
| *C. vitrea* | 7.37 | 0.26 | A | - | A | - |
| *Sapphirina auronitens* | 0.40 | 0.01 | A | - | A | - |
| *S. ovatolanceolata* | 13.96 | 0.50 | A | - | A | - |
| Unidentified | 0.24 | 0.01 | 19.75 | 2.14 | 186.46 | 5.36 |
| Total individuals 100 m$^{-3}$ | 2813 |  | 921 |  | 3481 |  |

Table 6.6. Seasonal variations in abundance (individuals 100 $m^{-3}$) and percentage (%) of different copepod species in the 500-1000 m stratum in central Bay of Bengal

| | SUM | | FIM | | WM | |
|---|---|---|---|---|---|---|
| Species | Abun. | % | Abun. | % | Abun. | % |
| **CALANOIDA** | | | | | | |
| **Acartiidae** | | | | | | |
| *Acartia negligens* | 3.40 | 0.85 | 1.62 | 0.12 | A | - |
| *A. spinicauda* | 2.63 | 0.65 | A | - | A | - |
| **Aetideidae** | | | | | | |
| *Euchirella amoena* | A | - | 6.36 | 0.48 | A | - |
| *E. bitumida* | 0.30 | 0.08 | A | - | A | - |
| *E. curticauda* | A | - | 1.62 | 0.12 | A | - |
| *E. galeata* | A | - | 2.52 | 0.19 | 0.85 | 0.16 |
| *E. indica* | 4.22 | 1.05 | A | - | A | - |
| *E. maxima* | A | - | 0.51 | 0.04 | A | - |
| *E. rostrata* | A | - | 0.47 | 0.04 | A | - |
| *E. speciosa* | A | - | A | - | 1.03 | 0.20 |
| *E. truncata* | A | - | A | - | 2.88 | 0.55 |
| *Euchirella* sp. | A | - | A | - | 0.53 | 0.10 |
| *Psedochirella dentata* | 0.11 | 0.03 | A | - | A | - |
| *Gaetanus arminger* | A | - | 1.62 | 0.12 | A | - |
| *G. minor* | 2.63 | 0.65 | A | - | 1.03 | 0.20 |
| **Arietellidae** | | | | | | |
| *Arietellus giesbrechtii* | A | - | 0.94 | 0.07 | A | - |
| *Arietellus* sp. | A | - | 1.51 | 0.11 | A | - |
| **Augaptilidae** | | | | | | |
| *Augaptilus* sp. | 0.15 | 0.04 | 13.54 | 1.02 | A | - |
| *Centraugaptilus rattrayi* | A | - | 2.72 | 0.20 | A | - |
| *Euaugaptilus bullifer* | A | - | 64.90 | 4.89 | A | - |
| *E. hecticus* | A | - | 2.53 | 0.19 | A | - |
| *Haloptilus longicornis* | 2.63 | 0.65 | 1.62 | 0.12 | 2.88 | 0.55 |
| *H. spiniceps* | 0.15 | 0.04 | A | - | A | - |
| **Calanidae** | | | | | | |
| *Canthocalanus pauper* | A | - | A | - | 2.25 | 0.43 |
| *Undinula vulgaris* | 4.24 | 1.05 | A | - | 1.03 | 0.20 |
| **Candaciidae** | | | | | | |
| *Candacia bradyi* | 0.80 | 0.20 | A | - | A | - |
| *C. discaudata* | A | - | 1.66 | 0.13 | A | - |
| *C. pachydactyla* | 0.11 | 0.03 | A | - | A | - |
| *Candacia* sp. | A | - | 0.47 | 0.04 | 0.85 | 0.16 |
| *Paracandacia truncata* | A | - | 9.48 | 0.71 | A | - |
| **Centropagidae** | | | | | | |
| *Centropages furcatus* | A | - | A | - | 0.50 | 0.10 |
| *Centropages* sp. | A | - | A | - | 0.37 | 0.07 |
| **Clausocalanidae** | | | | | | |
| *Clausocalanus arcuicornis* | 19.71 | 4.90 | 17.85 | 1.34 | 3.03 | 0.58 |
| *C. furcatus* | A | - | 15.27 | 1.15 | 10.70 | 2.04 |
| *C. pergens* | 0.33 | 0.08 | 0.51 | 0.04 | A | - |
| *Clausocalanus* sp. | A | - | 12.74 | 0.96 | A | 0.03 |
| **Eucalanidae** | | | | | | |
| *Eucalanus crassus* | 0.15 | 0.04 | 31.12 | 2.34 | 0.85 | 0.16 |
| *E. subcrassus* | A | - | 2.13 | 0.16 | A | - |
| *E. elongatus* | 1.12 | 0.28 | 2.45 | 0.18 | 0.37 | 0.07 |
| *E. monachus* | 36.75 | 9.14 | 32.09 | 2.42 | 1.03 | 0.20 |
| *E. mucronatus* | 0.11 | 0.03 | 0.47 | 0.04 | 4.28 | 0.81 |
| *Pareucalanus attenuatus* | 5.19 | 1.29 | 5.96 | 0.45 | 3.14 | 0.60 |
| *Eucalanus* sp. | A | - | 3.30 | 0.25 | 0.50 | 0.10 |
| *Subeucalanus crassus* | 1.57 | 0.39 | A | - | A | - |
| **Euchaetidae** | | | | | | |
| *Euchaeta concinna* | A | - | 3.23 | 0.24 | A | - |
| *E. indica* | 1.57 | 0.39 | 5.36 | 0.40 | A | - |
| *E. marina* | 2.52 | 0.63 | 6.04 | 0.45 | 2.06 | 0.39 |
| *E. plana* | A | - | 0.51 | 0.04 | A | - |
| *Euchaeta* sp. | 2.63 | 0.65 | 0.51 | 0.04 | A | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Fosshageniidae** | | | | | | |
| *Temoropia mayumbaensis* | A | - | A | - | 7.59 | 1.45 |
| **Heterorhabdidae** | | | | | | |
| *Heterorhabdus abyssalis* | 7.88 | 1.96 | A | - | 0.85 | 0.16 |
| *H. pacificus* | 0.80 | 0.20 | 0.51 | 0.04 | A | - |
| *H. papilliger* | 0.27 | 0.07 | 17.76 | 1.34 | A | - |
| *H. spinifrons* | 0.16 | 0.04 | 2.72 | 0.20 | 0.36 | 0.07 |
| *Heterorhabdus* sp. | A | - | A | - | 2.06 | 0.39 |
| *Heterostylites longicornis* | A | - | A | - | 0.17 | 0.03 |
| **Lucicutiidae** | | | | | | |
| *Lucicutia flavicornis* | 46.21 | 11.49 | 107.08 | 8.06 | 12.57 | 2.39 |
| *L. maxima* | 7.72 | 1.92 | 51.30 | 3.86 | 10.44 | 1.99 |
| *L. ovalis* | A | - | 2.53 | 0.19 | 0.85 | 0.16 |
| **Mecynoceridae** | | | | | | |
| *Mecynocera clausii* | A | - | 4.23 | 0.32 | A | - |
| **Megacalanidae** | | | | | | |
| *Megacalanus princeps* | A | - | 0.47 | 0.04 | A | - |
| **Metridinidae** | | | | | | |
| *Gaussia princeps* | 0.15 | 0.04 | 3.04 | 0.23 | A | - |
| *Metridia brevicauda* | 0.95 | 0.24 | 0.51 | 0.04 | 2.25 | 0.43 |
| *M. cuticauda* | A | - | A | - | 2.88 | 0.55 |
| *M. princeps* | A | - | 5.06 | 0.38 | A | - |
| *Metridia* sp. | A | - | 19.25 | 1.45 | 0.26 | 0.05 |
| *Pleuromamma abdominalis* | A | - | 1.52 | 0.11 | A | - |
| *P. gracilis* | 0.80 | 0.20 | 4.75 | 0.36 | 3.90 | 0.74 |
| *P. indica* | 21.50 | 5.35 | 54.14 | 4.08 | 3.10 | 0.59 |
| *P. quadrangulata* | A | - | 5.44 | 0.41 | 1.03 | 0.20 |
| *P. robusta* | A | - | 4.74 | 0.36 | A | - |
| *P. xiphias* | A | - | A | - | 2.88 | 0.55 |
| *Pleuromamma* sp. | A | - | 1.98 | 0.15 | 0.17 | 0.03 |
| **Nullosetigeridae** | | | | | | |
| *Nullosetigera bidentata* | 0.30 | 0.08 | A | - | A | - |
| *Nullosetigera* sp. | 0.22 | 0.06 | A | - | A | - |
| **Paracalanidae** | | | | | | |
| *Acrocalanus gibber* | 0.15 | 0.04 | A | - | A | - |
| *A. gracilis* | 0.46 | 0.11 | 0.51 | 0.04 | 0.17 | 0.03 |
| *A. longicornis* | 0.26 | 0.07 | 6.66 | 0.50 | 2.09 | 0.40 |
| *Calocalanus pavo* | 2.03 | 0.51 | A | - | 0.85 | 0.16 |
| *C. pavoninus* | 0.22 | 0.06 | A | - | A | - |
| *C. plumulosus* | A | - | A | - | 0.17 | 0.03 |
| *Paracalanus indicus* | 6.38 | 1.59 | 8.10 | 0.61 | A | - |
| *P. aculeatus* | 2.78 | 0.69 | 1.52 | 0.11 | A | - |
| *P. parvus* | 1.68 | 0.42 | A | - | A | - |
| **Phaennidae** | | | | | | |
| *Amallophora conifer* | A | - | A | - | 1.03 | 0.20 |
| **Pontellidae** | | | | | | |
| *Calanopia aurivilli* | 1.57 | 0.39 | A | - | A | - |
| *C. elliptica* | A | - | 0.94 | 0.07 | A | A |
| *C. minor* | 0.61 | 0.15 | A | - | A | A |
| *Pontellina plumata* | A | - | 11.67 | 0.88 | 0.17 | 0.03 |
| **Rhincalanidae** | | | | | | |
| *Rhincalanus cornutus* | A | - | 0.94 | 0.07 | A | - |
| *R. nasutus* | A | - | 0.47 | 0.04 | A | - |
| *R. rostrifrons* | 1.57 | 0.39 | 3.29 | 0.25 | 1.29 | 0.25 |
| **Scolecitrichidae** | | | | | | |
| *Amallothrix gracilis* | A | - | A | - | 0.10 | 0.02 |
| *Lophothrix frontalis* | 1.10 | 0.27 | 0.47 | 0.04 | 5.17 | 0.98 |
| *L. humilifrons* | A | - | A | - | 0.26 | 0.05 |
| *Scaphocalanus echinatus* | A | - | 5.06 | 0.38 | A | - |
| *S. elongatus* | A | - | A | - | 0.26 | 0.05 |
| *Scaphocalanus* sp. | 0.15 | 0.04 | A | - | 0.50 | 0.10 |
| *Scolecithricella abyssalis* | A | - | 1.52 | 0.11 | A | - |
| *S. bradyi* | 4.20 | 1.04 | A | - | A | - |
| *S. dentata* | A | - | A | - | 0.10 | 0.02 |
| *S. vittatta* | A | - | A | - | 2.09 | 0.40 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Scolecithricella* sp. | A | - | 1.01 | 0.08 | A | - |
| *Scolecithrichopsis ctenopus* | 2.63 | 0.65 | 13.84 | 1.04 | A | - |
| *Scolecithrix bradyi* | 2.78 | 0.69 | A | - | A | - |
| *S. danae* | 0.95 | 0.24 | 24.64 | 1.86 | 1.22 | 0.23 |
| *S. nicobarica* | A | - | 0.47 | 0.04 | A | - |
| *Scolecithrix* sp. | A | - | 1.89 | 0.14 | 0.17 | 0.03 |
| *Scottocalanus helenae* | A | - | 13.20 | 0.99 | 2.88 | 0.55 |
| **Spinocalanidae** | | | | | | |
| *Monacilla tenera* | 28.91 | 7.19 | A | - | A | - |
| *M. typica* | A | - | A | - | 0.52 | 0.10 |
| *Spinocalanus* sp. | A | - | A | - | 2.09 | 0.40 |
| **Temoridae** | | | | | | |
| *Temora discaudata* | 0.15 | 0.04 | 2.53 | 0.19 | A | - |
| **Tharybidae** | | | | | | |
| *Tharybis* sp. | A | - | 0.47 | 0.04 | A | - |
| *Undinella* sp. | A | - | 3.13 | 0.24 | A | - |
| **CYCLOPOIDA** | | | | | | |
| **Oithonidae** | | | | | | |
| *Oithona brevicornis* | 0.15 | 0.04 | 1.66 | 0.13 | 1.03 | 0.20 |
| *O. plumifera* | 3.07 | 0.76 | 0.51 | 0.04 | A | - |
| *O. setigera* | A | - | A | - | 0.85 | 0.16 |
| *O. similis* | 9.88 | 2.46 | 27.81 | 2.09 | 10.85 | 2.07 |
| *O. spinirostris* | 6.27 | 1.56 | 10.84 | 0.82 | 0.90 | 0.17 |
| **HARPACTICOIDA** | | | | | | |
| **Aegisthidae** | | | | | | |
| *Aegisthus aculeatus* | A | - | A | - | 0.26 | 0.05 |
| *A. mucronatus* | 5.26 | 1.31 | A | - | A | - |
| **Clytemnestridae** | | | | | | |
| *Clytemnestra scutellata* | 0.11 | 0.03 | A | - | 1.02 | 0.19 |
| **Ectinosomatidae** | | | | | | |
| *Microsetella rosea* | 0.11 | 0.03 | 0.51 | 0.04 | A | - |
| **Miraciidae** | | | | | | |
| *Macrosetella gracilis* | 23.88 | 5.94 | 5.03 | 0.38 | 0.70 | 0.13 |
| *Miracia efferata* | 0.15 | 0.04 | A | - | A | - |
| **MORMONILLOIDA** | | | | | | |
| **Mormonillidae** | | | | | | |
| *Mormonilla minor* | 25.80 | 6.42 | 57.26 | 4.31 | 112.28 | 21.38 |
| **POECILOSTOMATOIDA** | | | | | | |
| **Corycaeidae** | | | | | | |
| *Corycaeus catus* | 2.44 | 0.61 | 3.00 | 0.23 | 1.99 | 0.38 |
| *C. danae* | 0.98 | 0.24 | 8.97 | 0.68 | 1.53 | 0.29 |
| *C. longistylis* | A | - | A | - | 0.43 | 0.08 |
| *C. speciosus* | 2.74 | 0.68 | 0.47 | 0.04 | 0.17 | 0.03 |
| *Corycaeus* sp. | A | - | A | - | 2.09 | 0.40 |
| *Farranula gibbula* | 1.57 | 0.39 | 0.47 | 0.04 | A | - |
| **Lubbockidae** | | | | | | |
| *Lubbockia* sp. | A | - | 1.51 | 0.11 | A | - |
| **Oncaeidae** | | | | | | |
| *Conaea gracilis* | 44.87 | 11.16 | 2.83 | 0.21 | 255.55 | 48.67 |
| *Oncaea mediterranea* | A | - | A | - | 1.39 | 0.27 |
| *O. notopus* | A | - | A | - | 5.03 | 0.96 |
| *O. venusta* | 27.74 | 6.90 | 514.61 | 38.76 | 4.80 | 0.91 |
| *Oncaea* sp. | A | - | 0.94 | 0.07 | A | - |
| *Triconia conifera* | 2.63 | 0.65 | 12.97 | 0.98 | 4.52 | 0.86 |
| **Sapphirinidae** | | | | | | |
| *Copilia quadrata* | 0.52 | 0.13 | A | - | A | - |
| *Sapphirina metallina* | 1.57 | 0.39 | A | - | A | - |
| *S. ovatolanceolata* | A | - | A | - | 0.17 | 0.03 |
| *Sapphirina* sp. | 2.63 | 0.65 | A | - | A | - |
| Unidentified | 1.68 | 0.42 | 28.25 | 2.13 | 6.69 | 1.28 |
| Total individuals 100 m$^{-3}$ | 402 | | 1328 | | 525 | |

In each of these strata mentioned above, the species were further found to vary seasonally. In the MLD, species of *Acartia* were most abundant during FIM, while only *A. negligens* was found during months of FIM and SpIM (Table 6.2). Many deep-water species showed seasonal appearance in this stratum. For instance, *Conaea gracilis* and species of Spinocalanidae were absent during both the intermonsoons. Fewer species of Aetideidae were noticed during FIM, WM and SpIM. During these seasons again, no species of *Undinella*, *Rhincalanus, Nullosetigera* and Phaennidae were present. Similarly, species of Heterorhabdidae were absent during FIM and just one species each was found during WM and SpIM.

In the thermocline stratum, species of *Acartia, Centropages, Acrocalanus*, all species of Scolecithrichidae, Spinocalanidae and Temoridae were absent during SUM (Table 6.3). During SpIM, all species of Sapphirinidae, Spinocalanidae, Temoridae and most species of Aetideidae and Scolecithrichidae were absent.

In the TT-300 m stratum, the lowest number of species was observed during SpIM (Table 6.4). During this season, species of Calanidae, Centropagiidae, Euchaetidae and Pontellidae were absent. Also the least number of species of Aetideidae, Candaciidae, Clausocalanidae, Paracalanidae, Corycaeidae, Clausiidae, Lubbockidae and harpacticoids was notable.

In the 300-500 m stratum, the most number of species, particularly those of Aetideidae were present during WM (Table 6.5). Seasonal changes in species were also felt in the deepest stratum (Table 6.6).

Seasonally, the number of species occurring in the upper 1000 m was the least during SpIM (SUM: 162, FIM: 170, WM: 172, SpIM: 96).

### 6.2.5. Dominant species

All the species accounting for $\geq 2\%$ of the total copepod abundance were considered as dominant ones. During SUM, *Oncaea venusta, Mormonilla minor, Pleuromamma indica, Oithona similis, Macrosetella gracilis, Lucicutia flavicornis, Paracalanus indicus, Corycaeus danae, Conaea gracilis, Clausocalanus furcatus, Corycaeus catus* and *Eucalanus monachus* dominated the collections (Table 6.7). These 12 species together contributed to 71.4% of the total copepod abundance in the 0-1000 m column. Based on

Table 6.7. Copepod species contributing ≥2% of total abundance (individuals m$^{-2}$) in the upper 1000 m of the central Bay during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM)

| Season | Species | Abundance in 1000 m (ind m$^{-2}$) | % |
|---|---|---|---|
| SUM | *Oncaea venusta* | 5688 | 31.3 |
| | *Mormonilla minor* | 1287 | 7.1 |
| | *Pleuromamma indica* | 1056 | 5.8 |
| | *Oithona similis* | 922 | 5.1 |
| | *Macrosetella gracilis* | 889 | 4.9 |
| | *Lucicutia flavicornis* | 643 | 3.5 |
| | *Paracalanus indicus* | 462 | 2.5 |
| | *Corycaeus danae* | 453 | 2.5 |
| | *Conaea gracilis* | 416 | 2.3 |
| | *Clausocalanus furcatus* | 393 | 2.2 |
| | *Corycaeus catus* | 380 | 2.1 |
| | *Eucalanus monachus* | 377 | 2.1 |
| FIM | *Oncaea venusta* | 16770 | 21.4 |
| | *Paracalanus indicus* | 15026 | 19.2 |
| | *Lucicutia flavicornis* | 3724 | 4.8 |
| | *Eucalanus monachus* | 3575 | 4.6 |
| | *Corycaeus danae* | 3097 | 4.0 |
| | *Oithona similis* | 2816 | 3.6 |
| | *Paracalanus aculeatus* | 2332 | 3.0 |
| | *Pleuromamma indica* | 2293 | 2.9 |
| WM | *Oncaea venusta* | 11042 | 15.4 |
| | *Oithona similis* | 7437 | 10.3 |
| | *Clausocalanus arcuicornis* | 4999 | 7.0 |
| | *Pleuromamma indica* | 4225 | 5.9 |
| | *Paracalanus indicus* | 3486 | 4.8 |
| | *Mormonilla minor* | 3114 | 4.3 |
| | *Clausocalanus furcatus* | 2587 | 3.6 |
| | *Corycaeus catus* | 2215 | 3.1 |
| | *Lucicutia flavicornis* | 1722 | 2.4 |
| | *Conaea gracilis* | 1631 | 2.3 |
| SpIM | *Clausocalanus arcuicornis* | 4113 | 15.9 |
| | *Oncaea venusta* | 3871 | 15.0 |
| | *Oithona similis* | 1547 | 6.0 |
| | *Lucicutia flavicornis* | 1306 | 5.1 |
| | *Pleuromamma indica* | 1225 | 4.7 |
| | *Mormonilla minor* | 951 | 3.7 |
| | *Corycaeus catus* | 891 | 3.4 |
| | *Oncaea mediterranea* | 672 | 2.6 |
| | *Acrocalanus gracilis* | 592 | 2.3 |
| | *Calocalanus pavo* | 586 | 2.3 |
| | *Clausocalanus furcatus* | 583 | 2.3 |
| | *Corycaeus speciosus* | 576 | 2.2 |

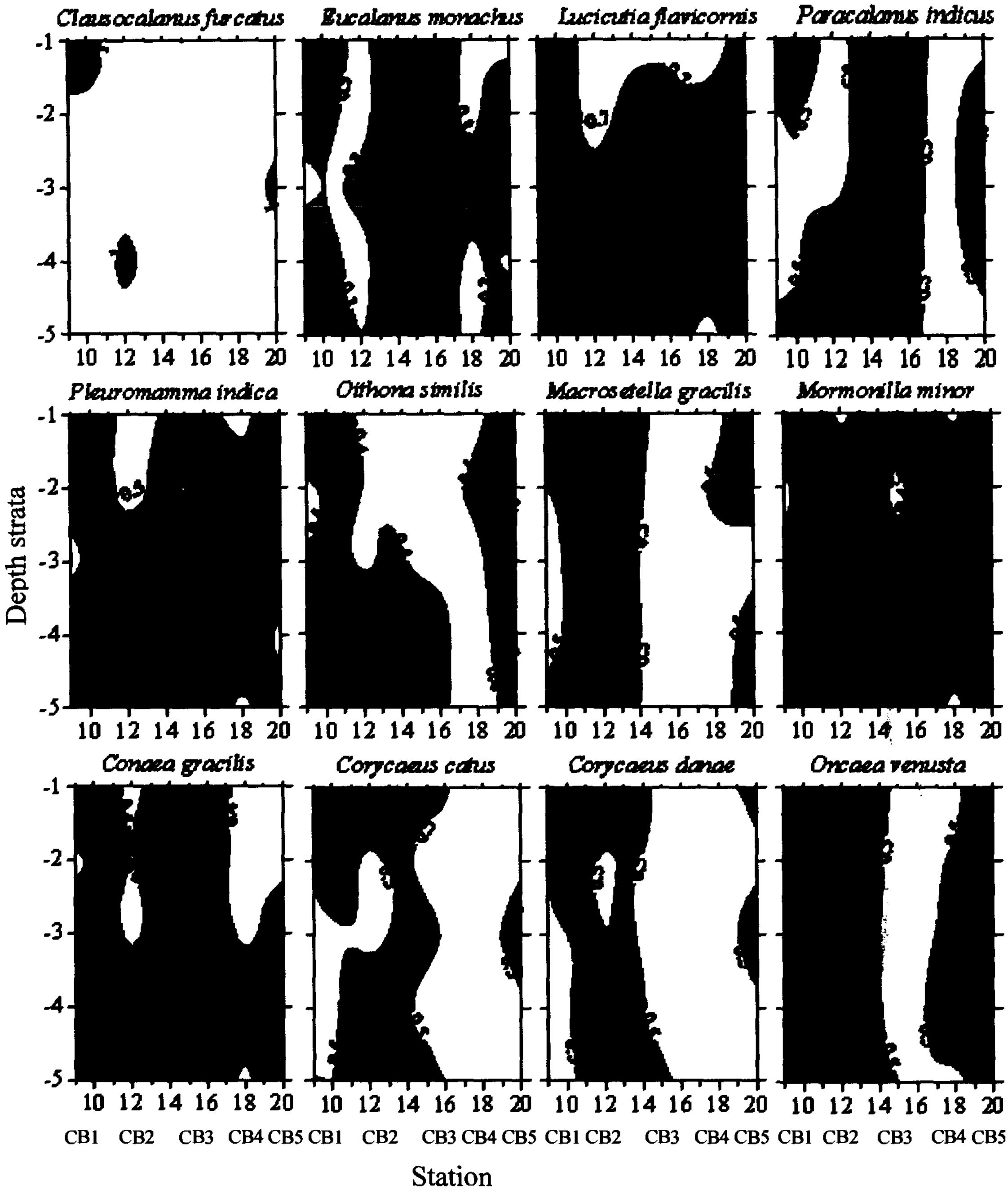


Figure 6.4. Distribution of major copepod species along central Bay during summer monsoon. Abundance (number 100 m$^{-3}$; on labeled contours) is indicated in log numbers.

Depth strata: -1: surface-mixed layer depth (mld); -2: top of thermocline (TT)-base of thermocline (BT); -3: BT-300m; -4: 300-500m; -5: 500-1000m

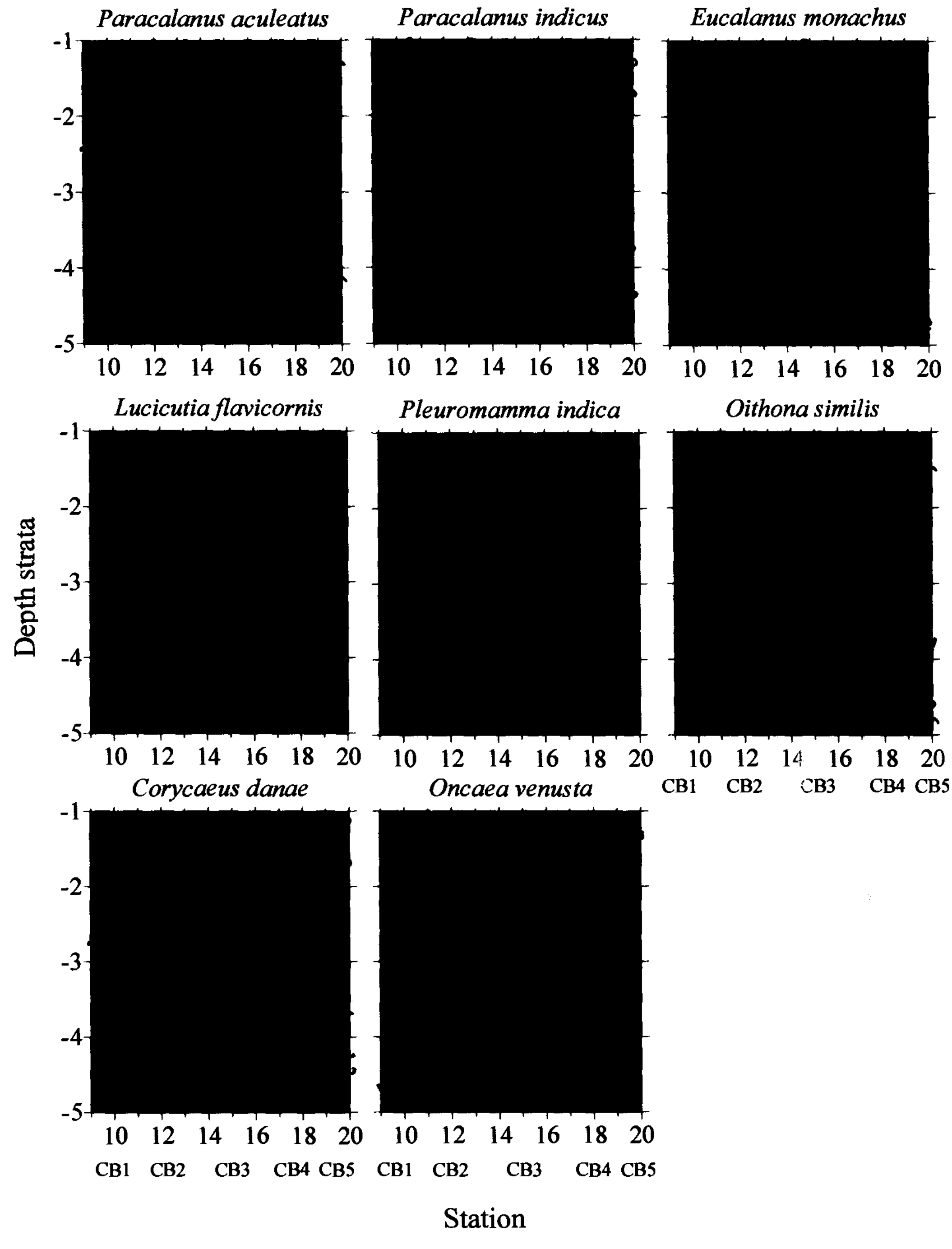


Figure 6.5. Distribution of major copepod species along central Bay during fall inter monsoon. Abundance (number 100 m$^{-3}$; on labeled contours) is indicated in log numbers.

Depth strata: -1: surface - mixed layer depth (mld); -2: top of thermocline (TT)-base of thermocline (BT); -3: BT - 300m; -4: 300-500m; -5: 500-1000m

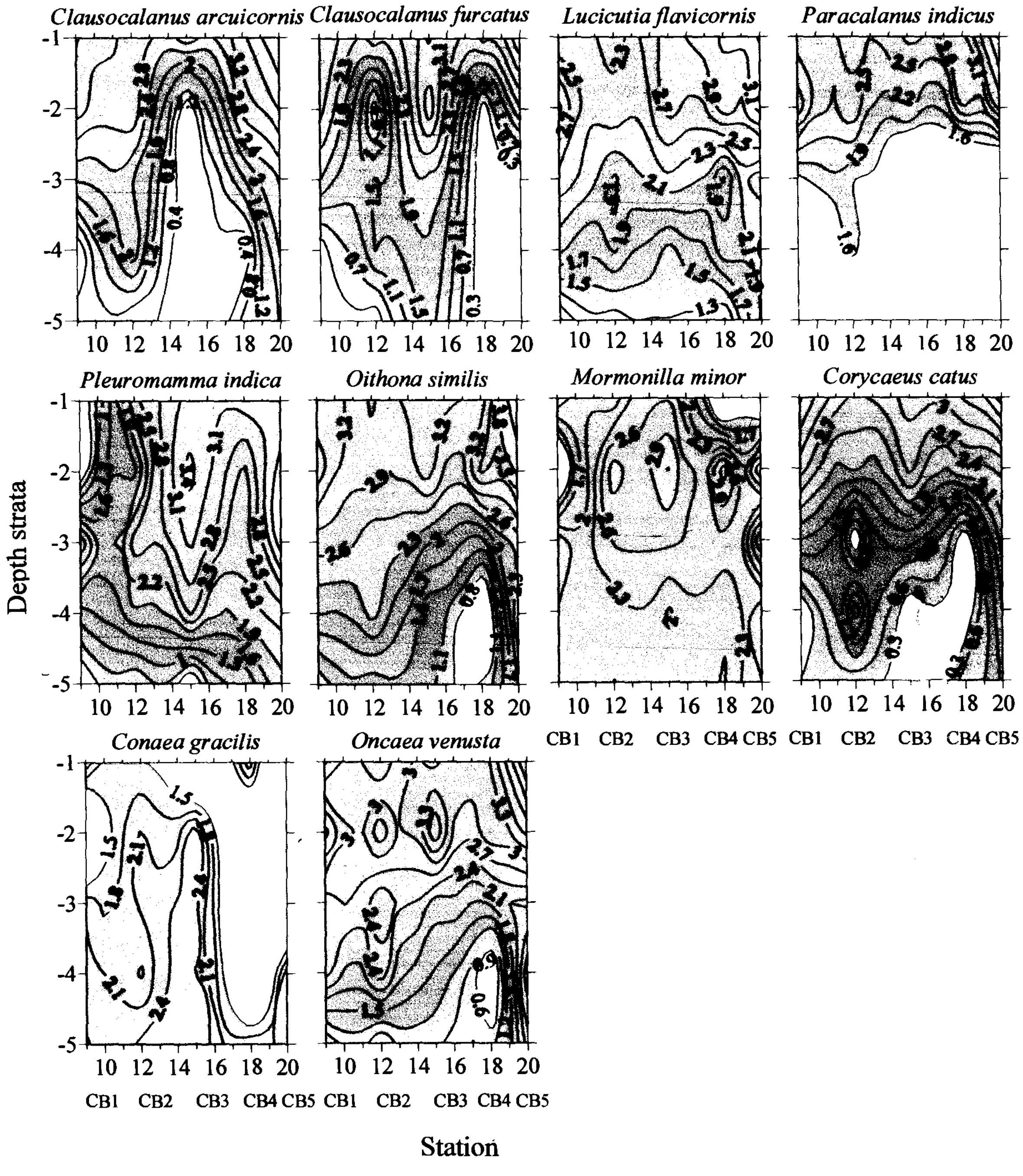


Figure 6.6. Distribution of major copepod species along central Bay during winter monsoon. Abundance (number 100m$^{-3}$; on labeled contours) is indicated in log numbers.

Depth strata: -1: surface-mixed layer depth (mld); -2: top of thermocline (TT)-Base of thermocline (BT); -3: BT-300m; -4: 300-500m; -5: 500-1000m

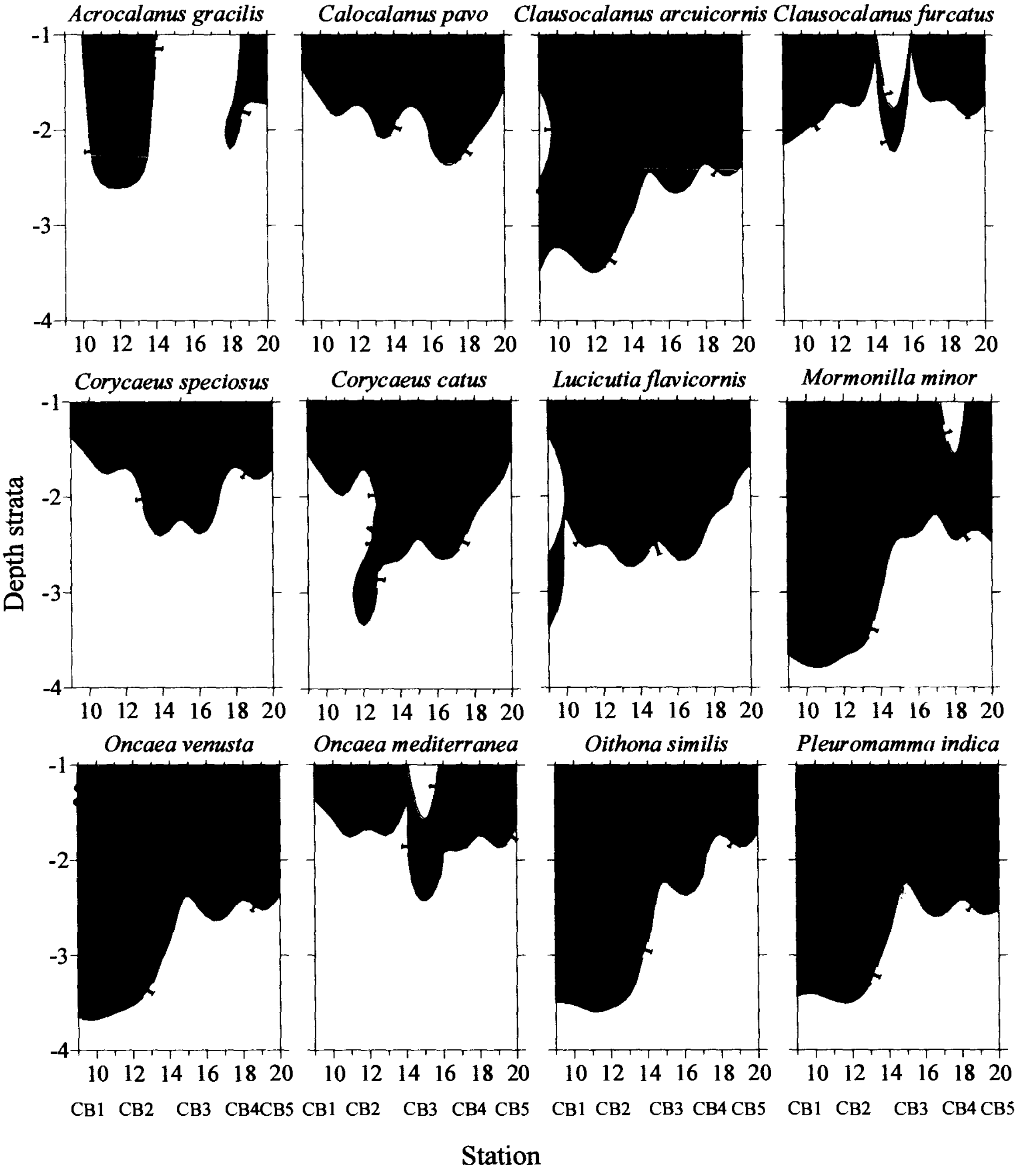


Figure 6.7. Distribution of major copepod species along central Bay during spring inter monsoon. Abundance (number $100m^{-3}$; on labeled contours) is indicated in log numbers.

Depth strata: -1; surface-mixed layer depth (MLD); -2: top of thermocline (TT) - Base of thermocline (BT); -3: BT - 300 m; -4: 300-500 m;

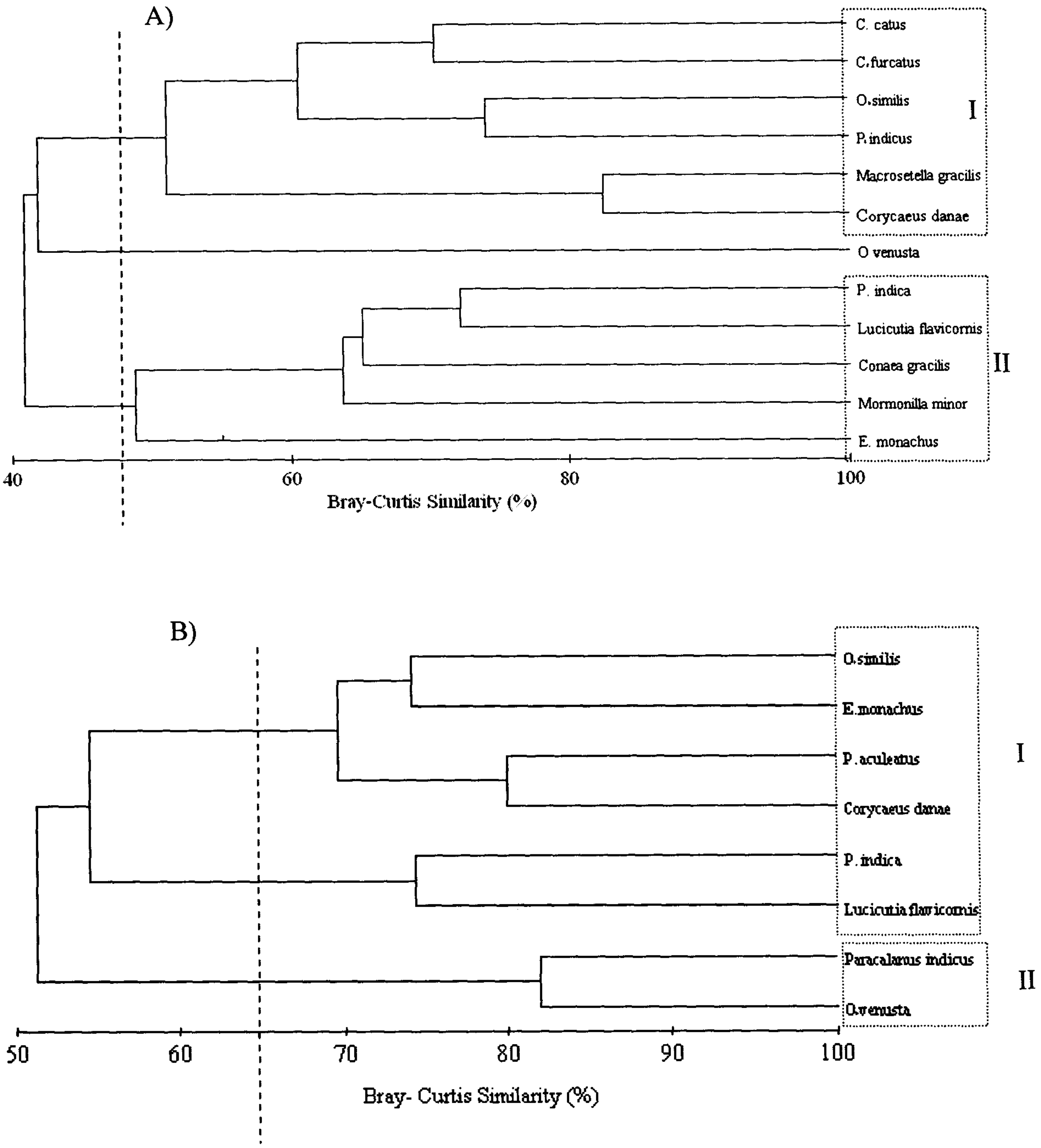


Figure 6.8. Cluster dendrogram of the major copepod species (≥2%) from the central Bay during summer monsoon (A) and fall intermonsoon (B), using Bray- Curtis similarity (%) and group average method

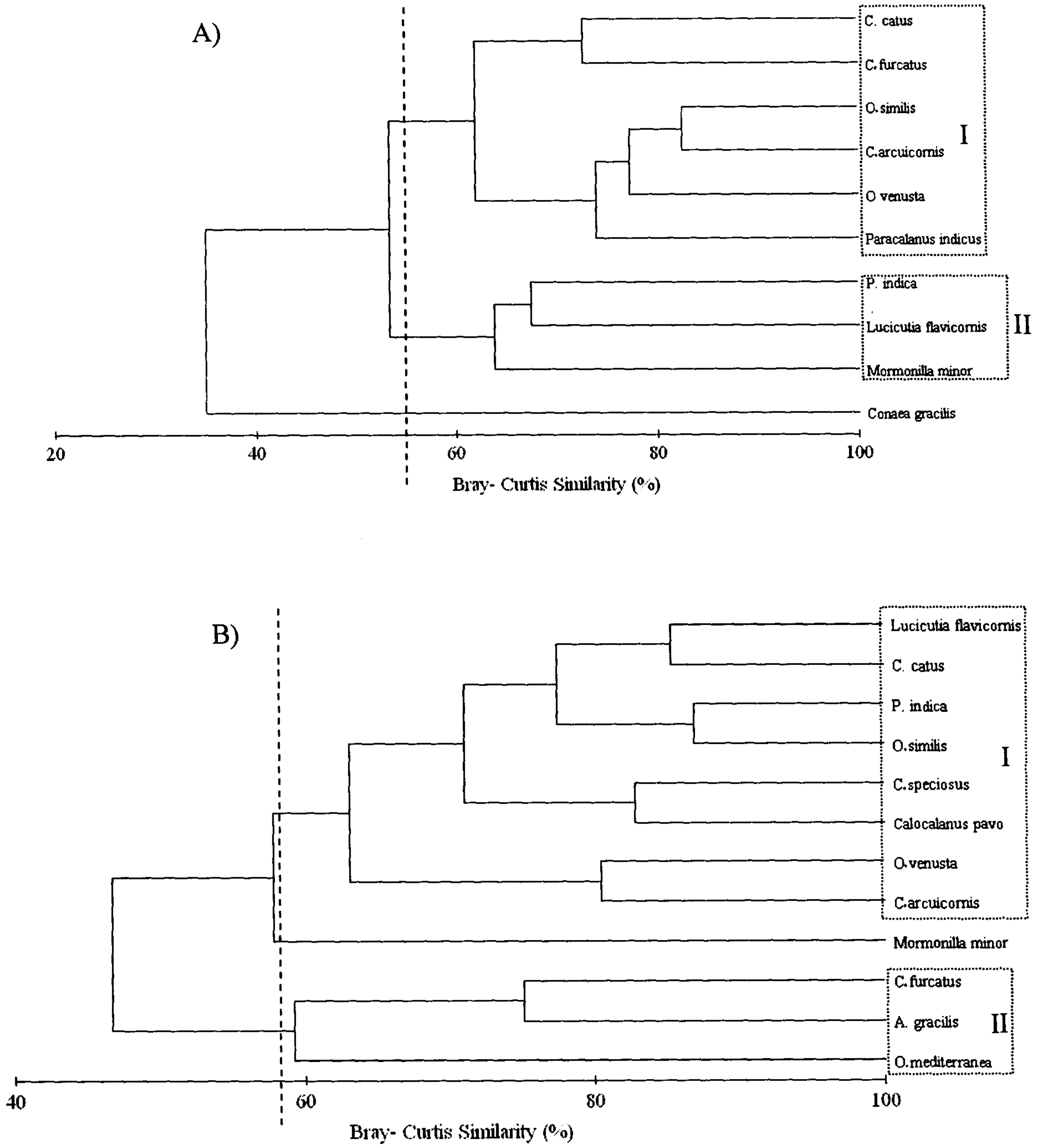


Figure 6.9. Cluster dendrogram of the major copepod species (≥2%) from the central Bay during winter monsoon (A) and spring inter monsoon (B), using Bray- Curtis similarity (%) and group average method

their distribution pattern, they fell into two distinct clusters plus a single ('stand-alone') species (Fig. 6.8 A). Species with usually higher surface abundances *e.g. Corycaeus catus*, *Clausocalanus furcatus*, *O. similis*, *P. indicus*, *M. gracilis* and *C. danae* formed one cluster. In the other cluster were, *P. indica*, *L. flavicornis*, *Conaea gracilis*, *M. minor* and *E. monachus,* usually with higher abundances at various depths below MLD. Standing alone, *Oncaea venusta* was abundant at all depths except at station CB3 (Fig. 6.4; 6.8 A).

During FIM, eight dominant species, *Oncaea venusta, Paracalanus indicus, Lucicutia flavicornis, Eucalanus monachus, Corycaeus danae, Oithona similis, Paracalanus aculeatus* and *Pleuromamma indica* contributed to 64% of the total abundance (Table 6.7). *Pleuromamma indica*, *L. flavicornis*, *O. similis*, *E. monachus*, *P. aculeatus* and *C. danae* which clustered in group I had higher abundances in the MLD at CB1 and CB4. *Paracalanus indicus* and *O. venusta* in cluster II, were abundant in the MLD and decreased gradually with increasing depth (Fig. 6.5; 6.8 B).

During WM, 10 species were dominant with *O. venusta, O. similis, Clausocalanus arcuicornis, P. indica, P. indicus, Mormonilla minor, Clausocalanus furcatus, C. catus, L. flavicornis* and *Conaea gracilis* forming 59% of the total copepod abundance (Table 6.7). *Corycaeus catus*, *C. furcatus*, *O. similis*, *Clausocalanus arcuicornis*, *O. venusta* and *P. indicus* in cluster I, had moderate abundance in the upper two strata at CB1, CB3 and CB5 and decreased with increasing depth. Most of them were absent from the 300-1000 m layers at CB4. At all stations, *P. indicus* was absent in these strata. *Pleuromamma indica, L. flavicornis* and *M. minor* in cluster II, were abundant even in the deepest stratum though their core abundance was in the thermocline. The single species *Conaea gracilis* that did not cluster with others was dominant in the deepest layer at CB3, decreasing in abundance at shallower depths (Fig. 6.6; 6.9 A).

Contributing to 65.4%, 12 species *viz. Clausocalanus arcuicornis, O. venusta, O. similis, L. flavicornis, P. indica, M. minor, C. catus, Oncaea mediterraneana, Acrocalanus gracilis, Calocalanus pavo, Clausocalanus furcatus* and *Corycaeus speciosus* were dominant during SpIM (Table 6.7). *Lucicutia flavicornis, C. catus, P. indica, O. similis, C. speciosus, C. pavo, O. venusta* and *C. arcuicornis* in cluster I were most abundant in the MLD especially at CB3 and dwindled with increasing depth.

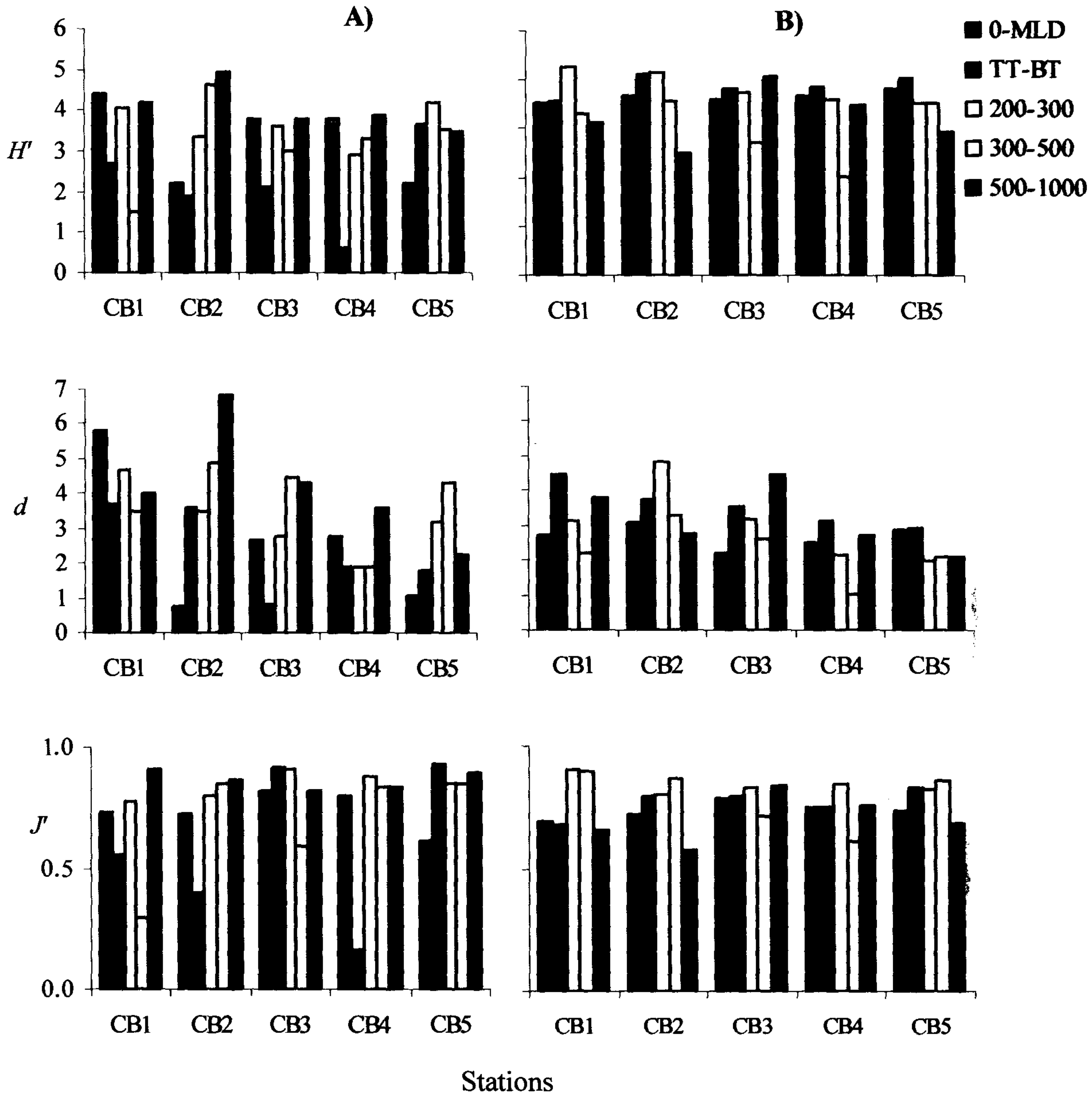


Figure 6.10. Depth-wise variation of copepod species diversity (*H'*), richness (*d*), and evenness (*J'*) at different sampling stations in central Bay of Bengal during summer monsoon (A) and fall intermonsoon (B)

*Mormonilla minor* that stood apart was abundant in the MLD as well as in the 200-300 m stratum between CB1 and CB2. Falling into cluster II, *Acrocalanus gracilis, Clausocalanus furcatus* and *O. mediterranea* were present in the uppermost two strata except at CB3 (Fig. 6.7; 6.9 B).

### 6.2.6. Species diversity, evenness and species richness

Shannon diversity (*H'*), richness (*d*) and evenness (*J'*) for copepod species varied greatly with depth and between stations. During SUM, *H'* varied from 0.6 to 4.9, *d* from 0.8 to 6.9 and *J'* from 0.30-0.94 in the CB. Diversity, richness and evenness were higher in some surface strata and mostly in the deepest stratum. All these parameters showed seemed to decrease towards the northern Bay (Fig. 6.10 A).

During FIM, *H'* ranged from 2.0 to 4.3 and was higher in the upper three strata and some deepest strata. In the MLD and thermocline, it did not vary between stations. In the two strata between 200 and 500 m, it decreased towards north but in the deepest layer it increased northward. Ranging from 1 to 4.9, the *d* was higher in the thermocline and again in the deepest layer. Overall, there was a clear northward decrease. Evenness (0.61-0.91) was higher in the subsurface depths of 300 m and remained similar at all stations (Fig. 6.10 B).

The *H'* ranging from 2.8 to 4.4 during WM, was higher in the surface and 300-500 m stratum. Ranging from 1.9 to 4.4, *d* was mostly higher in the 300-500 m strata with an overall decrease northwards. Evenness ranging from 0.49 to 0.90 decreased with depth. Similar to H', *J'* varied with depth and was uniform at all stations (Fig. 6.11 A).

During SpIM, *H'* ranged from 1.0 to 5.0. It decreased with increasing depth especially between CB3 and CB5. Similar trend was seen in the *d*, which ranged from 0.5 to 4.8. *J'* (0.71-0.97) seemed to decrease with increasing depth in the first two stations, however, it showed an increasing trend from CB3 to CB5 (Fig. 6.11 B).

### 6.2.7. Correlation analysis

Copepod abundance correlated negatively with temperature during both monsoons and positively with salinity during SUM and FIM. Though it was positively correlated with chl *a* in all seasons, it was significant only during FIM.

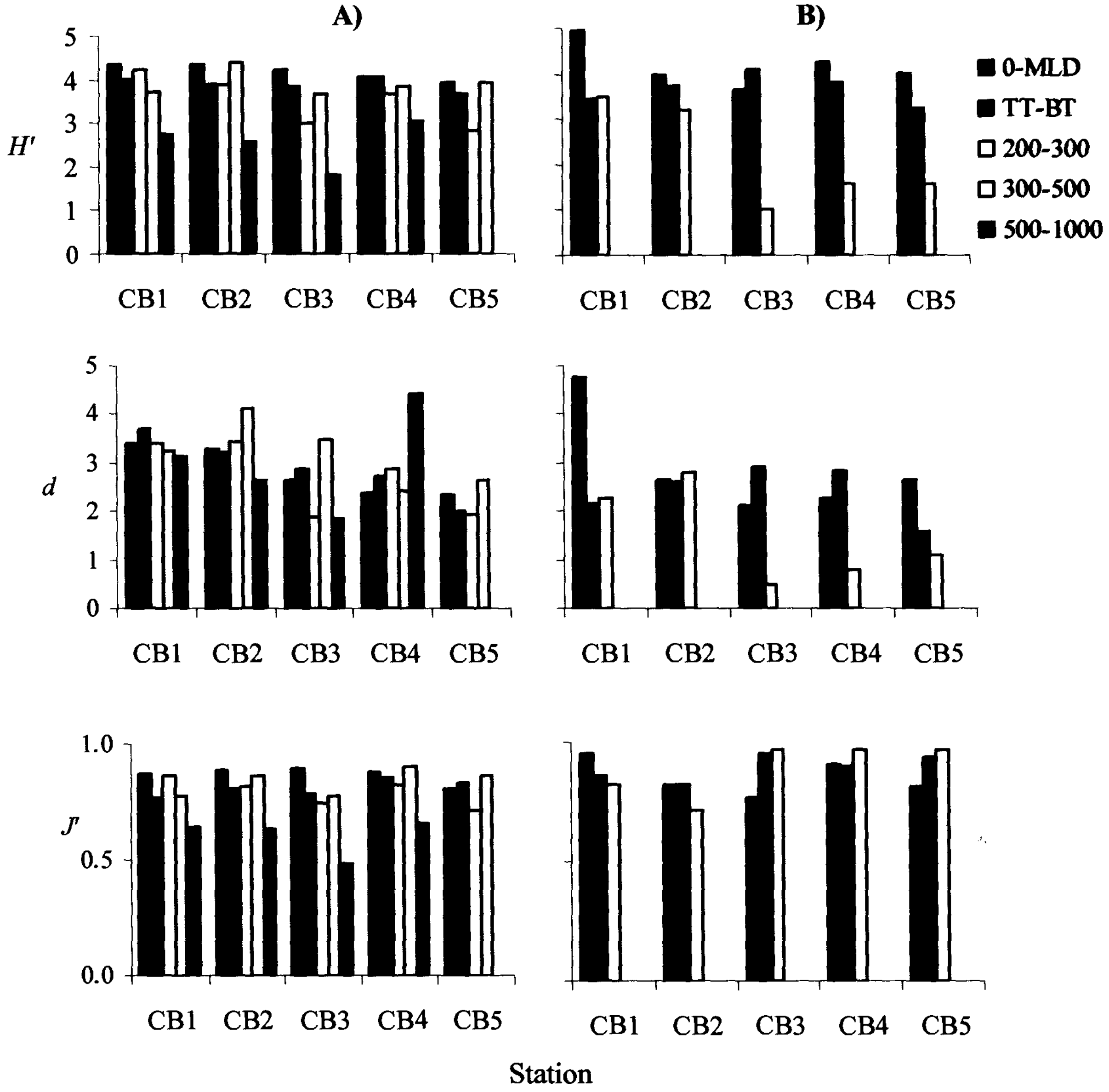


Figure 6.11. Depth-wise variation of copepod species diversity (*H'*), richness (*d*), and evenness (*J'*) at different sampling stations in central Bay of Bengal during winter monsoon (A) and spring intermonsoon (B)

Diversity (*H'*) was negatively correlated with total biomass, abundance, temperature and chl *a* and, positively with salinity (except during FIM). In general, species richness also correlated negatively with total biomass and abundance. It did not show a clear relationship with temperature, but had a clear positive relation with salinity and negative one with chl *a*. Evenness was also negatively correlated with total biomass, abundance and chl *a*, did not show a general trend with temperature and salinity (Table 6.8).

## 6.3. Discussion

### 6.3.1. A general comparative account of abundance *vis-à-vis* global oceans and AS

Copepods, the main herbivores among the zooplankton (Panikkar and Rao 1973) constituted 74-93 % of the standing stocks in the CB (Chapter 4). Such dominance of over 70% has been documented earlier from northeast Atlantic (Clark et al. 2001), BATS site (Bermuda Atlantic time-series; Piontkovski et al. 2006), Red Sea (Cornils et al. 2007), Arabian Sea (Madhupratap et al. 2001) among other locations. Spatial variability in their abundance ranging from a mere 35 to 273588 individuals 100 $m^{-3}$ within the upper 1000 m in the CB is apparently quite common in many parts of the world oceans (Nair et al. 1981; Padmavati et al. 1998; Yamaguchi et al. 2002). Gaard et al. (2008) observed copepod abundances ranging from 45,000 to 178,000 individuals $m^{-2}$ in the upper 2500 m along a transect on the mid Atlantic ridge. The mean copepod abundance obtained in the upper 200 m was 126700 ind.100 $m^{-3}$ in the Monterey Bay (Hopcroft et al. 2002). It ranged from 69500 to 412000 ind.100 $m^{-3}$ in the surface waters and, from 48300 to 331900 100 $m^{-3}$ in the entire water column in the Discovery Bay off Jamaica in the Caribbean (Webber and Roff 1999).

During this study, significant differences were observed between the stations with higher abundances within cold-core eddies. At most of these stations, enhanced chl *a* was reported (Gomes et al. 2000; Prasannakumar et al. 2004, 2007). In the perennially strongly stratified upper layers of the Bay, mesoscale processes like cyclonic eddies, play a significant role in the re-supply of nutrients to the photic zone, which enhances primary production inside them (Falkowski et al. 1991). Influence of ocean eddies on the spatial-temporal structure and functioning of plankton communities has been the subject of studies carried out in the Gulf Stream, the East Australian Current and the California

Table 6.8. Correlation coefficients of copepod abundance, species diversity (*H'*), richness (*d*) and evenness (*J'*) with various parameters (total zooplankton biomass, abundance, temperature, salinity, chlorophyll *a* and copepod abundance) in the central Bay during different sampling seasons

| | *Biomass* | *Abundance* | *Temp* | *Sal* | *Chl a* | *Cop_abun* |
|---|---|---|---|---|---|---|
| SUM | | | | | | |
| Cop_abun | 0.674 | 0.675 | **-0.827** | 0.802 | 0.131 | 1.000 |
| *H'* | -0.444 | -0.658 | -0.211 | 0.549 | -0.186 | 0.105 |
| *d* | 0.034 | -0.338 | -0.647 | 0.634 | 0.195 | 0.448 |
| *J'* | **-0.977** | **-0.891** | 0.657 | -0.069 | -0.582 | -0.647 |
| FIM | | | | | | |
| Cop_abun | **0.920** | **0.969** | 0.275 | 0.788 | **0.801** | 1.000 |
| *H'* | -0.684 | -0.570 | -0.653 | -0.440 | **-0.837** | -0.365 |
| *d* | -0.075 | 0.102 | 0.292 | 0.500 | -0.060 | 0.201 |
| *J'* | -0.618 | -0.747 | -0.435 | **-0.920** | -0.567 | -0.787 |
| WM | | | | | | |
| Cop_abun | **0.984** | 1.000 | -0.294 | -0.479 | 0.583 | 1.000 |
| *H'* | -0.764 | -0.779 | 0.061 | 0.783 | 0.025 | -0.777 |
| *d* | -0.535 | -0.552 | -0.052 | 0.856 | 0.288 | -0.550 |
| *J'* | **-0.934** | **-0.959** | 0.229 | 0.391 | -0.636 | -0.959 |
| SpIM | | | | | | |
| Cop_abun | 0.599 | -0.238 | **0.889** | 0.052 | 0.656 | 1.000 |
| *H'* | -0.392 | -0.813 | 0.066 | 0.750 | -0.338 | -0.008 |
| *d* | -0.687 | -0.692 | -0.344 | 0.657 | -0.645 | -0.427 |
| *J'* | -0.123 | -0.789 | 0.377 | 0.671 | -0.105 | 0.287 |

r values marked in **bold** are significant at $p<0.05$; SUM-summer monsoon; FIM-fall intermonsoon; WM- winter monsoon and, SpIM- spring intermonsoon; Temp-temperature, Sal-salinity; Chl *a*- chlorophyll *a*; Cope_abun-copepod abundance. All zooplankton related parameters are from mixed layer depth, while the physico-chemical parameters and chl *a* are averages from the upper 120 m

Current System (Wiebe et al. 1976; Ortner et al. 1979; Kosnirev and Shapiro 1981; The Ring Group 1981; Bradford et al. 1982; Tranter et al. 1983; Haury 1984; Piontkovski et al. 1985).

As mentioned in Chapter 4 and 5, copepods are known to migrate near surface to feed during night and stay subsurface during daytime. Unlike in other oceanic regions, copepod diel vertical migration (DVM) was not significant in this study. Oxygen minimum zone (OMZ) restricts vertical migration of most copepods (Saltzman and Wishner 1997), except *Pleuromamma indica* in the eastern Arabian Sea. Low oxygen waters, common in low latitudes, below the near-surface layer with higher biological productivity, extending to over 600 m in the Bay could have prevented significant DVM.

Highest copepod abundance was always in the MLD and similar to other studies (Wishner and Allison 1986), their numbers decreased with depth. However the relative contribution of copepods increased with depth (Chapter 4) as also reported from the Arabian Sea (Madhupratap and Haridas 1990). In the Gulf Stream too, the abundance ranging from 3200 to 7500 ind.100 $m^{-3}$ in the upper 75 m, fell to <300 ind. 100 $m^{-3}$ below 200 m (Wishner and Allison 1986). Copepod eggs and nauplii (Chapter 4) were found at all depths, indicating that spawning and hatching occurred throughout the water column (Fernandez de Puelles et al. 1996).

### 6.3.2. Influence of hydrography on copepod distribution, abundance and type

Tropical oceanic waters are generally regarded as relatively stable environments, typified by small seasonal changes in physical and chemical parameters (Longhurst and Pauly 1987). Calef and Grice (1967) identified seasonal changes in zooplankton abundance off Barbados. Moore and Sander (1977) conducted a similar investigation of zooplankton and environmental conditions in the tropical western Atlantic, near Barbados, noting a lack of seasonal pattern. Within such an steady-state environment, planktonic communities may be expected to demonstrate minimal seasonal variation, with standing stocks of organisms changing by only a factor of two or three over an annual cycle (Blackburn 1981). Highly significant seasonal variation in copepod abundance was observed during this study. The CB was abundant with copepods during FIM (av: 23643 individuals 100 $m^{-3}$), SpIM (22246) and WM (21150) compared to SUM (8773). As mentioned in Chapters 4 and 5, SUM season favored the development of large *Pyrosoma* swarms causing the overall reduction of other plankton including copepods.

In tropical oceans, where the "seasons" are difficult to predict and usually less pronounced compared to temperate waters, annual fluctuations are generally related to the rather variable pattern of annual rainfall (Chisholm and Roff 1990). In estuaries on the west coast of India, copepods that dominate the mesozooplankton groups (Madhupratap 1979), showed strong seasonality in accordance with the changes in salinity (Pillai et al. 1973; Madhupratap 1987). Madhu et al. (2007) also found that the zooplankton was less abundant during the SUM and FIM months owing to the reduction in salinity following rains and runoff. Similar results during this study showing positive correlation of copepod abundance and salinity during the SUM and FIM months of lower surface salinity indicate that the assemblages are mostly marine.

From the generally positive correlation with chlorophyll *a* in the euphotic zone, it is evident that consistent relationships exist between copepods and other physical and biological variables *e.g.* maximum copepod biomass is generally at the depth of the chl *a* maximum, or at the depth of maximum primary production (Hobson and Lorenzen 1972; Ortner et al. 1980; Herman 1983, 1989; Roman et al. 1986) as also pointed out by many authors.

### 6.3.3. Prominent orders, families, genera and species in the CB

Five orders of Copepoda *viz.* the Calanoida, Cyclopoida, Harpacticoida, Mormonilloida and Poecilostomatoida identified during this study in the CB have all been previously reported from the Arabian Sea (Madhupratap and Haridas 1990; Bottger-Schnack 1995). In spite of the seasonal differences in the distribution patterns of these orders in the upper 1000 m, Calanoida was always dominant, as has also been reported from all the oceans (Pacific: Farran 1936; Atlantic: Deevey and Brooks 1977; Indian Ocean: Madhupratap and Haridas 1990). Further, all the calanoid (Madhupratap et al. 1990; Padmavati et al 1998; Madhupratap et al 2001) as well as non-calanoid (Bottger-Schnack 1995) families of copepods observed in this study have been reported previously from the Arabian Sea. Characteristic pattern in most seasons was subsurface maxima in calanoid abundance at 200-500 m. This was mainly due to abundance of omnivorous families such as

*Mormonillidae, Lucicutiidae, Metridinidae, Eucalanidae* and *Spinocalanidae.* Apparently the members of these families are not restricted by low oxygen in the OMZ.

Although a large number of families prevail in the Bay, only a few are numerically dominant (≥5%), with the maximum number of them accounting <1% of total copepods. Clear vertical partitioning of families was evidenced from this study. As reported earlier, dominant herbivorous calanoid assemblages of Paracalanidae (Stephen and Kunjamma 1987; Padmavati et al. 1998), Clausocalanidae (Kouwenberg 1994; Cornils et al. 2007) and Eucalanidae (Saltzman and Wishner 1997) were generally dominant in the top 200 m. While the relative abundance of the former two families decreased with increasing depth, that of Eucalanidae increased with depth during SpIM in particular. As recorded during this study, species of *Eucalanus* have been commonly reported to occupy the upper and lower OMZ interface in the eastern tropical Pacific (Fernandez-Alamo and Faber-Lorda 2006).

Cyclopoida comprising exclusively the members of Oithonidae was most abundant in the thermocline - 300 m stratum, although scarce in other strata. This observation is in agreement with the studies of Nishida and Marumo (1982) and Padmavati et al. (1998). According to Kellermann (1987), adults of *Oithona* spp. prefer to stay in deeper waters, supposedly to avoid ''visual hunters'' such as predatory fish larvae.

The warm water families Corycaeidae, Oncaeidae and Sapphirinidae (Raymont 1983) in the order Poecilostomatoida, the second-most dominant were also abundant in the MLD and decreased in particular in the OMZ. Similar to observations of Bottger-Schnack (1995), members of Oncaeidae were more again in deeper depths. Mormonilloida, comprising a sole mesopelagic family Mormonillidae (Boxshall 1986) was abundant at all depths below MLD. Similar to observations of Weikert (1982), *Macrosetella gracilis* the dominant harpacticoid was most abundant in the MLD during SUM, although was present throughout the 1000 m.

As also observed by Deevey (1964) and, Deevey and Brooks (1977) smaller species were more numerous at the surface and larger copepods occurred mainly in the deeper waters. Species in the genera such as *Acartia, Paracalanus*, *Clausocalanus* were mostly surface living. *Acartia*, a major constituent of the holozooplankton communities in many semi-enclosed marine areas (Abraham 1969; Lakkis 1994), showed high degree of seasonality in the MLD. For instance, during WM and SpIM when vertical salinity gradients were lesser, only the oceanic species *i.e. Acartia negligens* was observed. Deeper-living calanoid copepods such as *Conaea gracilis*, *Megacalanus princeps* (bathypelagic), *Eucalanus elongatus*, and those belonging to the families Aetideidae (*Chiridiella, Pseudochirella, Gaetanus, Undeuchaeta*), Scolecitrichidae (*Scottocalanus*), Metridinidae (*Metridia princeps*), Lucicutiidae (*Lucicutia ovalis*) Augaptilidae (*Augaptilus*, *Euaugaptilus* spp.), Arietellidae (*Arietellus*) and *Aegisthus* were generally found in mesopelagic depths and rarely in MLD (Madhupratap and Haridas 1986; Padmavati et al. 1998; Stephen and Rao 1980). *Lucicutia maxima* that has been described as a possible seasonal migrant, inhabiting the OMZ (Vinogradov and Voronina 1962), was abundant at these mesopelagic depths during FIM. The bathypelagic species *Gaussia princeps* was observed only within the upper 300 m during all seasons except FIM. Gueredrat (1969) explains that this warm water species, recorded in the equatorial Pacific has a wider vertical migration in the region of weak upwelling. Never being reported from the upwelling areas of the Arabian Sea, several specimens were recorded from the Bay of Bengal during the SUM coinciding with the surfacing of intermediate waters within 200 m (Saraswathy 1973) thus bringing up the rare deep-water inhabitants. From this occurrence it is suggested that this is the first report of *G. princeps* from the deep waters of the Bay of Bengal.

Deevey and Brooks (1977) found 326 species of copepods in the upper 2000 m of the water column in the Sargasso Sea. Padmavati et al (1998) reported 98 species of calanoids in the Arabian Sea. With 55 species found in the upper 200 m, copepod diversity was reported to be low in the Alboran Mediterranean Sea (Youssara and Gaudy 2001).

As many as 251 species were recorded during the present investigation. The assemblages contained the least number of species during SpIM (96), moderate numbers during SUM (162) and the highest numbers during FIM (170) and WM (172). Various theories about the co-existence of so many copepod species have been advanced. McGowan and Walker (1979) indicated that many similar species coexist, and that, selective predation or density-independent predation as the reason for such coexistence. Most species identified during this study in the CB are tropical-subtropical recorded earlier from Atlantic, Pacific and Indian Oceans (Table 7.9, Chapter 7; Bradford-Grieve 1994; Owre and Foyo 1967; Tanaka 1956; Bradford and Jillett 1980; Razouls et al. 2005-http://copepodes.obs-banyuls.fr/en). Some cosmopolitan species such as *Clausocalanus arcuicornis*, *Pontellina plumata* and *Eucalanus elongatus* (Fleminger and Hulsemann 1973) with circumglobal distribution were also found.

Most of the available data on copepod distribution in the Bay during IIOE (Kasturirangan et al. 1973, Fleminger and Hulsemann 1973, Stephen et al. 1992, Gopalakrishnan and Balachandran 1992) are mostly pertaining to large calanoid copepods. The IIOE samples were also typically limited to the 0-200 m strata and therefore, under-represent forms, which have deeper distributions. Unfortunately, the details of distribution and abundance are only for a few species; notably for *Gaussia princeps* (Saraswathy 1973 a, b), *Euchaeta* spp. (Tanaka 1973) and, *Haloptilus acutifrons* (Stephen and Saraladevi 1973). Further, lack of identification and enumeration of the entire copepod assemblage from samples collected within a defined region and season during the IIOE plankton does not give any idea about the dominant copepod species and their diversity regionally or seasonally.

### 6.3.4. First Reports from this study and significance

From this extensive analysis, as many as 15 species identified from the CB are recorded for the first time from the Indian Ocean. While species such as *Chirudiella* sp., *Euchirella speciosa, Euaugaptilus mixtus, Pseudhaloptilus abbreviatus, Drepanopsis orbus, Metridia pacifica, Amallophora conifer, A. oculata* and *Tharybis* sp. were exclusively present in the CB, *Euchirella rostromagna, Heterorhabdus pacificus, Xanthocalanus pectinatus, Scottocalanus rotundatus, Monacilla gracilis,* and *Undinella spinifer* were present in the WB as well (Table 7.9; Chapter 7).

The following species were recorded previously from open waters of the Bay: *Pleuromamma indica*, *Acartia negligens*, *Scolecithrix danae*, *Scolecithrichopsis ctenopus*, *Rhincalanus cornutus, Euchirella* sp. (Nair et al. 1981), *Haloptilus acutifrons* (Stephen and Saraladevi 1973), *Gaussia princeps* (Saraswathy 1973), *Acartia erythraea, Lucicutia flavicornis, Euchaeta indica, Centropages calaninus, C. gracilis, Pontellina plumata, Undinula vulgaris, Cosmocalanus darwinii, Labidocera acuta, L. pavo,* *Pareucalanus attenuatus, Eucalanus pseudattenuatus, Calanopia elliptica, C. minor, Acrocalanus gibber, Temora discaudata, T. turbinata, Nannocalanus minor, Canthocalanus pauper, Sapphirina nigromaculata, Corycaeus speciosus, C. catus, C. danae, Farrannula gibbula, Miracia efferata, Oncaea venusta, Macrosetella gracilis* (Rakhesh et al. 2006), *Paracandacia truncata, P. simplex, Candacia catula, C. bispinosa, C. discaudata* (Lawson 1977) and *Ratania flava* (Saraswathy 1982).

Other than these 41 species, all the rest identified in this study have been reported for the first time from the central Bay of Bengal. It is a point of significance to note that the unfolding of copepod assemblages only means that there is so much yet to be learnt from the BoB for its zooplankton diversity. Stereozoom- and light microscopy photographs for some of the species identified from the Bay are in Plates 5-8.

The copepod assemblages reported in the Bay are very similar to those reported from the Arabian Sea. As Rao and Madhupratap (1986) suggest, the North Indian Ocean is biogeographically a single unit. From this total of 251 species recorded in this study, only a fraction *i.e.* 69 species were present at all stations during all seasons. This means that more than two thirds of the species occurred seasonally. An intriguing question concerning the ephemeral species is where did they go in certain seasons and, how did they get back? Apart from the deficiencies of sampling (no duplicate hauls), entry into diapause is a common trait of many species of marine copepods (Grice and Marcus 1981). Some copepods are found to produce diapause eggs that will not hatch until the end of a refractory period (Marcus 1989; Chen and Marcus 1997). Having diapause as part of a life history is clearly advantageous under a number of circumstances, especially when environmental conditions are periodically adverse for an organism (De Stasio 2004).

A few calanoids especially *Calanus* (*e.g. Pseudocalanus* in particular) are typically abundant in colder high latitudes. *Calanus finmarchicus* is a dominant, large copepod in temperate and boreal waters in the North Atlantic (Williams 1988). Similarly, *Calanus cristatus* inhabits the North Pacific (Johnson and Brinton 1963). In this study, the predominance of *O. venusta* during all seasons suggests its continuous breeding throughout the year in the CB as Hopkins (1977) proposed. Deevey (1971) too observed the predominance of *Oncaea* in the Sargasso Sea. In addition to this species, herbivorous

*Clausocalanus arcuicornis* was also predominant during SpIM. Similarly, its other relative, *C. furcatus*, one of the dominant species in most seasons in CB, is known to benefit in low phytoplankton conditions (Mazzocchi and Paffenhofer 1998). They are reported to be widespread (Frost and Fleminger 1968) with maximum occurrence in subtropical and tropical waters (Deevey 1971; Schulz 1986; Webber and Roff 1995). They are also represented to be an important numerical component of the copepod communities throughout the year in the Gulf of Naples, dominating when the autotrophic biomass was particularly scarce (Peralba and Mazzochi 2004).

The dominant species accounting to ≥2% of the total copepods also displayed a wide range of vertical distribution patterns, such as shallow, intermediate and deep-water distribution. The mesopelagic species, *Eucalanus elongatus*, varying seasonally, was deeper from summer to autumn and shallower in winter and spring in the Sargasso Sea (Deevey and Brooks 1977). The Bay being a warm tropical region, this species was always in the deeper depths irrespective of seasons. The dominant species, *Oncaea venusta, O. mediterranea, Clausocalanus arcuicornis, C. furcatus, Mormonilla minor, Paracalanus aculeatus, P. indicus, Oithona similis, Macrosetella gracilis, Corycaeus catus, C. danae, C. speciosus, Acrocalanus gracilis, Eucalanus monachus, Calocalanus pavo, Conaea gracilis* and *Pleuromamma indica* in various seasons were a mix of oceanic as well as coastal forms reflecting the euryhaline nature of these organisms. *Paracalanus* spp. can sustain themselves even when their food type and concentrations are low as in the offshore waters (Paffenhofer and Stearns 1988).

Affirming their cosmopolitan nature (Bigelow 1926; Rose 1929, 1933; Wilson 1942; Sewell 1947), *Oithona similis* and *Oncaea venusta* with mostly higher abundance in top 200 m were also present at all sampled depths and stations during all the seasons. *Lucicutia flavicornis* and *Pleuromamma indica* as seen in this study, are known to occur throughout the 1000 m water column (Saltzman and Wishner 1997). As they also propose, *P. indica*, *Eucalanus elongatus* and *M. minor* being able to survive low-oxygen conditions, were observed to have higher abundances at subsurface depths. *Conaea gracilis* with a truly deeper distribution as reported by Raymont (1983) was found in increased abundances in the deeper waters of the CB.

### 6.3.5. Diversity

Estimating diversity in the pelagic realm is particularly relevant when examining relationships between hydrography and the pelagic biota. Diversity varied not only with depth but also seasonally. Akin to earlier observations (Deevey and Brooks 1977), copepod diversity in the CB was higher in the warmer surface waters and also in deeper waters. This trend could not be ascertained during SpIM where there was little or no biomass below 300 m. Longhurst (1985) in an observation from the eastern tropical Pacific Ocean suggested that a stable vertical structure of the water column might be one of the more important causes of variation in regional plankton diversity in the euphotic zone.

Padmavati et al. (1998) attributed the high diversity in the deepest layer to the stable environment there. From this study, it is possible to suggest that the high diversity in the deeper strata is ascribable to marked chemical and physical gradients, providing a stable structured environment (Angel 1993).

The species richness was higher in the surface and the deepest stratum during SUM, in the thermocline during FIM, in the 300-500 m stratum during WM, and in the surface during SpIM. Peak occurrence of species at various depths has been documented in earlier studies (Roe 1972, 1984; Deevey and Brooks 1977; Scotto di Carlo et al. 1984; Richter 1994; Kosobokova and Hirche 2000). Hayward and McGowan (1979) observed the species do not seem to be specialists and niche separation is much more subtle than expected. Species richness was higher in all seasons except the SpIM. In the overall, *H'* and *d* did not show much latitudinal variation. Evenness, a major component of diversity (Ortner et al. 1982), generally increased with depth registering its highest during SpIM (0.97).

Both *H'* and *J'* are reported to plateau out at 200–300 m depth layers (Shimode et al. 2006). Species richness (<2.4) and evenness (<0.5) reported from the subtropical Inland Sea of Japan (Madhupratap and Onbe 1986) are lower than those observed during this study. The numbers of copepod species found from the Kuroshio range from 8 to 94 (He and Yang 1990). Also, *H'* values varying from 1.39 to 3.13 reported from the Southeast China Sea (Shih and Chiu 1998) are lower than the values observed during this study. Changes in water temperature; salinity and spring phytoplankton bloom (Davis 1987;

Siokou-Frangou 1996) are considered to be the primary factors that induce internal changes in community structure and biodiversity.

### 6.3.6. Conclusion

The mesozooplankton community in the Bay of Bengal is copepod dominated. Though the Bay is a tropical basin, high seasonal variability in copepod abundance was observed with the highest abundance during the intermonsoons and the least during SUM, generally concurrent with primary production rates (lowest during SUM). Indeed, the overall abundance (and production) of copepod community appears to be food limited. However, the coexistence of as many as 69 species throughout the year is suggestive that the degree of limitation is different both within and between species (Webber and Roff 1995). Well adapted to the low primary production situation, opportunistic feeders such as *Clausocalanus* species can be extremely successful in the oligotrophic open waters of the BoB. Although small copepods such as *Oithona* spp. are among the main dietary sources for many commercially important fish, their role in the pelagic trophic dynamics has traditionally been underestimated due to larger mesh sizes of the nets used for mesozooplankton sampling (Porri et al. 2007; Gallienne and Robin 2001; Hopcroft et al. 2005). *Oithona similis*, despite being a smaller sized (500-700 μm) species, its considerable dominance in the Bay is an intriguing phenomenon. Fine tuned studies are advocated for resolving such issues of zooplankton ecology in the BoB.

In this region, species coexistence seems to be particularly important for copepods, which seem to have successfully populated the sampled water column and dominate (numerically) the zooplankton communities under a very large variety of ecological conditions of the BoB. Large variations in salinity (22-35 psu), warm pool during most part of the year and lower chl *a* (0.01-0.44 mg $m^{-3}$) notwithstanding, the high diversity and numerical abundance of copepods are first reports from this sparingly studied tropical basin. In particular, small sized *Oncaea venusta*, an carnivorous-omnivorous poecilostomatoid seems to be well adapted to the low-moderate chlorophyll *a* regime in the central Bay.

# Chapter 7

# Chapter 7

## *Copepoda in Western Bay of Bengal*

Planktonic copepods are the main consumers of diatoms, in general linking microscopic algal cells to juvenile fish to whales in the marine food chain. Their distribution in coastal as well as oceanic regions has been extensively studied by several authors and, under several programmes such as ICES, JGOFS and GLOBEC in all the three oceans. Many details of these are provided in Chapter 6.

The Indian Ocean harbors the greatest copepod diversity (http://copepodes.obs-banyuls.fr/en). Yet, after the IIOE (International Indian Ocean Expedition), the Bay of Bengal has remained relatively unexplored. To meet up one of the objectives of understanding the abundance and distribution of copepods in the coastal regions, sampling was carried out in the western margin of the Bay of Bengal. It was also aimed to understand the seasonal variability in abundance of copepod species at various depths in the upper 1000 m along the western Bay.

## 7.1. Materials and Methods

As described in Chapter 5, zooplankton samples were collected from five strata from four stations in the western Bay of Bengal (WB) using a multiple plankton closing net. All other details of collection, identification, statistical analyses and calculation of diversity indices are as described in Chapter 6.

## 7.2. Results

### 7.2.1. Abundance

In the WB, the copepod abundance (individuals 100 $m^{-3}$; Fig. 7.1) varied from 0.8 to 213540 (average: 16161 ind. 100 $m^{-3}$), 764 to 114067 (26761 ind. 100 $m^{-3}$), 394 to 147965 (33047 ind. 100 $m^{-3}$) and 186 to 417920 (36778 ind. 100 $m^{-3}$) during SUM (summer monsoon), FIM (fall inter monsoon), WM (winter monsoon) and SpIM (spring inter monsoon) respectively. While the abundance was significantly higher at WB3 during SUM, the station-wise difference was insignificant during the rest of the seasons

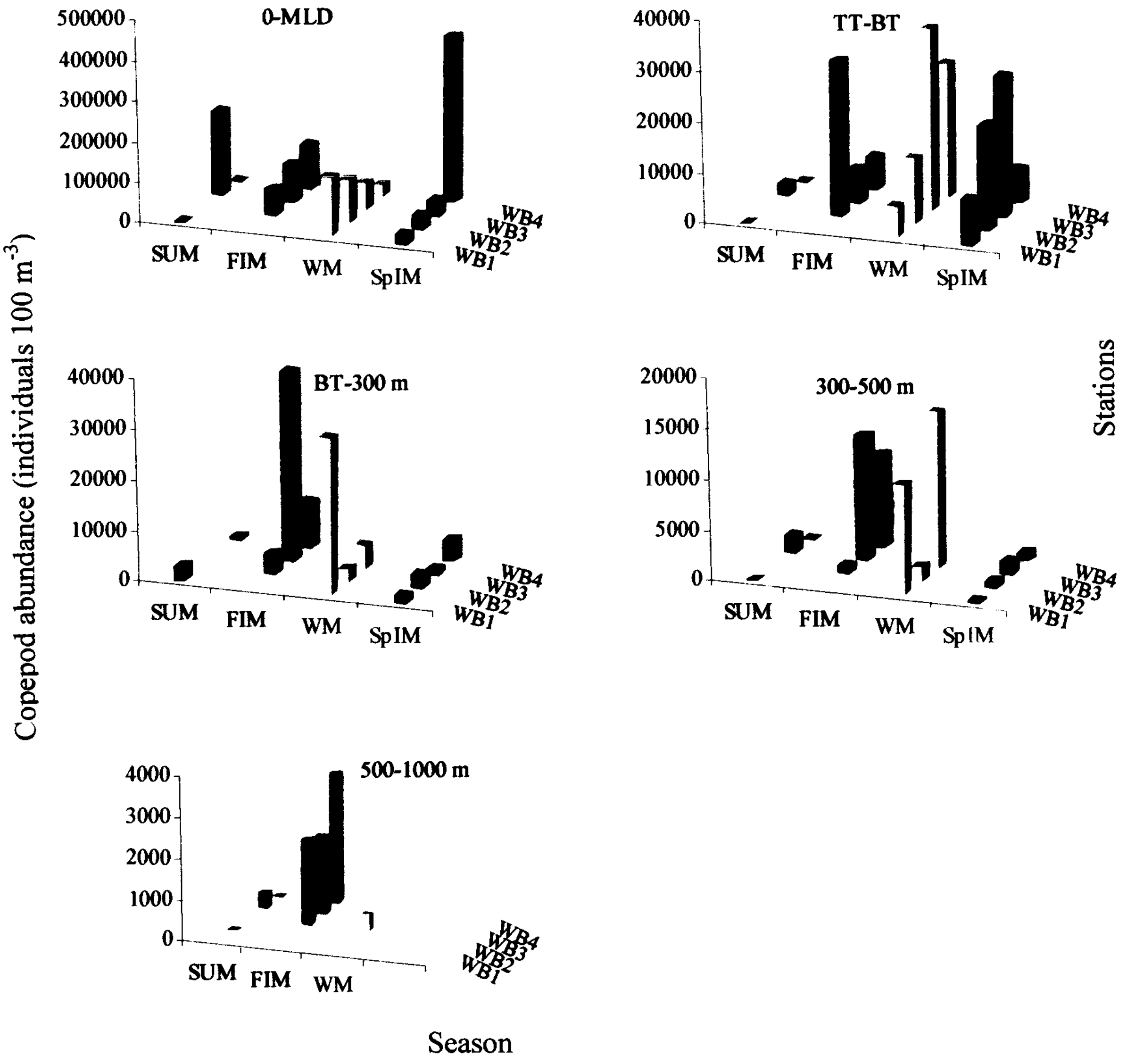


Figure 7.1. Spatio-temporal variation in copepod abundance at different depths in the western Bay of Bengal. SUM: Summer monsoon, FIM: fall intermonsoon, WM: winter monsoon and SpIM: spring intermonsoon. Scales are different for each graph

(Table 7.1). It decreased significantly with increasing depth only during the intermonsoons.

Compared to that in the CB, the abundance was higher during all seasons in the WB, but was significantly higher only during SUM. With the average abundance increasing from SUM to SpIM, the seasonal variation was also statistically significant. The diel variation was significant only during SpIM (Table 7.1). Cluster analysis revealed that spatial distribution of copepod abundance during SpIM, FIM and WM, differed from that during SUM (Fig. 7.2).

### 7.2.2. Orders

Six orders *viz.* Calanoida, Cyclopoida, Harpacticoida, Mormonilloida, Poecilostomatoida and Siphonostomatoida were identified from the WB (Fig. 7.3; Tables 7.2-7.6). For the ease of comparison, seasonal variations in the abundance of individuals from different families under these orders are described below.

*Calanoida:* During SUM, Calanoida ranging from 34 to 88% showed two subsurface peaks, one at 200-300 m and the other in the deepest stratum. During FIM (range: 42-67%) and SpIM (43-71%), it decreased relatively in the 200-300 m stratum before increasing again in the strata below. Calanoid abundance accounting for 34-56.4% of the total copepods, decreased from the surface to 1000 m during WM.

As in the CB, this order comprised as many as 24 families in the WB. The individual species belonging to the family Paracalanidae (17.7%) and Metridinidae (14.5%) during SUM, Paracalanidae (14.9%) during FIM, Paracalanidae (10.4%) and Clausocalanidae (9.1%) during WM and, Eucalanidae (19.1%) and Metridinidae (9.8%) during SpIM were highly preponderant.

*Cyclopoida:* Comprising a single family, Oithonidae, Cyclopoida (2.1-32%) was abundant in the thermocline and the 300-500 m stratum during SUM (Fig. 7.3). It was most abundant in the TT-300 m during FIM (1.4-15.6%), and SpIM (4-15%). During WM, accounting for 2.4-12.6% of the total copepods, cyclopoids were mostly in the upper 500 m.

Table 7.1. Diel, spatial and temporal difference in copepod abundance in the western Bay of Bengal during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM) as deciphered through non-parametric tests

| Wilcoxon Matched Pairs Test between day and night | | | | |
|---|---|---|---|---|
| Seasons | N | T | Z | $p$ |
| SUM | 20 | 27 | 1.60 | $p > 0.05$ |
| FIM | 15 | 49 | 0.62 | $p > 0.05$ |
| WM | 20 | 47 | 0.74 | $p > 0.05$ |
| SpIM | 12 | 11 | 2.20 | **$p < 0.05$** |

| Friedman ANOVA | | | | |
|---|---|---|---|---|
| Seasons | Chi Sqr. | N | df | $p$ |
| | Between stations | | | |
| SUM | 6.5 | 4 | 2 | **$p < 0.05$** |
| FIM | 1.2 | 5 | 2 | $p > 0.05$ |
| WM | 0.6 | 2 | 3 | $p > 0.05$ |
| SpIM | 3.6 | 4 | 3 | $p > 0.05$ |
| | Between depths | | | |
| SUM | 7.2 | 2 | 4 | $p > 0.05$ |
| FIM | 9.33 | 3 | 4 | **$p = 0.05$** |
| WM | 5.8 | 3 | 3 | $p > 0.05$ |
| SpIM | 11.1 | 4 | 3 | **$p < 0.05$** |
| | Between Seasons | | | |
| | 20.14 | 14 | 3 | **$p < 0.05$** |
| | Between transects | | | |
| SUM | 4.57 | 14 | 1 | **$p < 0.05$** |
| FIM | 0 .60 | 15 | 1 | $p > 0.05$ |
| WM | 0 .06 | 15 | 1 | $p > 0.05$ |
| SpIM | 2.25 | 16 | 1 | $p > 0.05$ |

Significant results are marked **bold**

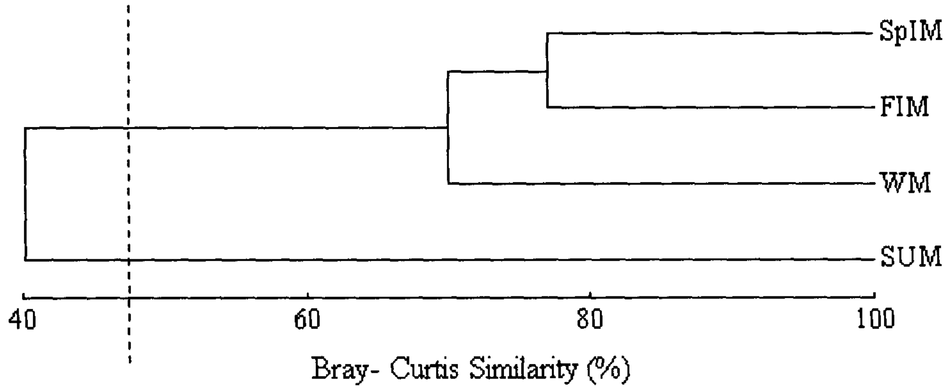


Figure 7.2. Cluster dendrogram based on Bray- Curtis similarity coefficients, depicting similarity in copepod abundance between seasons in the western Bay.

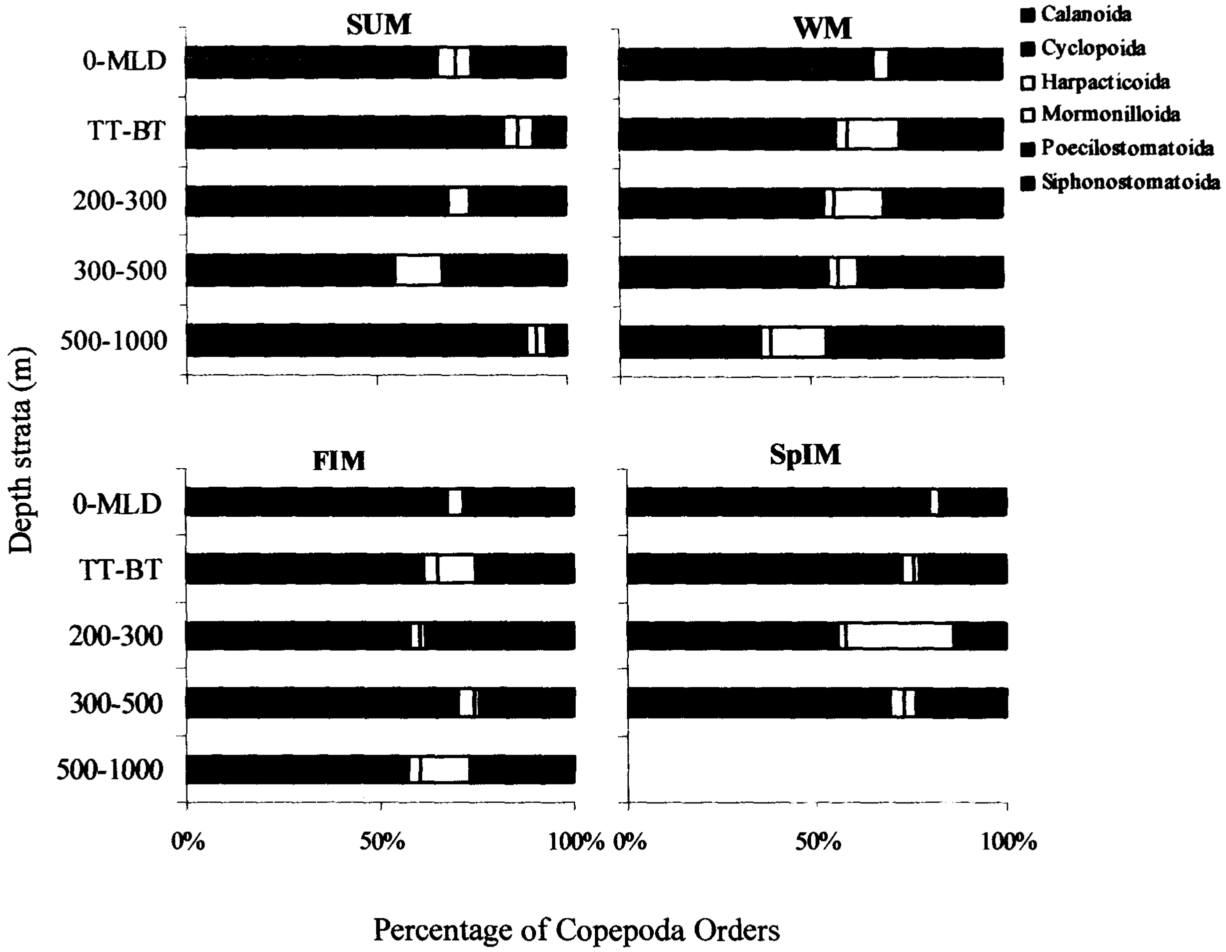


Figure 7.3. Vertical distribution of Copepoda orders at different depths during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM) in the western Bay of Bengal

*Harpacticoida:* Present throughout the sampled column, harpacticoids registered a range of 3.1-13.3% and were the most abundant during SUM. In the other three seasons, they accounted for <4% of total copepods at all sampled depths.

*Mormonilloida:* This order consisting of a single family Mormonillidae, was observed in the upper two layers during SUM (2.6-4.2%). In other three seasons, it was prominently observed below the MLD (FIM: 0.5-10.8%; WM: 0.5-14.6%; SpIM: 0.7-28.2%).

*Poecilostomatoida:* Contributing widely to 5-22% of the total copepods, members of this order occurred at all depths. They were the most dominant in the surface and the strata between 200-500 m during SUM. Their contribution to total copepods ranged from 22.7 to 38.3% during FIM with the highest percentage in the 200-300 m stratum. Varying from 25.4 to 46.2%, poecilostomatoids relatively increased with depth during WM. During SpIM, they accounted for 13.9-23.6% of the total copepods. They were more in upper two and the lowermost strata sampled. Five families were identified under this order, with Oncaeidae as the most dominant one during all easons.

*Siphonostomatoida:* This order was observed with just one family, Rataniidae in the thermocline region during WM only.

Overall, Calanoida was almost always the most dominant order (53%), followed by Poecilostomatoida (24.3%), Cyclopoida (9.6%), Mormonilloida (6.0%) and Harpacticoida (3.7%). Siphonostomatoida (0.01%) was rare among the 6 orders identified.

### 7.2.3. Families

From a total of 38 families (Tables 7.2-7.6) that occurred during the study period, the numerical abundance of individuals of only eight families (Clausocalanidae, Eucalanidae, Metridinidae, Paracalanidae, Oithonidae, Mormonillidae, Corycaeidae and Oncaeidae) was greater than five. Twelve families (Acartiidae, Calanidae, Candaciidae, Centropagidae, Euchaetidae, Lucicutiidae, Scolecithrichidae, Spinocalanidae, Clytemnestridae, Euterpinidae, Miraciidae and Sapphirinidae) were minor, comprising 1-5% of total individuals. The remaining 18 families (Aetideidae, Arietellidae, Augaptilidae Fosshageniidae Heterorhabdidae Mecynoceridae, Megacalanidae, Nullosetigeridae, Phaennidae, Pontellidae, Rhincalanidae, Temoridae, Tharybidae,

Table 7.2. Seasonal variations in abundance (individuals 100 m$^{-3}$) and percentage (%) of different copepod species in the mixed layer depth in western Bay of Bengal

| | SUM | | FIM | | WM | | SpIM | |
|---|---|---|---|---|---|---|---|---|
| Species | Abundance | % | Abundance | % | Abundance | % | Abundance | % |
| **CALANOIDA** | | | | | | | | |
| **Acartiidae** | | | | | | | | |
| *Acartia amboinensis* | A | - | 316.20 | 0.34 | A | - | A | - |
| *A. negligens* | 401.71 | 0.55 | 752.21 | 0.82 | 92.51 | 0.11 | 2295.23 | 1.80 |
| *A. spinicauda* | A | - | 7919.12 | 8.64 | A | - | A | - |
| **Aetideidae** | | | | | | | | |
| *Aetideus armatus* | A | - | A | - | 1.67 | 0.00 | A | - |
| *Chirundina streetsi* | A | - | A | - | 1.67 | 0.00 | A | - |
| *Euchirella amoena* | A | - | A | - | A | - | 99.14 | 0.08 |
| *E. bitumida* | A | - | A | - | 1.67 | 0.00 | 713.01 | 0.56 |
| *E. curticauda* | A | - | 104.33 | 0.11 | A | - | A | - |
| *E. galeata* | A | - | A | - | 1.67 | 0.00 | A | - |
| *E. indica* | 724.81 | 1.00 | A | - | A | - | A | - |
| *Euchirella* sp. | A | - | A | - | 1.00 | 0.00 | 2882.77 | 2.26 |
| **Arietellidae** | | | | | | | | |
| *Arietellus giesbrechtii* | A | - | 316.20 | 0.34 | A | - | A | - |
| **Augaptilidae** | | | | | | | | |
| *Haloptilus longicornis* | A | - | A | - | 57.84 | 0.07 | 29.06 | 0.02 |
| *H. ornatus* | A | - | 60.01 | 0.07 | A | - | A | - |
| *Pseudhaloptilus pacificus* | A | - | A | - | A | - | 1.67 | 0.00 |
| **Calanidae** | | | | | | | | |
| *Canthocalanus pauper* | 401.71 | 0.55 | 912.02 | 0.99 | 2476.36 | 2.86 | 988.08 | 0.77 |
| *Cosmocalanus darwinii* | A | - | A | - | 616.71 | 0.71 | 102.75 | 0.08 |
| *Mesocalanus tenuicornis* | A | - | 119.81 | 0.13 | A | - | A | - |
| *Undinula vulgaris* | 1528.22 | 2.11 | 1908.63 | 2.08 | 2636.31 | 3.04 | 994.07 | 0.78 |
| **Candaciidae** | | | | | | | | |
| *Candacia bradyi* | 724.81 | 1.00 | 692.42 | 0.76 | 754.53 | 0.87 | 166.88 | 0.13 |
| *C. discaudata* | A | - | A | - | 0.83 | 0.00 | 742.07 | 0.58 |
| *C. pachydactyla* | A | - | 873.07 | 0.95 | A | - | 3.34 | 0.00 |
| *Candacia* sp. | 401.71 | 0.55 | A | - | 75.73 | 0.09 | 800.07 | 0.63 |
| *Paracandacia truncata* | 401.71 | 0.55 | A | - | A | - | 49.80 | 0.04 |
| **Centropagidae** | | | | | | | | |
| *Centropages calaninus* | A | - | A | - | A | - | 1046.78 | 0.82 |
| *C. dorsispinatus* | A | - | A | - | A | - | A | - |
| *C. furcatus* | 724.81 | 1.00 | A | - | 1264.05 | 1.46 | 4544.16 | 3.55 |
| *C. gracilis* | A | - | A | - | 92.51 | 0.11 | A | - |
| **Clausocalanidae** | | | | | | | | |
| *Clausocalanus arcuicornis* | 724.81 | 1.00 | A | - | 6603.53 | 7.62 | 8826.99 | 6.91 |
| *C. furcatus* | A | - | 3213.97 | 3.50 | 2774.73 | 3.20 | 356.82 | 0.28 |
| *C. pergens* | A | - | A | - | A | - | 720.94 | 0.56 |
| *Clausocalanus* sp. | A | - | A | - | 149.46 | 0.17 | A | - |
| **Eucalanidae** | | | | | | | | |
| *Eucalanus crassus* | A | - | 436.53 | 0.48 | A | - | 2923.92 | 2.29 |
| *E. subcrassus* | A | - | A | - | A | - | A | - |
| *E. elongatus* | A | - | 164.34 | 0.18 | A | - | A | - |
| *E. monachus* | 5955.68 | 8.21 | 2533.82 | 2.76 | 3532.54 | 4.08 | A | 17.36 |
| *E. mucronatus* | A | - | A | - | 60.00 | 0.07 | 52.68 | 0.04 |
| *E. pseudattenuatus* | A | - | A | - | A | - | A | - |
| *Eucalanus* sp. | A | - | 1264.81 | 1.38 | A | - | 52.68 | 0.04 |
| *Pareucalanus attenuatus* | A | - | A | - | 1044.53 | 1.21 | 1522.37 | 1.19 |
| *Subeucalanus crassus* | A | - | A | - | A | - | A | - |
| **Euchaetidae** | | | | | | | | |
| *Euchaeta concinna* | 323.10 | 0.45 | 119.81 | 0.13 | A | - | A | - |
| *E. indica* | 401.71 | 0.55 | 316.20 | 0.34 | 233.33 | 0.27 | 713.01 | 0.56 |
| *E. marina* | 969.30 | 1.34 | 599.03 | 0.65 | 754.89 | 0.87 | 2437.72 | 1.91 |
| *Euchaeta* sp. | A | - | A | - | 113.53 | 0.13 | 29.06 | 0.02 |
| **Fosshageniidae** | | | | | | | | |
| *Temoropia mayumbaensis* | A | - | 857.07 | 0.93 | A | - | 932.57 | 0.73 |
| **Heterorhabdidae** | | | | | | | | |
| *Hemirhabdus grimaldi* | A | - | 104.33 | 0.11 | A | - | A | - |
| *Heterorhabdus abyssalis* | A | - | 104.33 | 0.11 | A | - | A | - |
| *H. pacificus* | A | - | 240.03 | 0.26 | A | - | A | - |
| *H. papilliger* | A | - | A | - | 21.02 | 0.02 | 720.94 | 0.56 |
| *H. spinifrons* | 401.71 | 0.55 | A | - | 756.20 | 0.87 | A | - |
| **Lucicutiidae** | | | | | | | | |
| *Lucicutia flavicornis* | 1528.22 | 2.11 | 3393.20 | 3.70 | 141.02 | 0.16 | 3239.33 | 2.53 |
| *L. magna* | A | - | 60.01 | 0.07 | A | - | A | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *L. maxima* | 401.71 | 0.55 | 224.35 | 0.24 | 120.00 | 0.14 | A | - |
| *L. ovalis* | A | - | 164.34 | 0.18 | A | - | A | - |
| **Mecynoceridae** | | | | | | | | |
| *Mecynocera clausii* | A | - | A | - | 484.61 | 0.56 | 108.19 | 0.08 |
| **Megacalanidae** | | | | | | | | |
| *Megacalanus princeps* | A | - | A | - | A | - | 720.94 | 0.56 |
| **Metridinidae** | | | | | | | | |
| *Metridia brevicauda* | A | - | 120.02 | 0.13 | 1.67 | 0.00 | 720.94 | 0.56 |
| *Pleuromamma gracilis* | A | - | 493.02 | 0.54 | 1846.22 | 2.13 | 1491.94 | 1.17 |
| *P. indica* | 2733.35 | 3.77 | 1635.01 | 1.78 | 210.35 | 0.24 | 8791.38 | 6.88 |
| *P. quadrangulata* | A | - | A | - | A | - | 29.06 | 0.02 |
| *P. robusta* | A | - | A | - | A | - | 6789.76 | 5.31 |
| *Pleuromamma* sp. | A | - | 316.20 | 0.34 | 92.51 | 0.11 | A | - |
| **Nullosetigeridae** | | | | | | | | |
| *Nullosetigera* sp. | A | - | A | - | A | - | 713.01 | 0.56 |
| **Paracalanidae** | | | | | | | | |
| *Acrocalanus gibber* | 724.81 | 1.00 | 316.20 | 0.34 | 405.52 | 0.47 | 155.43 | 0.12 |
| *A. gracilis* | 803.42 | 1.11 | 718.83 | 0.78 | 2088.00 | 2.41 | 3038.88 | 2.38 |
| *A. longicornis* | 646.20 | 0.89 | 600.87 | 0.66 | 4158.77 | 4.80 | 2228.70 | 1.74 |
| *A. monachus* | A | - | A | - | 57.84 | 0.07 | 383.83 | 0.30 |
| *Calocalanus pavo* | 724.81 | 1.00 | 239.61 | 0.26 | 1714.21 | 1.98 | 289.80 | 0.23 |
| *C. pavoninus* | A | - | 479.22 | 0.52 | A | - | A | - |
| *C. plumulosus* | A | - | A | - | 324.51 | 0.37 | 0.00 | 0.00 |
| *Paracalanus indicus* | 12383.01 | 17.07 | 2786.43 | 3.04 | 6969.85 | 8.04 | 1789.64 | 1.40 |
| *P. aculeatus* | 1371.01 | 1.89 | 2541.04 | 2.77 | 754.53 | 0.87 | A | - |
| *P. parvus* | 724.81 | 1.00 | 3887.16 | 4.24 | 393.20 | 0.45 | A | - |
| **Phaennidae** | | | | | | | | |
| *Amallophora crassirostris* | A | - | 104.33 | 0.11 | A | - | A | - |
| *A. irritans* | 803.42 | 1.11 | A | - | A | - | A | - |
| *Cephalophanes frigidus* | A | - | A | - | A | - | 50.07 | 0.04 |
| *Phaenna spinifera* | A | - | 1897.22 | 2.07 | A | - | A | - |
| *Xanthocalanus pectinatus* | 323.10 | 0.45 | 1264.81 | 1.38 | A | - | A | - |
| **Pontellidae** | | | | | | | | |
| *Calanopia elliptica* | A | - | A | - | 754.53 | 0.87 | 713.01 | 0.56 |
| *Labidocera acuta* | A | - | 180.02 | 0.20 | A | - | 1433.95 | 1.12 |
| *L. minuta* | A | - | 316.20 | 0.34 | 5.00 | 0.01 | A | - |
| *L. pectinata* | A | - | A | - | A | - | A | - |
| *L. pavo* | A | - | 436.53 | 0.48 | 754.53 | 0.87 | 75.52 | 0.06 |
| *Pontellina plumata* | A | - | 239.61 | 0.26 | 1128.46 | 1.30 | 294.14 | 0.23 |
| *Pontellopsis scotti* | A | - | 436.53 | 0.48 | A | - | A | - |
| **Rhincalanidae** | | | | | | | | |
| *Rhincalanus cornutus* | A | - | A | - | 230.00 | 0.27 | 713.01 | 0.56 |
| **Scolecitrichidae** | | | | | | | | |
| *Amallothrix gracilis* | A | - | 60.01 | 0.07 | 230.00 | 0.27 | 166.88 | 0.13 |
| *Lophothrix frontalis* | 401.71 | 0.55 | 164.34 | 0.18 | 1.67 | 0.00 | A | A |
| *Scaphocalanus magnus* | A | - | A | - | A | - | 713.01 | 0.56 |
| *S. major* | A | - | 60.01 | 0.07 | A | - | A | - |
| *Scaphocalanus* sp. | A | - | A | - | 60.00 | 0.07 | 713.01 | 0.56 |
| *S. dentata* | A | - | A | - | A | - | 713.01 | 0.56 |
| *Scolecithricella* sp. | A | - | 632.41 | 0.69 | A | - | 102.75 | 0.08 |
| *Scolecithrichopsis ctenopus* | A | - | A | - | A | - | 219.57 | 0.17 |
| *S. danae* | 724.81 | 1.00 | A | - | 21.02 | 0.02 | 887.82 | 0.69 |
| *S. nicobarica* | A | - | 239.61 | 0.26 | A | - | A | - |
| *Scolecithrix* sp. | A | - | A | - | A | - | 52.68 | 0.04 |
| *Scottocalanus helenae* | A | - | A | - | A | - | 29.06 | 0.02 |
| **Spinocalanidae** | | | | | | | | |
| *Monacilla gracilis* | A | - | 6324.07 | 6.90 | A | - | A | - |
| **Temoridae** | | | | | | | | |
| *Temora turbinata* | A | - | A | - | A | - | 208.11 | 0.16 |
| *T. discaudata* | A | - | 660.67 | 0.72 | 1278.73 | 1.48 | 829.13 | 0.65 |
| *T. stylifera* | A | - | A | - | 1048.73 | 1.21 | 958.24 | 0.75 |
| **Tharybidae** | | | | | | | | |
| *Undinella brevipes* | A | - | A | - | A | - | A | - |
| **CYCLOPOIDA** | | | | | | | | |
| **Oithonidae** | | | | | | | | |
| *Oithona brevicornis* | 401.71 | 0.55 | 119.81 | 0.13 | A | - | A | - |
| *O. plumifera* | A | - | 1634.59 | 1.78 | 2608.55 | 3.01 | 2244.56 | 1.76 |
| *O. similis* | 5632.58 | 7.76 | 1377.87 | 1.50 | 4713.22 | 5.44 | 5923.76 | 4.63 |
| *O. spinirostris* | 401.71 | 0.55 | 436.01 | 0.48 | A | - | A | - |
| *Oithona* sp. | A | - | 312.99 | 0.34 | A | - | A | - |
| **HARPACTICOIDA** | | | | | | | | |
| **Aegisthidae** | | | | | | | | |
| *Aegisthus mucronatus* | A | - | 632.41 | 0.69 | A | - | A | - |
| **Clytemnestridae** | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Clytemnestra scutellata* | A | - | A | - | 904.88 | 1.04 | A | - |
| **Ectinosomatidae** | | | | | | | | |
| *Microsetella rosea* | A | - | 119.81 | 0.13 | A | - | 50.07 | 0.04 |
| **Euterpinidae** | | | | | | | | |
| *Euterpina acutifrons* | 323.10 | 0.45 | 316.20 | 0.34 | 1509.07 | 1.74 | A | - |
| **Miraciidae** | | | | | | | | |
| *Macrosetella gracilis* | 1528.22 | 2.11 | 817.74 | 0.89 | 1215.97 | 1.40 | 99.14 | 0.08 |
| *Miracia efferata* | A | - | A | - | 95.76 | 0.11 | 168.44 | 0.13 |
| **MORMONILLOIDA** | | | | | | | | |
| **Mormonillidae** | | | | | | | | |
| *Mormonilla minor* | 2410.25 | 3.32 | 493.02 | 0.54 | 450.35 | 0.52 | 871.27 | 0.68 |
| *M. phasma* | 401.71 | 0.55 | A | - | A | - | A | - |
| **POECILOSTOMATOIDA** | | | | | | | | |
| **Corycaeidae** | | | | | | | | |
| *Corycaeus asiaticus* | A | - | 316.20 | 0.34 | A | - | A | - |
| *C. catus* | 803.42 | 1.11 | 2044.70 | 2.23 | 2589.21 | 2.99 | 2019.59 | 1.58 |
| *C. danae* | 724.81 | 1.00 | 3669.46 | 4.00 | 396.45 | 0.46 | 1551.61 | 1.21 |
| *C. longistylis* | A | - | 436.53 | 0.48 | A | - | A | - |
| *C. speciosus* | 1126.52 | 1.55 | 2947.15 | 3.21 | 582.04 | 0.67 | 2058.63 | 1.61 |
| *C. typicus* | A | - | A | - | 964.00 | 1.11 | A | - |
| *Corycaeus* sp. | A | - | A | - | 57.84 | 0.07 | 750.00 | 0.59 |
| **Lubbockidae** | | | | | | | | |
| *Lubbockia aculeata* | A | - | A | - | A | - | 166.88 | 0.13 |
| **Oncaeidae** | | | | | | | | |
| *Conaea gracilis* | A | - | A | - | 300.00 | 0.35 | A | - |
| *Oncaea mediterranea* | A | - | A | - | 1166.57 | 1.35 | 157.27 | 0.12 |
| *O. venusta* | 11265.16 | 15.53 | 12292.27 | 13.40 | A | 19.43 | 9579.13 | 7.49 |
| *Triconia conifera* | A | - | 765.00 | 0.83 | 57.84 | 0.07 | 713.01 | 0.56 |
| **Sapphirinidae** | | | | | | | | |
| *Copilia longistylis* | 803.42 | 1.11 | A | - | 74.73 | 0.09 | A | - |
| *C. mirabilis* | A | - | 119.81 | 0.13 | A | - | 153.53 | 0.12 |
| *C. quadrata* | A | - | 539.23 | 0.59 | 1231.86 | 1.42 | 1653.51 | 1.29 |
| *C. vitrea* | 401.71 | 0.55 | 119.81 | 0.13 | A | - | A | - |
| *Sapphirina auronitens* | 323.10 | 0.45 | A | - | 2.50 | 0.00 | A | - |
| *S. nigromaculata* | A | - | 239.61 | 0.26 | A | A | 166.88 | 0.13 |
| *S. ovatolanceolata* | 803.42 | 1.11 | A | - | 92.51 | 0.11 | A | - |
| *Sapphirina* sp. | A | - | A | - | 60.00 | 0.07 | 1555.93 | 1.22 |
| Unidentified | 6829.04 | 9.41 | 6848.29 | 7.47 | 1349.89 | 1.56 | 1463.01 | 1.14 |
| Total individuals 100 $m^{-3}$ | 72560 | | 91706 | | 86652 | | 127830 | |

Table 7.3. Seasonal variations in abundance (individuals 100 m$^{-3}$) and percentage (%) of different copepod species in the thermocline in western Bay of Bengal

| | SUM | | FIM | | WM | | SpIM | |
|---|---|---|---|---|---|---|---|---|
| Species | Abundance | % | Abundance | % | Abundance | % | Abundance | % |
| **CALANOIDA** | | | | | | | | |
| **Acartiidae** | | | | | | | | |
| *Acartia erythraea* | A | - | 72.59 | 0.49 | A | - | A | - |
| *A. negligens* | A | - | 7.73 | 0.05 | 0.50 | 0.00 | 48.67 | 0.30 |
| *A. spinicauda* | 12.11 | 1.41 | A | - | A | - | A | - |
| **Aetideidae** | | | | | | | | |
| *Aetideus acutus* | A | - | 7.73 | 0.05 | A | - | A | - |
| *A. armatus* | A | - | A | - | 0.42 | 0.00 | A | - |
| *A. giesbrechtii* | A | - | A | - | A | - | 10.11 | 0.06 |
| *Euchirella bitumida* | A | - | A | - | 0.50 | 0.00 | 10.73 | 0.07 |
| *E. galeata* | A | - | 73.55 | 0.50 | A | - | A | - |
| *E. indica* | A | - | A | - | 16.68 | 0.08 | 10.11 | 0.06 |
| *E. latirostris* | A | - | A | - | A | - | 0.28 | 0.00 |
| *E. rostromagna* | A | - | 7.73 | 0.05 | A | - | A | - |
| *E. venusta* | A | - | A | - | 9.83 | 0.05 | A | - |
| *Euchirella* sp. | A | - | 3.66 | 0.02 | 20.42 | 0.10 | 13.01 | 0.08 |
| *Gaetanus miles* | A | - | A | - | 0.40 | 0.00 | A | - |
| *Undeuchaeta* sp. | A | - | 23.20 | 0.16 | A | - | A | - |
| **Arietellidae** | | | | | | | | |
| *Arietellus giesbrechtii* | A | - | A | - | A | - | 0.28 | 0.00 |
| **Augaptilidae** | | | | | | | | |
| *Euaugaptilus hecticus* | A | - | A | - | A | - | 0.28 | 0.00 |
| *E. laticeps* | A | - | A | - | 0.42 | 0.00 | 0.28 | 0.00 |
| *Haloptilus longicornis* | A | - | 30.56 | 0.21 | 1.40 | 0.01 | 84.64 | 0.52 |
| *H. spiniceps* | A | - | 30.19 | 0.20 | 0.86 | 0.00 | A | - |
| *Pseudhaloptilus pacificus* | A | - | A | - | 0.42 | 0.00 | A | - |
| **Calanidae** | | | | | | | | |
| *Canthocalanus pauper* | A | - | 15.10 | 0.10 | 124.79 | 0.60 | 149.45 | 0.93 |
| *Cosmocalanus darwinii* | A | - | A | - | 15.89 | 0.08 | 25.25 | 0.16 |
| *Mesocalanus tenuicornis* | A | - | 72.59 | 0.49 | A | - | A | - |
| *Undinula vulgaris* | A | - | 4.43 | 0.03 | 158.81 | 0.77 | 417.62 | 2.59 |
| **Candaciidae** | | | | | | | | |
| *Candacia bradyi* | A | - | 15.47 | 0.10 | 47.87 | 0.23 | 124.79 | 0.77 |
| *C. catula* | A | - | A | - | A | - | 10.11 | 0.06 |
| *C. discaudata* | A | - | 145.17 | 0.98 | 82.13 | 0.40 | 9.87 | 0.06 |
| *C. pachydactyla* | A | - | A | - | A | - | 35.36 | 0.22 |
| *Candacia* sp. | 12.11 | 1.41 | A | - | A | - | 253.61 | 1.57 |
| *Paracandacia truncata* | A | - | A | - | A | - | 35.94 | 0.22 |
| *P. simplex* | A | - | A | - | A | - | A | - |
| **Centropagidae** | | | | | | | | |
| *Centropages calaninus* | A | - | A | - | 0.50 | 0.00 | A | - |
| *C. furcatus* | 24.23 | 2.82 | 30.93 | 0.21 | 493.06 | 2.39 | 198.65 | 1.23 |
| **Clausocalanidae** | | | | | | | | |
| *Clausocalanus arcuicornis* | 24.23 | 2.82 | 0.96 | 0.01 | 2942.13 | 14.24 | 1124.47 | 6.97 |
| *C. furcatus* | A | - | 840.16 | 5.68 | 233.86 | 1.13 | 195.04 | 1.21 |
| *C. pergens* | A | - | 176.10 | 1.19 | A | - | A | - |
| *Drepanopsis frigidus* | A | - | 72.59 | 0.49 | A | - | A | - |
| **Eucalanidae** | | | | | | | | |
| *Eucalanus crassus* | A | - | 45.29 | 0.31 | 30.18 | 0.15 | 0.28 | 0.00 |
| *E. subcrassus* | A | - | A | - | A | - | A | - |
| *E. elongatus* | A | - | 162.38 | 1.10 | 272.31 | 1.32 | 44.57 | 0.28 |
| *E. monachus* | 96.91 | 11.27 | 981.53 | 6.64 | 206.81 | 1.00 | 2519.60 | 15.61 |
| *E. mucronatus* | 12.11 | 1.41 | 1.92 | 0.01 | 24.12 | 0.12 | 144.77 | 0.90 |
| *E. pseudattenuatus* | A | - | 0.96 | 0.01 | A | - | A | - |
| *Eucalanus* sp. | A | - | 219.49 | 1.49 | 63.56 | 0.31 | 19.59 | 0.12 |
| *Pareucalanus attenuatus* | A | - | A | - | 171.52 | 0.83 | 169.71 | 1.05 |
| **Euchaetidae** | | | | | | | | |
| *Euchaeta concinna* | 24.23 | 2.82 | A | - | A | - | A | - |
| *E. indica* | A | - | A | - | 0.42 | 0.00 | 10.38 | 0.06 |
| *E. marina* | A | - | 238.93 | 1.62 | 302.43 | 1.46 | 10.38 | 0.06 |
| *Euchaeta* sp. | A | - | 95.33 | 0.65 | 139.79 | 0.68 | 119.57 | 0.74 |
| **Fosshageniidae** | | | | | | | | |
| *Temoropia mayumbaensis* | A | - | 194.09 | 1.31 | 255.46 | 1.24 | 154.66 | 0.96 |
| **Heterorhabdidae** | | | | | | | | |
| *Heterorhabdus abyssalis* | A | - | 29.92 | 0.20 | A | - | A | - |
| *H. papilliger* | A | - | 30.19 | 0.20 | 105.85 | 0.51 | 144.42 | 0.89 |
| *H. spinifrons* | A | - | A | - | 37.90 | 0.18 | 44.83 | 0.28 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Heterorhabdus* sp. | A | - | A | - | A | - | 2.62 | 0.02 |
| *Heterostylites longicornis* | A | - | A | - | A | - | 0.28 | 0.00 |
| **Lucicutiidae** | | | | | | | | |
| *Lucicutia flavicornis* | 36.34 | 4.23 | 564.81 | 3.82 | 262.82 | 1.27 | 561.37 | 3.48 |
| *L. lucida* | A | - | 0.96 | 0.01 | A | - | A | - |
| *L. maxima* | A | - | A | - | 77.23 | 0.37 | 2.62 | 0.02 |
| *L. ovalis* | A | - | 4.80 | 0.03 | 63.56 | 0.31 | 10.11 | 0.06 |
| **Mecynoceridae** | | | | | | | | |
| *Mecynocera clausii* | A | - | 80.32 | 0.54 | 82.27 | 0.40 | 20.22 | 0.13 |
| **Metridinidae** | | | | | | | | |
| *Metridia brevicauda* | A | - | 15.10 | 0.10 | 23.95 | 0.12 | A | - |
| *Metridia* sp. | A | - | 2.70 | 0.02 | A | - | A | - |
| *Pleuromamma gracilis* | A | - | 31.52 | 0.21 | 232.11 | 1.12 | 32.08 | 0.20 |
| *P. indica* | 24.23 | 2.82 | 943.30 | 6.38 | 984.50 | 4.76 | 969.32 | 6.00 |
| *P. robusta* | A | - | 145.17 | 0.98 | 115.75 | 0.56 | 64.97 | 0.40 |
| *Pleuromamma* sp. | A | - | 54.13 | 0.37 | 167.14 | 0.81 | A | - |
| **Nullosetigeridae** | | | | | | | | |
| *Nullosetigera* sp. | A | - | 7.73 | 0.05 | A | - | A | - |
| **Paracalanidae** | | | | | | | | |
| *Acrocalanus gibber* | 36.34 | 4.23 | 16.83 | 0.11 | 16.77 | 0.08 | A | - |
| *A. gracilis* | 24.23 | 2.82 | 72.59 | 0.49 | 77.43 | 0.37 | 372.61 | 2.31 |
| *A. longicornis* | 24.23 | 2.82 | 3.47 | 0.02 | 336.70 | 1.63 | 144.55 | 0.90 |
| *A. monachus* | A | - | A | - | A | - | 10.11 | 0.06 |
| *Calocalanus pavo* | A | - | 30.19 | 0.20 | 373.76 | 1.81 | 161.60 | 1.00 |
| *C. plumulosus* | A | - | A | - | 147.39 | 0.71 | 10.11 | 0.06 |
| *Paracalanus indicus* | 84.80 | 9.86 | 279.59 | 1.89 | 837.75 | 4.05 | 267.99 | 1.66 |
| *P. aculeatus* | A | - | 177.06 | 1.20 | A | - | A | - |
| *P. crassirostris* | A | - | A | - | A | - | A | - |
| *P. parvus* | A | - | 264.29 | 1.79 | 94.10 | 0.46 | 50.50 | 0.31 |
| **Phaennidae** | | | | | | | | |
| *Amallophora crassirostris* | A | - | 7.73 | 0.05 | A | - | A | - |
| *Cephalophanes frigidus* | A | - | A | - | A | - | 25.25 | 0.16 |
| *Onchocalanus affinis* | A | - | 0.96 | 0.01 | A | - | A | - |
| *Phaenna spinifera* | A | - | 23.20 | 0.16 | A | - | A | - |
| *Xanthocalanus pectinatus* | A | - | 30.93 | 0.21 | A | - | A | - |
| **Pontellidae** | | | | | | | | |
| *Calanopia minor* | A | - | A | - | A | - | 26.22 | 0.16 |
| *Labidocera acuta* | A | - | A | - | A | - | 19.59 | 0.12 |
| *Pontellina plumata* | A | - | 72.59 | 0.49 | A | - | 25.52 | 0.16 |
| **Rhincalanidae** | | | | | | | | |
| *Rhincalanus cornutus* | A | - | A | - | 31.71 | 0.15 | 20.81 | 0.13 |
| *R. nasutus* | A | - | A | - | 0.38 | 0.00 | A | - |
| *R. rostrifrons* | A | - | A | - | 9.33 | 0.05 | 9.87 | 0.06 |
| **Scolecitrichidae** | | | | | | | | |
| *Amallothrix gracilis* | A | - | A | - | 162.41 | 0.79 | 119.30 | 0.74 |
| *Lophothrix frontalis* | A | - | A | - | 0.83 | 0.00 | A | - |
| *Scaphocalanus echinatus* | A | - | 0.96 | 0.01 | A | - | A | - |
| *S. major* | A | - | 0.96 | 0.01 | A | - | A | - |
| *Scaphocalanus* sp. | A | - | A | - | 0.40 | 0.00 | A | - |
| *Scolecithricella dentata* | A | - | 1.92 | 0.01 | 15.89 | 0.08 | A | - |
| *Scolecithricella* sp. | A | - | 72.59 | 0.49 | A | - | 12.73 | 0.08 |
| *Scolecithrichopsis ctenopus* | A | - | 7.73 | 0.05 | 30.56 | 0.15 | 10.11 | 0.06 |
| *Scolecithrix bradyi* | A | - | 7.73 | 0.05 | A | - | A | - |
| *S. danae* | 12.11 | 1.41 | 273.81 | 1.85 | 19.40 | 0.09 | 10.11 | 0.06 |
| *S. nicobarica* | A | - | 22.83 | 0.15 | A | - | A | - |
| *Scolecithrix* sp. | A | - | A | - | A | - | 19.59 | 0.12 |
| **Spinocalanidae** | | | | | | | | |
| *Monacilla gracilis* | A | - | 23.20 | 0.16 | 65.33 | 0.32 | A | - |
| *M. typica* | A | - | 7.73 | 0.05 | A | - | A | - |
| *Spinocalanus magnus* | A | - | 9.47 | 0.06 | A | - | A | - |
| **Temoridae** | | | | | | | | |
| *Temora turbinata* | A | - | 72.59 | 0.49 | A | - | 10.11 | 0.06 |
| *T. discaudata* | A | - | 74.32 | 0.50 | 0.38 | 0.00 | 44.83 | 0.28 |
| *T. stylifera* | A | - | A | A | A | - | 10.11 | 0.06 |
| **CYCLOPOIDA** | | | | | | | | |
| **Oithonidae** | | | | | | | | |
| *Oithona brevicornis* | A | - | 72.59 | 0.49 | A | - | A | - |
| *O. plumifera* | A | - | 247.95 | 1.68 | 188.06 | 0.91 | 297.99 | 1.85 |
| *O. similis* | 266.51 | 30.99 | 1112.04 | 7.52 | 1573.26 | 7.61 | 2130.82 | 13.20 |
| *O. spinirostris* | 12.11 | 1.41 | 247.95 | 1.68 | A | - | 25.25 | 0.16 |
| *Oithona* sp. | A | - | 16.83 | 0.11 | A | - | A | - |
| **HARPACTICOIDA** | | | | | | | | |
| **Aegisthidae** | | | | | | | | |
| *Aegisthus mucronatus* | A | - | 108.26 | 0.73 | 17.58 | 0.09 | A | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Clytemnestridae** | | | | | | | | |
| *Clytemnestra scutellata* | A | - | A | - | 63.94 | 0.31 | 0.28 | 0.00 |
| **Ectinosomatidae** | | | | | | | | |
| *Microsetella norveigica* | A | - | A | - | 15.89 | 0.08 | A | - |
| *M. rosea* | A | - | A | - | 81.39 | 0.39 | A | - |
| **Euterpinidae** | | | | | | | | |
| *Euterpina acutifrons* | A | - | A | - | 16.77 | 0.08 | A | - |
| **Miraciidae** | | | | | | | | |
| *Macrosetella gracilis* | 12.11 | 1.41 | 72.29 | 0.49 | 82.27 | 0.40 | 25.83 | 0.16 |
| *Miracia efferata* | A | - | A | - | 10.33 | 0.05 | 144.55 | 0.90 |
| *Oculosetella gracilis* | A | - | A | - | 0.38 | 0.00 | A | - |
| **MORMONILLOIDA** | | | | | | | | |
| **Mormonillidae** | | | | | | | | |
| *Mormonilla minor* | 36.34 | 4.23 | 1089.07 | 7.37 | 2697.18 | 13.05 | 204.15 | 1.26 |
| *M. phasma* | A | - | 149.55 | 1.01 | A | - | A | - |
| **POECILOSTOMATOIDA** | | | | | | | | |
| **Corycaeidae** | | | | | | | | |
| *Corycaeus catus* | 12.11 | 1.41 | 248.32 | 1.68 | 357.91 | 1.73 | 235.24 | 1.46 |
| *C. danae* | 24.23 | 2.82 | 337.33 | 2.28 | 254.97 | 1.23 | 70.48 | 0.44 |
| *C. longistylis* | A | - | 72.59 | 0.49 | 0.33 | 0.00 | A | - |
| *C. speciosus* | A | - | 190.46 | 1.29 | 36.84 | 0.18 | 418.38 | 2.59 |
| *C. typicus* | A | - | A | - | 48.85 | 0.24 | A | - |
| **Lubbockidae** | | | | | | | | |
| *Lubbockia aculeata* | A | - | A | - | 0.50 | 0.00 | 25.25 | 0.16 |
| *L. squillimana* | A | - | A | - | 15.89 | 0.08 | A | - |
| **Oncaeidae** | | | | | | | | |
| *Conaea gracilis* | A | - | A | - | 69.99 | 0.34 | 2.62 | 0.02 |
| *Oncaea mediterranea* | A | - | A | - | 684.17 | 3.31 | 358.28 | 2.22 |
| *O. notopus* | A | - | A | - | A | - | A | - |
| *O. venusta* | 24.23 | 2.82 | 2152.05 | 14.56 | 3529.31 | 17.08 | 1928.40 | 11.95 |
| *Pachos punctatum* | A | - | A | - | A | - | 0.55 | 0.00 |
| *Triconia conifera* | A | - | A | - | 61.61 | 0.30 | 134.31 | 0.83 |
| **Sapphirinidae** | | | | | | | | |
| *Copilia mirabilis* | A | - | 72.59 | 0.49 | A | - | 144.55 | 0.90 |
| *C. quadrata* | A | - | A | - | 66.69 | 0.32 | 57.56 | 0.36 |
| *C. vitrea* | A | - | 72.59 | 0.49 | 131.00 | 0.63 | A | - |
| *Sapphirina auronitens* | A | - | 103.15 | 0.70 | 0.90 | 0.00 | A | - |
| *S. intestinata* | A | - | 7.73 | 0.05 | A | - | A | - |
| *S. nigromaculata* | 12.11 | 1.41 | 87.68 | 0.59 | A | - | 119.30 | 0.74 |
| *S. ovatolanceolata* | A | - | A | - | 1.00 | 0.00 | 10.11 | 0.06 |
| *Sapphirina* sp. | A | - | 15.10 | 0.10 | A | - | 64.42 | 0.40 |
| **SIPHONOSTOMATOIDA** | | | | | | | | |
| **Rataniidae** | | | | | | | | |
| *Ratania flava* | A | - | A | - | 47.33 | 0.23 | A | - |
| Unidentified | 12.11 | 1.41 | 1266.53 | 8.57 | 615.89 | 2.98 | 558.66 | 3.46 |
| Total individuals 100 m$^{-3}$ | 860 | | 14780 | | 20663 | | 16143 | |

Aegisthidae, Ectinosomatidae, Clausidiidae, Lubbockidae and Rataniidae) accounted for less than 1% of total copepods.

In the MLD, the largest number of families occurred during most seasons (SUM: 21, FIM: 29, WM: 26 and SpIM: 30;Table 7.2). Members of Oncaeidae contributing from 8.2 to 21.2%, Paracalanidae from 6.2 to 24.0%, Eucalanidae from 4.8-20.9% and Oithonidae from 4.2 to 8.9% were dominant in this stratum during all seasons. Representatives of Corycaeidae (4.9-10.3%) were in higher abundance during FIM, WM and SpIM. Members of Acartiidae (9.8%), Calanidae (6.6%) and Metridinidae (14%) were the most abundant in MLD during FIM, WM and SpIM respectively. Clausocalanidae was observed in greater abundance during WM (11%) and SpIM (7.8%).

The number of families occurring in the thermocline (SUM: 17, FIM: 29, WM: 31, SpIM: 30; Table 7.3) decreased during SUM and increased during WM compared to that in the MLD. Paracalanidae (5.7-20%) and Oithonidae (8.5-32.4%) were preponderant during all seasons. Eucalanidae accounting to 10-18% was dominant in most seasons except WM. Similarly; members of Clausocalanidae (7.4-15.4%), Oncaeidae (15-21%) and Metridinidae (6.6-8%) were preponderant during all seasons except SUM. Mormonillidae was dominant during FIM (8.4%) and WM (13%).

In the stratum between the bottom of the thermocline and 300 m, lesser number of families occurred compared to the strata above (SUM: 13, FIM: 26, WM: 29, SpIM: 24; Table 7.4). Only the members of Eucalanidae (5-18.4%) were preponderant during all four seasons. Families, Metridinidae (4.5-7.4%), Oithonidae (7.5-15.6%) and Oncaeidae (10.6-33.8%) were dominant during all seasons in this stratum except SUM. Paracalanidae, accounting to 9.2-33.3% decreased in abundance from SUM to WM and was not dominant during SpIM. Members of Mormonillidae accounted for 13% during WM and 28% during SpIM. In the same seasons, Metridinidae accounted for 7.4 and 6% respectively. Maximum percentage of members of Clausocalanidae (11.3%) and Corycaeidae (19.4%) was during WM and SUM.

Compared to other seasons (FIM: 28, WM: 27, SpIM: 23), the numbers of families were only six during SUM in the 300-500 m stratum (Table 7.5). Families such as Acartiidae, Augaptilidae, Centropagidae, Clausocalanidae, Eucalanidae, Euchaetidae, Heterorhabdidae, Lucicutiidae, Metridinidae, Pontellidae, Rhincalanidae and Temoridae

Table 7.4. Seasonal variations in abundance (individuals 100 m$^{-3}$) and percentage (%) of different copepod species in the base of the thermocline to 300 m stratum in western Bay

| | SUM | | FIM | | WM | | SpIM | |
|---|---|---|---|---|---|---|---|---|
| Species | Abundance | % | Abundance | % | Abundance | % | Abundance | % |
| **CALANOIDA** | | | | | | | | |
| **Acartiidae** | | | | | | | | |
| *Acartia amboinensis* | A | - | 1.61 | 0.01 | A | - | A | - |
| *A. centrura* | A | - | A | - | 0.50 | 0.00 | A | - |
| *A. erythraea* | 52.27 | 2.78 | A | - | A | - | A | - |
| *A. negligens* | A | - | 27.41 | 0.16 | A | - | 2.57 | 0.11 |
| *A. spinicauda* | A | - | 4.82 | 0.03 | A | - | A | - |
| **Aetideidae** | | | | | | | | |
| *Aetideus armatus* | A | - | A | - | 0.89 | 0.01 | A | - |
| *Euchirella bitumida* | A | - | A | - | A | - | 0.98 | 0.04 |
| *E. indica* | A | - | A | - | 30.34 | 0.24 | A | - |
| *Euchirella* sp. | A | - | A | - | 25.29 | 0.20 | A | - |
| *Gaetanus miles* | A | - | A | - | 6.97 | 0.05 | 2.57 | 0.11 |
| *Valdiviella brevicornis* | A | - | 54.82 | 0.32 | A | - | A | - |
| **Augaptilidae** | | | | | | | | |
| *Euaugaptilus angustus* | A | - | A | - | A | - | A | 0.23 |
| *Haloptilus longicornis* | A | - | 15.60 | 0.09 | 32.11 | 0.25 | 23.01 | 0.97 |
| *H. ornatus* | A | - | 27.41 | 0.16 | A | - | A | - |
| **Calanidae** | | | | | | | | |
| *Canthocalanus pauper* | A | - | 15.60 | 0.09 | 98.61 | 0.78 | A | - |
| *Undinula vulgaris* | A | - | 295.25 | 1.71 | 129.83 | 1.02 | A | - |
| **Candaciidae** | | | | | | | | |
| *Candacia bradyi* | A | - | 1.61 | 0.01 | 99.50 | 0.78 | 0.49 | 0.02 |
| *C. discaudata* | A | - | A | - | 24.40 | 0.19 | A | - |
| *C. pachydactyla* | A | - | A | - | 5.93 | 0.05 | A | - |
| *Candacia* sp. | A | - | A | - | 5.93 | 0.05 | A | - |
| *Paracandacia truncata* | A | - | 25.70 | 0.15 | A | - | 2.57 | 0.11 |
| **Centropagidae** | | | | | | | | |
| *C. furcatus* | 52.27 | 2.78 | 31.19 | 0.18 | A | - | 16.25 | 0.68 |
| *Centropages* sp. | A | - | A | - | 25.42 | 0.20 | A | - |
| **Clausocalanidae** | | | | | | | | |
| *Clausocalanus arcuicornis* | 26.13 | 1.39 | A | - | 1218.17 | 9.59 | 46.01 | 1.94 |
| *C. furcatus* | A | - | 94.26 | 0.54 | 212.66 | 1.67 | 7.39 | 0.31 |
| *C. pergens* | A | - | 3.21 | 0.02 | A | - | A | - |
| **Eucalanidae** | | | | | | | | |
| *Eucalanus crassus* | 26.13 | 1.39 | 15.60 | 0.09 | A | - | A | - |
| *E. elongatus* | A | - | 999.77 | 5.78 | 350.49 | 2.76 | 9.95 | 0.42 |
| *E. monachus* | 52.27 | 2.78 | 2.29 | 0.01 | 247.93 | 1.95 | 410.38 | 17.26 |
| *E. mucronatus* | A | - | 31.19 | 0.18 | 33.60 | 0.26 | 8.76 | 0.37 |
| *Eucalanus* sp. | 52.27 | 2.78 | A | - | A | - | A | - |
| *Pareucalanus attenuatus* | A | - | A | - | 1.03 | 0.01 | 7.39 | 0.31 |
| **Euchaetidae** | | | | | | | | |
| *Euchaeta concinna* | A | - | 15.60 | 0.09 | A | - | A | - |
| *E. indica* | A | - | 1.61 | 0.01 | 74.07 | 0.58 | 23.01 | 0.97 |
| *E. marina* | A | - | 155.97 | 0.90 | 148.66 | 1.17 | 3.05 | 0.13 |
| *Euchaeta* sp. | A | - | 15.60 | 0.09 | 5.93 | 0.05 | A | - |
| **Fosshageniidae** | | | | | | | | |
| *Temoropia mayumbaensis* | A | - | 3.89 | 0.02 | A | - | 7.92 | 0.33 |
| **Heterorhabdidae** | | | | | | | | |
| *Heterorhabdus abyssalis* | A | - | 17.18 | 0.10 | A | - | A | - |
| *H. fistulosus* | A | - | A | - | 6.40 | 0.05 | A | - |
| *H. pacificus* | A | - | 0.68 | 0.00 | 5.93 | 0.05 | A | - |
| *H. papilliger* | A | - | 114.21 | 0.66 | 30.34 | 0.24 | 6.36 | 0.27 |
| *H. spinifrons* | A | - | A | A | 80.90 | 0.64 | 13.28 | 0.56 |
| *Heterorhabdus* sp. | A | - | 54.82 | 0.32 | 6.40 | 0.05 | 7.92 | 0.33 |
| *Heterostylites longicornis* | A | - | A | A | 24.92 | 0.20 | A | - |
| *H. major* | A | - | A | A | 1.03 | 0.01 | A | - |
| **Lucicutiidae** | | | | | | | | |
| *Lucicutia flavicornis* | A | - | 229.09 | 1.32 | 298.25 | 2.35 | 107.04 | 4.50 |
| *L. maxima* | 104.54 | 5.56 | 2.05 | 0.01 | 5.93 | 0.05 | A | - |
| *L. ovalis* | A | - | 295.25 | 1.71 | A | - | A | - |
| **Mecynoceridae** | | | | | | | | |
| *Mecynocera clausii* | A | - | A | - | 6.40 | 0.05 | 7.39 | 0.31 |
| **Metridinidae** | | | | | | | | |
| *Gaussia princeps* | A | - | A | - | 0.89 | 0.01 | 1.47 | 0.06 |
| *Metridia brevicauda* | A | - | 1.36 | 0.01 | 15.24 | 0.12 | A | - |
| *Metridia* sp. | A | - | 2.98 | 0.02 | A | - | A | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Pleuromamma gracilis* | A | - | 9.59 | 0.06 | 278.93 | 2.20 | 20.08 | 0.84 |
| *P. indica* | 26.13 | 1.39 | 704.59 | 4.07 | 460.26 | 3.62 | 109.20 | 4.59 |
| *P. robusta* | A | - | 56.42 | 0.33 | 128.77 | 1.01 | 12.74 | 0.54 |
| *P. xiphias* | A | - | A | - | 24.40 | 0.19 | A | - |
| *Pleuromamma* sp. | A | - | A | - | 31.36 | 0.25 | A | - |
| **Paracalanidae** | | | | | | | | |
| *Acrocalanus gibber* | 26.13 | 1.39 | 979.33 | 5.66 | A | - | 5.36 | 0.23 |
| *A. gracilis* | 26.13 | 1.39 | 0.68 | 0.00 | 173.57 | 1.37 | 2.57 | 0.11 |
| *A. longicornis* | 104.54 | 5.56 | 621.69 | 3.59 | 376.30 | 2.96 | A | - |
| *Calocalanus pavo* | 26.13 | 1.39 | A | - | 204.37 | 1.61 | 12.74 | 0.54 |
| *C. plumulosus* | A | - | A | - | 74.07 | 0.58 | 16.34 | 0.69 |
| *Paracalanus indicus* | 418.15 | 22.22 | 1671.16 | 9.65 | 260.11 | 2.05 | 31.76 | 1.34 |
| *P. aculeatus* | A | - | 31.88 | 0.18 | A | - | A | - |
| *P. parvus* | 26.13 | 1.39 | 529.21 | 3.06 | 74.07 | 0.58 | A | - |
| **Phaennidae** | | | | | | | | |
| *Onchocalanus affinis* | A | - | 31.19 | 0.18 | A | - | A | - |
| *Phaenna spinifera* | A | - | 1.61 | 0.01 | A | - | A | - |
| **Pontellidae** | | | | | | | | |
| *Labidocera acuta* | A | - | A | - | 48.81 | 0.38 | A | - |
| *Pontellina plumata* | A | - | A | - | 74.07 | 0.58 | A | - |
| **Rhincalanidae** | | | | | | | | |
| *Rhincalanus cornutus* | A | - | A | - | 83.38 | 0.66 | 39.11 | 1.65 |
| *R. rostrifrons* | A | - | A | - | 0.89 | 0.01 | A | - |
| **Scolecitrichidae** | | | | | | | | |
| *Amallothrix arcuata* | A | - | 1.61 | 0.01 | A | - | A | - |
| *Pseudoamallothrix ovata* | A | - | 27.41 | 0.16 | A | - | A | - |
| *Lophothrix frontalis* | A | - | 0.68 | 0.00 | 65.06 | 0.51 | 0.98 | 0.04 |
| *Scaphocalanus magnus* | A | - | A | - | A | - | 0.98 | 0.04 |
| *Scaphocalanus* sp. | A | - | A | - | 34.72 | 0.27 | A | - |
| *Scolecithricella* sp. | A | - | 29.43 | 0.17 | A | - | A | - |
| *Scolecithrichopsis ctenopus* | A | - | 15.60 | 0.09 | A | - | A | - |
| *Scolecithrix danae* | A | - | 124.78 | 0.72 | A | - | A | - |
| *S. nicobarica* | A | - | 0.68 | 0.00 | A | - | A | - |
| **Spinocalanidae** | | | | | | | | |
| *Monacilla gracilis* | A | - | 3.21 | 0.02 | A | - | A | - |
| *M. tenera* | A | - | A | - | A | - | 14.78 | 0.62 |
| *M. typica* | A | - | A | - | 109.48 | 0.86 | A | - |
| **Temoridae** | | | | | | | | |
| *Temora turbinata* | 52.27 | 2.78 | A | - | A | - | A | - |
| *T. discaudata* | A | - | 15.60 | 0.09 | 83.38 | 0.66 | 29.36 | 1.24 |
| *T. stylifera* | A | - | A | - | 25.42 | 0.20 | 7.39 | 0.31 |
| **CYCLOPOIDA** | | | | | | | | |
| **Oithonidae** | | | | | | | | |
| *Oithona brevicornis* | A | - | 295.25 | 1.71 | A | - | A | - |
| *O. plumifera* | A | - | 295.25 | 1.71 | 86.87 | 0.68 | 30.93 | 1.30 |
| *O. setigera* | A | - | 27.41 | 0.16 | A | - | A | - |
| *O. similis* | 52.27 | 2.78 | 237.38 | 1.37 | 824.56 | 6.49 | 270.84 | 11.39 |
| *O. spinirostris* | A | - | 70.41 | 0.41 | 25.42 | 0.20 | A | - |
| *Oithona* sp. | A | - | 1771.50 | 10.23 | 9.30 | 0.07 | A | - |
| **HARPACTICOIDA** | | | | | | | | |
| **Aegisthidae** | | | | | | | | |
| *Aegisthus mucronatus* | A | - | A | - | 6.40 | 0.05 | A | - |
| **Clytemnestridae** | | | | | | | | |
| *Clytemnestra scutellata* | A | - | 1.61 | 0.01 | 151.23 | 1.19 | A | - |
| **Ectinosomatidae** | | | | | | | | |
| *Microsetella norveigica* | A | - | A | - | 0.52 | 0.00 | A | - |
| **Euterpinidae** | | | | | | | | |
| *Euterpina acutifrons* | 287.48 | 15.28 | A | - | 99.50 | 0.78 | A | - |
| **Miraciidae** | | | | | | | | |
| *Macrosetella gracilis* | 52.27 | 2.78 | 63.42 | 0.37 | 1.35 | 0.01 | A | - |
| **MORMONILLOIDA** | | | | | | | | |
| **Mormonillidae** | | | | | | | | |
| *Mormonilla minor* | A | - | 247.58 | 1.43 | 1651.72 | 13.00 | 662.59 | 27.87 |
| *M. phasma* | A | - | 31.30 | 0.18 | A | - | 7.92 | 0.33 |
| **POECILOSTOMATOIDA** | | | | | | | | |
| **Corycaeidae** | | | | | | | | |
| *Corycaeus agilis* | A | - | 15.60 | 0.09 | A | - | A | - |
| *C. asiaticus* | A | - | 17.20 | 0.10 | A | - | A | - |
| *C. catus* | A | - | 43.69 | 0.25 | 102.21 | 0.80 | 36.28 | 1.53 |
| *C. danae* | 365.88 | 19.44 | 1.61 | 0.01 | 181.70 | 1.43 | 14.28 | 0.60 |
| *C. speciosus* | A | - | 354.53 | 2.05 | 5.93 | 0.05 | 15.85 | 0.67 |
| *C. typicus* | A | - | A | - | 249.84 | 1.97 | A | - |
| *Farranula carinata* | A | - | 46.79 | 0.27 | A | - | A | - |
| **Lubbockidae** | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Lubbockia aculeata* | A | - | A | - | A | - | 2.57 | 0.11 |
| **Oncaeidae** | | | | | | | | |
| *Conaea gracilis* | A | - | A | - | 6.40 | 0.05 | A | - |
| *Oncaea mediterranea* | A | - | A | - | 1014.98 | 7.99 | 32.29 | 1.36 |
| *O. venusta* | 52.27 | 2.78 | 5843.50 | 33.76 | 2278.03 | 17.94 | 220.25 | 9.26 |
| *Triconia conifera* | A | - | A | - | 31.82 | 0.25 | A | - |
| **Sapphirinidae** | | | | | | | | |
| *Copilia quadrata* | A | - | 1.61 | 0.01 | 9.77 | 0.08 | 0.49 | 0.02 |
| *C. vitrea* | A | - | A | - | 5.93 | 0.05 | A | - |
| *Sapphirina nigromaculata* | A | - | A | - | 0.46 | 0.00 | A | - |
| *S. ovatolanceolata* | A | - | 15.60 | 0.09 | A | - | 7.88 | 0.33 |
| *Sapphirina* sp. | A | - | 295.25 | 1.71 | A | - | A | - |
| *Vettoria granulosa* | A | - | A | - | 6.40 | 0.05 | A | - |
| Unidentified | A | - | 219.26 | 1.27 | 78.82 | 0.62 | 50.86 | 2.14 |
| Total individuals 100 m$^{-3}$ | 1882 | | 17311 | | 12701 | | 2378 | |

that were present in this stratum during other seasons were absent during SUM. Like in the upper three strata, Oncaeidae ranging from 16.4 to 33.3% was major family. Members of Paracalanidae contributing from 8.4 to 32.2% were abundant during SUM, FIM and WM. Representatives of Eucalanidae (4.7-19%) and Corycaeidae (6.5-11.4%) dominated from FIM to SpIM. Members of Candaciidae and Miraciidae contributing to 11% each were the most dominant in this stratum only during SUM. Calanidae formed 11-12% of the total abundance only during SUM and FIM. Clausocalanidae (8%) and Metridinidae (5.2 and 12.6%) were more abundant only during WM and SpIM. Oithonidae comprised 22- and 13% of the total abundance during SUM and WM respectively.

In the deepest stratum sampled in this study, the numbers of families occurring were 19, 28 and 16 during SUM, FIM and WM respectively (Table 7.6). While the relative abundance of Metridinidae (5-67%) decreased from SUM to WM, that of Lucicutiidae (11-12%) did not change over seasons. Higher abundance of Oncaeidae (22 and 46%) and Mormonillidae (11 and 15%) was observed only during FIM and WM. Augaptilidae reached a maximum abundance of 9% during FIM. Members of Paracalanidae (6%) and Spinocalanidae (7%) were abundant in this stratum only during WM.

In the overall, members of Arietellidae, Megacalanidae, Rhincalanidae, Tharybidae, Aegisthidae, Ectinosomatidae, Clausiidae, Lubbockidae and Rataniidae were absent in the samples during SUM. Members of the families Megacalanidae, Clausiidae, Lubbockidae and Rataniidae were absent during FIM. Representatives of families such as Arietellidae, Megacalanidae, Nullosetigeridae, Phaennidae, Tharybidae and Clausiidae were not found during WM. Members of Arietellidae, Tharybidae, Aegisthidae, Euterpinidae Clausiidae and Rataniidae were not recorded from any sample during SpIM.

### 7.2.4. Genera and species

A total 82 genera was identified during the study period (Table 7.2-7.6). Though number of genera occurring did not vary much with depth (MLD: 65, TT-BT: 68, BT-300 m: 57, 300-500 m: 58, 500-1000 m: 54), it did vary with seasons (SUM: 37, FIM: 70, WM: 55 and SpIM: 53). Within each of the strata too, seasonal differences were evident.

Table 7.5. Variations in abundance (individuals 100 m$^{-3}$) and percentage (%) of different copepod species in the 300-500 m stratum in western Bay

| | SUM | | FIM | | WM | | SpIM | |
|---|---|---|---|---|---|---|---|---|
| Species | Abundance | % | Abundance | % | Abundance | % | Abundance | % |
| **CALANOIDA** | | | | | | | | |
| **Acartiidae** | | | | | | | | |
| *Acartia amboinensis* | A | - | 46.60 | 0.61 | A | - | A | - |
| *A. negligens* | A | - | 1.21 | 0.02 | 48.01 | 0.52 | 24.57 | 3.22 |
| *A. spinicauda* | A | - | 73.39 | 0.96 | A | - | A | - |
| **Aetideidae** | | | | | | | | |
| *Aetideus armatus* | A | - | A | - | 0.67 | 0.01 | A | - |
| *Chirundina streetsi* | A | - | 7.53 | 0.10 | A | - | A | - |
| *Euchirella bitumida* | A | - | A | - | 7.95 | 0.09 | A | - |
| *Euchirella* sp. | A | - | 2.41 | 0.03 | 0.67 | 0.01 | A | - |
| *Gaetanus kruppii* | A | - | A | - | 0.33 | 0.00 | A | - |
| **Augaptilidae** | | | | | | | | |
| *Euaugaptilus bullifer* | A | - | 5.27 | 0.07 | 0.33 | 0.00 | A | - |
| *E. hecticus* | A | - | 31.36 | 0.41 | 0.33 | 0.00 | A | - |
| *Haloptilus longicornis* | A | - | A | - | 11.87 | 0.13 | 5.50 | 0.72 |
| **Calanidae** | | | | | | | | |
| *Canthocalanus pauper* | A | - | 470.71 | 6.19 | 162.02 | 1.74 | 4.59 | 0.60 |
| *Cosmocalanus darwinii* | A | - | A | - | 40.50 | 0.43 | A | - |
| *Undinula vulgaris* | 68.93 | 11.11 | 457.75 | 6.02 | 55.97 | 0.60 | A | - |
| **Candaciidae** | | | | | | | | |
| *Candacia bradyi* | A | - | 90.78 | 1.19 | 47.68 | 0.51 | 5.50 | 0.72 |
| *C. catula* | A | - | 1.21 | 0.02 | A | - | A | - |
| *C. discaudata* | A | - | 45.39 | 0.60 | 95.36 | 1.02 | 4.59 | 0.60 |
| *Candacia* sp. | A | - | 45.39 | 0.60 | A | - | A | - |
| *Paracandacia truncata* | 68.93 | 11.11 | 1.21 | 0.02 | A | - | A | - |
| **Centropagidae** | | | | | | | | |
| *Centropages alcocki* | A | - | 28.00 | 0.37 | A | - | A | - |
| *C. furcatus* | A | - | 7.53 | 0.10 | 48.01 | 0.52 | 7.39 | 0.97 |
| **Clausocalanidae** | | | | | | | | |
| *Clausocalanus arcuicornis* | A | - | A | - | 610.11 | 6.55 | 34.32 | 4.50 |
| *C. furcatus* | A | - | 213.41 | 2.81 | 136.86 | 1.47 | 25.02 | 3.28 |
| *C. pergens* | A | - | 6.48 | 0.09 | A | - | A | - |
| **Eucalanidae** | | | | | | | | |
| *Eucalanus elongatus* | A | - | 29.83 | 0.39 | 227.85 | 2.45 | 19.47 | 2.55 |
| *E. monachus* | A | - | 326.02 | 4.29 | 324.10 | 3.48 | 110.53 | 14.50 |
| *E. mucronatus* | A | - | A | - | 8.28 | 0.09 | 4.59 | 0.60 |
| *Eucalanus* sp. | A | - | A | - | 47.68 | 0.51 | 4.59 | 0.60 |
| *Pareucalanus attenuatus* | A | - | A | - | 0.67 | 0.01 | 5.50 | 0.72 |
| **Euchaetidae** | | | | | | | | |
| *Euchaeta concinna* | A | - | A | - | A | - | 5.50 | 0.72 |
| *E. marina* | A | - | 46.60 | 0.61 | 8.28 | 0.09 | 22.00 | 2.89 |
| **Fosshageniidae** | | | | | | | | |
| *Temoropia mayumbaensis* | A | - | A | - | A | - | 12.89 | 1.69 |
| **Heterorhabdidae** | | | | | | | | |
| *Heterorhabdus papilliger* | A | - | 14.92 | 0.20 | 7.73 | 0.08 | 4.59 | 0.60 |
| *H. spinifrons* | A | - | A | - | 19.48 | 0.21 | A | - |
| *Heterorhabdus* sp. | A | - | 5.27 | 0.07 | A | - | A | - |
| *Heterostylites longicornis* | A | - | A | - | 0.33 | 0.00 | 5.50 | 0.72 |
| *H. major* | A | - | A | - | A | - | 11.00 | 1.44 |
| **Lucicutiidae** | | | | | | | | |
| *Lucicutia flavicornis* | A | - | 111.73 | 1.47 | 298.07 | 3.20 | 39.19 | 5.14 |
| *L. lucida* | A | - | 15.68 | 0.21 | A | - | A | - |
| *L. magna* | A | - | 1.21 | 0.02 | A | - | A | - |
| *L. maxima* | A | - | 7.52 | 0.10 | 71.21 | 0.76 | A | - |
| *L. ovalis* | A | - | 12.80 | 0.17 | A | - | A | - |
| **Mecynoceridae** | | | | | | | | |
| *Mecynocera clausii* | A | - | 10.10 | 0.13 | A | - | A | - |
| **Metridinidae** | | | | | | | | |
| *Gaussia princeps* | A | - | A | - | 1.33 | 0.01 | 1.89 | 0.25 |
| *Metridia brevicauda* | A | - | 4.82 | 0.06 | 78.49 | 0.84 | A | - |
| *Pleuromamma gracilis* | A | - | 16.42 | 0.22 | 31.35 | 0.34 | 13.00 | 1.71 |
| *P. indica* | A | - | 80.49 | 1.06 | 297.08 | 3.19 | 54.11 | 7.10 |
| *P. robusta* | A | - | 21.69 | 0.29 | 27.33 | 0.29 | 17.59 | 2.31 |
| *Pleuromamma* sp. | A | - | A | - | 47.68 | 0.51 | 9.18 | 1.20 |
| **Paracalanidae** | | | | | | | | |
| *Acrocalanus gibber* | A | - | 209.57 | 2.76 | A | - | A | - |
| *A. gracilis* | A | - | 213.41 | 2.81 | 40.50 | 0.43 | A | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *A. longicornis* | A | - | 118.79 | 1.56 | 81.01 | 0.87 | A | - |
| *Calocalanus pavo* | A | - | A | A | 129.02 | 1.38 | 7.50 | 0.98 |
| *C. plumulosus* | A | - | A | A | 128.69 | 1.38 | A | - |
| *Paracalanus indicus* | A | - | 1256.29 | 16.52 | 196.29 | 2.11 | 19.71 | 2.59 |
| *P. aculeatus* | 68.93 | 11.11 | 189.09 | 2.49 | A | - | A | - |
| *P. parvus* | A | - | 460.09 | 6.05 | 202.52 | 2.17 | A | - |
| **Phaennidae** | | | | | | | | |
| *Onchocalanus affinis* | A | - | 45.39 | 0.60 | A | - | A | - |
| *Phaenna spinifera* | A | - | 10.85 | 0.14 | A | - | A | - |
| *Xanthocalanus pectinatus* | A | - | 7.53 | 0.10 | A | - | A | - |
| **Pontellidae** | | | | | | | | |
| *Calanopia elliptica* | A | - | 35.53 | 0.47 | A | - | A | - |
| *Labidocera acuta* | A | - | A | - | 1.33 | 0.01 | A | - |
| *Pontellina plumata* | A | - | A | - | A | - | 5.50 | 0.72 |
| **Rhincalanidae** | | | | | | | | |
| *Rhincalanus cornutus* | A | - | 45.39 | 0.60 | 12.20 | 0.13 | 1.89 | 0.25 |
| *R. nasutus* | A | - | A | - | 0.33 | 0.00 | A | - |
| *R. rostrifrons* | A | - | A | - | 0.33 | 0.00 | A | - |
| **Scolecitrichidae** | | | | | | | | |
| *Lophothrix frontalis* | A | - | 7.53 | 0.10 | 148.43 | 1.59 | 2.98 | 0.39 |
| *Scaphocalanus echinatus* | A | - | 7.53 | 0.10 | A | - | A | - |
| *Scaphocalanus* sp. | A | - | A | - | 3.33 | 0.04 | A | - |
| *Scolecithricella* sp. | A | - | 3.62 | 0.05 | A | A | A | - |
| *Scolecithrichopsis ctenopus* | A | - | A | - | 47.68 | 0.51 | A | - |
| *Scolecithrix danae* | A | - | A | - | 7.73 | 0.08 | 5.50 | 0.72 |
| *S. nicobarica* | A | - | A | - | 0.33 | 0.00 | A | - |
| **Spinocalanidae** | | | | | | | | |
| *Monacilla gracilis* | A | - | 7.53 | 0.10 | A | - | A | - |
| *M. tenera* | A | - | A | - | 7.61 | 0.08 | A | - |
| *M. typica* | A | - | 91.54 | 1.20 | A | - | A | - |
| *Spinocalanus angusticeps* | A | - | 5.27 | 0.07 | A | - | A | - |
| *S. longipes* | A | - | A | - | 7.73 | 0.08 | A | - |
| *S. magnus* | A | - | 5.27 | 0.07 | A | - | A | - |
| *Spinocalanus* sp. | A | - | 5.27 | 0.07 | A | - | A | - |
| **Temoridae** | | | | | | | | |
| *Temora turbinata* | A | - | A | - | A | - | 2.98 | 0.39 |
| *T. discaudata* | A | - | 137.38 | 1.81 | 40.50 | 0.43 | A | - |
| *T. stylifera* | A | - | A | - | 11.87 | 0.13 | 11.06 | 1.45 |
| **CYCLOPOIDA** | | | | | | | | |
| **Oithonidae** | | | | | | | | |
| *Oithona brevicornis* | A | - | 45.39 | 0.60 | 40.50 | 0.43 | A | - |
| *O. plumifera* | A | - | 28.00 | 0.37 | 143.04 | 1.54 | 6.41 | 0.84 |
| *O. setigera* | 68.93 | 11.11 | 6.48 | 0.09 | A | - | A | - |
| *O. similis* | 68.93 | 11.11 | 151.77 | 2.00 | 994.66 | 10.68 | 25.25 | 3.31 |
| *O. spinirostris* | A | - | 7.53 | 0.10 | A | - | A | - |
| *Oithona* sp. | A | - | 1.21 | 0.02 | A | - | A | - |
| **HARPACTICOIDA** | | | | | | | | |
| **Aegisthidae** | | | | | | | | |
| *Aegisthus mucronatus* | A | - | A | - | 0.33 | 0.00 | A | - |
| **Clytemnestridae** | | | | | | | | |
| *Clytemnestra scutellata* | A | - | A | - | 143.04 | 1.54 | A | - |
| **Ectinosomatidae** | | | | | | | | |
| *Microsetella rosea* | A | - | 73.39 | 0.96 | 7.61 | 0.08 | A | - |
| **Euterpinidae** | | | | | | | | |
| *Euterpina acutifrons* | A | - | A | - | 81.01 | 0.87 | A | - |
| **Miraciidae** | | | | | | | | |
| *Macrosetella gracilis* | 68.93 | 11.11 | 146.79 | 1.93 | A | - | 9.39 | 1.23 |
| **MORMONILLOIDA** | | | | | | | | |
| **Mormonillidae** | | | | | | | | |
| *Mormonilla minor* | A | - | 106.60 | 1.40 | 451.87 | 4.85 | 22.55 | 2.96 |
| *M. phasma* | A | - | 7.53 | 0.10 | A | - | A | - |
| **POECILOSTOMATOIDA** | | | | | | | | |
| **Corycaeidae** | | | | | | | | |
| *Corycaeus catus* | A | - | 47.80 | 0.63 | 290.70 | 3.12 | 30.18 | 3.96 |
| *C. danae* | A | - | 243.76 | 3.20 | 169.19 | 1.82 | 9.11 | 1.20 |
| *C. speciosus* | A | - | 146.79 | 1.93 | 276.42 | 2.97 | 5.50 | 0.72 |
| *C. typicus* | A | - | A | - | 283.53 | 3.04 | A | - |
| *Corycaeus* sp. | A | - | 136.17 | 1.79 | A | - | 4.59 | 0.60 |
| *Farranula gibbula* | A | - | A | - | 40.84 | 0.44 | A | - |
| **Lubbockidae** | | | | | | | | |
| *Lubbockia squillimana* | A | - | 2.41 | 0.03 | A | - | A | - |
| **Oncaeidae** | | | | | | | | |
| *Conaea gracilis* | A | - | 31.64 | 0.42 | 141.40 | 1.52 | 3.78 | 0.50 |
| *Oncaea mediterranea* | A | - | A | - | 121.51 | 1.30 | 8.48 | 1.11 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *O. venusta* | 206.78 | 33.33 | 1095.16 | 14.40 | 1879.65 | 20.18 | 105.22 | 13.80 |
| *Oncaea* sp. | A | - | A | - | A | - | 4.59 | 0.60 |
| *Triconia conifera* | A | - | 84.01 | 1.10 | 11.87 | 0.13 | 2.98 | 0.39 |
| **Sapphirinidae** | | | | | | | | |
| *Copilia mirabilis* | A | - | A | - | A | - | 5.50 | 0.72 |
| *C. quadrata* | A | - | 7.53 | 0.10 | 88.18 | 0.95 | A | - |
| *Sapphirina nigromaculata* | A | - | 28.00 | 0.37 | 47.68 | 0.51 | A | - |
| Unidentified | A | - | 96.06 | 1.26 | 271.73 | 2.92 | 9.05 | 1.19 |
| Total individuals 100 $m^{-3}$ | 620 | | 7606 | | 9316 | | 762 | |

Table 7.6. Variations in abundance (individuals 100 $m^{-3}$) and percentage (%) of different copepod species in the 500-1000 m stratum in western Bay

| | SUM | | FIM | | WM | |
|---|---|---|---|---|---|---|
| Species | Abundance | % | Abundance | % | Abundance | % |
| **CALANOIDA** | | | | | | |
| **Acartiidae** | | | | | | |
| *Acartia negligens* | 0.53 | 0.43 | A | - | A | - |
| *A. spinicauda* | A | - | 1.97 | 0.08 | A | - |
| **Aetideidae** | | | | | | |
| *Aetideopsis tumurosa* | A | - | 11.77 | 0.49 | A | - |
| *Aetideus acutus* | A | - | 22.31 | 0.93 | A | - |
| *Chiridius longispinus* | A | - | 7.44 | 0.31 | A | - |
| *Euchirella amoena* | A | - | 0.61 | 0.03 | A | - |
| *E. galeata* | A | - | 7.44 | 0.31 | A | - |
| *E. indica* | 1.59 | 1.29 | 9.74 | 0.41 | A | - |
| *E. rostromagna* | A | - | 0.61 | 0.03 | A | - |
| *Euchirella* sp. | A | - | 14.87 | 0.62 | A | - |
| *Gaetanus minor* | A | - | 7.44 | 0.31 | A | - |
| *G. pileatus* | A | - | 7.44 | 0.31 | A | - |
| *Undeuchaeta plumosa* | A | - | 4.34 | 0.18 | A | - |
| *Undeuchaeta* sp. | A | - | 4.34 | 0.18 | A | - |
| *Valdiviella brevicornis* | A | - | 12.00 | 0.50 | A | - |
| **Augaptilidae** | | | | | | |
| *Euaugaptilus angustus* | 0.53 | 0.43 | A | - | A | - |
| *E. bullifer* | A | - | 4.28 | 0.18 | A | - |
| *E. hecticus* | A | - | 192.08 | 7.99 | 0.80 | 0.20 |
| *E. oblongus* | A | - | 0.61 | 0.03 | A | - |
| *E. rigidus* | A | - | 7.89 | 0.33 | A | - |
| *Haloptilus longicornis* | A | - | 7.44 | 0.31 | 0.40 | 0.10 |
| *H. ornatus* | A | - | 13.52 | 0.56 | A | - |
| **Calanidae** | | | | | | |
| *Canthocalanus pauper* | A | - | 0.61 | 0.03 | A | - |
| *Cosmocalanus darwinii* | A | - | A | - | 4.80 | 1.22 |
| *Undinula vulgaris* | A | - | 7.44 | 0.31 | A | - |
| **Candaciidae** | | | | | | |
| *Candacia bradyi* | A | - | 9.74 | 0.41 | A | - |
| *C. catula* | A | - | 0.61 | 0.03 | A | - |
| **Clausocalanidae** | | | | | | |
| *Clausocalanus arcuicornis* | 2.64 | 2.15 | 14.87 | 0.62 | A | - |
| *C. furcatus* | A | - | 3.94 | 0.16 | A | - |
| **Eucalanidae** | | | | | | |
| *Eucalanus crassus* | 0.53 | 0.43 | 4.34 | 0.18 | A | - |
| *E. elongatus* | A | - | 31.77 | 1.32 | A | - |
| *E. monachus* | A | - | 14.14 | 0.59 | 10.80 | 2.74 |
| *E. mucronatus* | A | - | 2.31 | 0.10 | A | - |
| *Pareucalanus attenuatus* | 1.59 | 1.29 | A | - | 0.40 | 0.10 |
| **Euchaetidae** | | | | | | |
| *Euchaeta concinna* | 0.53 | 0.43 | A | - | A | - |
| *E. marina* | 1.06 | 0.86 | 11.77 | 0.49 | A | - |
| *Euchaeta* sp. | A | - | 0.61 | 0.03 | 0.40 | 0.10 |
| **Fosshageniidae** | | | | | | |
| *Temoropia mayumbaensis* | A | - | 6.25 | 0.26 | A | - |
| **Heterorhabdidae** | | | | | | |
| *Heterorhabdus abyssalis* | A | - | 27.88 | 1.16 | A | - |
| *H. pacificus* | A | - | 6.08 | 0.25 | A | - |
| *H. papilliger* | A | - | 19.60 | 0.82 | A | - |
| *H. spinifrons* | 1.59 | 1.29 | A | - | A | - |
| *Heterorhabdus* sp. | A | - | A | - | 0.40 | 0.10 |
| *Heterostylites longicornis* | A | - | 6.08 | 0.25 | A | - |
| **Lucicutiidae** | | | | | | |
| *Lucicutia flavicornis* | 7.40 | 6.01 | 204.53 | 8.51 | 28.80 | 7.30 |
| *L. lucida* | A | - | 13.01 | 0.54 | A | - |
| *L. magna* | A | - | 11.72 | 0.49 | A | - |
| *L. maxima* | 6.35 | 5.15 | 38.69 | 1.61 | 14.80 | 3.75 |
| *L. ovalis* | A | - | 22.31 | 0.93 | A | - |
| **Mecynoceridae** | | | | | | |
| *Mecynocera clausii* | A | - | 26.01 | 1.08 | A | - |
| **Metridinidae** | | | | | | |
| *Gaussia princeps* | A | - | 2.31 | 0.10 | A | - |
| *Metridia brevicauda* | 7.40 | 6.01 | 47.31 | 1.97 | 9.60 | 2.43 |
| *M. cuticauda* | A | - | 15.83 | 0.66 | 9.60 | 2.43 |
| *M princeps* | A | - | A | - | 0.40 | 0.10 |
| *Pleuromamma gracilis* | A | - | 72.44 | 3.01 | A | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| *P. indica* | 72.97 | 59.23 | 44.20 | 1.84 | A | - |
| *P. robusta* | 1.59 | 1.29 | 24.16 | 1.01 | A | - |
| *Pleuromamma* sp. | A | - | 1.97 | 0.08 | A | - |
| **Paracalanidae** | | | | | | |
| *Acrocalanus gracilis* | A | - | 13.52 | 0.56 | A | - |
| *Calocalanus pavoninus* | A | - | 4.34 | 0.18 | A | - |
| *Paracalanus indicus* | A | - | 7.44 | 0.31 | 24.00 | 6.09 |
| *P. parvus* | 0.53 | 0.43 | 28.39 | 1.18 | A | - |
| **Phaennidae** | | | | | | |
| *Amallophora crassirostris* | A | - | 20.55 | 0.86 | A | - |
| *Onchocalanus affinis* | A | - | 9.41 | 0.39 | A | - |
| *Phaenna spinifera* | A | - | 1.97 | 0.08 | A | - |
| **Pontellidae** | | | | | | |
| *Calanopia elliptica* | 0.53 | 0.43 | A | - | A | - |
| *Labidocera pectinata* | A | - | 7.44 | 0.31 | A | - |
| *Pontellina plumata* | A | - | A | - | 0.40 | 0.10 |
| **Scolecitrichidae** | | | | | | |
| *Acrocalanus gracilis* | A | - | A | - | 4.80 | 1.22 |
| *Lophothrix frontalis* | 0.53 | 0.43 | 32.16 | 1.34 | A | - |
| *Scaphocalanus echinatus* | A | - | 15.83 | 0.66 | A | - |
| *Scaphocalanus* sp. | 0.53 | 0.43 | 0.61 | 0.03 | A | - |
| *Scolecithrix vittatta* | A | - | 2.31 | 0.10 | A | - |
| *Scolecithrix bradyi* | A | - | 4.34 | 0.18 | A | - |
| *S. danae* | A | - | 21.51 | 0.90 | A | - |
| *Scottocalanus rotundatus* | 0.53 | 0.43 | A | - | A | - |
| **Spinocalanidae** | | | | | | |
| *Monacilla gracilis* | A | - | 7.44 | 0.31 | A | - |
| *M. tenera* | A | - | 4.61 | 0.19 | 4.80 | 1.22 |
| *M. typica* | 0.53 | 0.43 | 36.49 | 1.52 | 14.40 | 3.65 |
| *Spinocalanus longipes* | A | - | A | - | 9.60 | 2.43 |
| **Tharybidae** | | | | | | |
| *Undinella spinifer* | A | - | 2.31 | 0.10 | A | - |
| **CYCLOPOIDA** | | | | | | |
| **Oithonidae** | | | | | | |
| *Oithona similis* | 2.64 | 2.15 | 27.04 | 1.12 | 9.60 | 2.43 |
| *O. spinirostris* | A | - | 0.00 | 0.00 | A | - |
| *Oithona* sp. | A | - | 6.31 | 0.26 | A | - |
| **HARPACTICOIDA** | | | | | | |
| **Aegisthidae** | | | | | | |
| *Aegisthus aculeatus* | A | - | A | - | 0.80 | 0.20 |
| *A. mucronatus* | A | - | 11.72 | 0.49 | A | - |
| **Clytemnestridae** | | | | | | |
| *Clytemnestra scutellata* | A | - | 2.31 | 0.10 | A | - |
| **Ectinosomatidae** | | | | | | |
| *Microsetella rosea* | A | - | 0.61 | 0.03 | 4.80 | 1.22 |
| **Euterpinidae** | | | | | | |
| *Euterpina acutifrons* | 0.53 | 0.43 | A | - | A | - |
| **Miraciidae** | | | | | | |
| *Macrosetella gracilis* | 1.06 | 0.86 | 1.97 | 0.08 | A | - |
| **MORMONILLOIDA** | | | | | | |
| **Mormonillidae** | | | | | | |
| *Mormonilla minor* | 3.17 | 2.58 | 218.84 | 9.10 | 57.60 | 14.60 |
| *M. phasma* | A | - | 40.44 | 1.68 | A | - |
| **POECILOSTOMATOIDA** | | | | | | |
| **Corycaeidae** | | | | | | |
| *Corycaeus catus* | 0.53 | 0.43 | 7.44 | 0.31 | A | - |
| *C. danae* | A | - | 19.82 | 0.82 | A | - |
| *C. speciosus* | 0.53 | 0.43 | A | - | A | - |
| **Oncaeidae** | | | | | | |
| *Conaea gracilis* | 3.17 | 2.58 | 215.29 | 8.96 | 139.20 | 35.29 |
| *Oncaea mediterranea* | A | - | A | - | 4.80 | 1.22 |
| *O. venusta* | 2.12 | 1.72 | 301.01 | 12.52 | 38.40 | 9.74 |
| *Oncaea* sp. | A | - | 8.95 | 0.37 | A | - |
| *Triconia conifera* | A | - | 3.94 | 0.16 | A | - |
| **Sapphirinidae** | | | | | | |
| *Copilia quadrata* | A | - | 1.97 | 0.08 | A | - |
| Unidentified | A | - | 277.46 | 11.54 | A | - |
| Total individuals 100 $m^{-3}$ | 123 | | 2404 | | 394 | |

The most dominant genera *Oncaea* (15.4%), *Oithona* (9.6%), *Pleuromamma* (8.3%), *Eucalanus* (8.0%), *Pleuromamma* (8.0%), *Paracalanus* (7.8%), *Mormonilla* (6.1%), *Corycaeus* (5.1%) and *Clausocalanus* (5.0%) contributed to 69% of the total copepod abundance in the WB.

From the total of 201 species that were identified, 40 species (*Acartia negligens, Euchirella indica, Canthocalanus pauper, Undinula vulgaris, Candacia bradyi, Candacia* sp., *Centropages furcatus, Clausocalanus arcuicornis, Eucalanus crassus, E. monachus, E. mucronatus, Eucalanus* sp., *Euchaeta indica, E. marina, Lucicutia flavicornis, L. maxima, Metridia brevicauda, Pleuromamma indica, P. robusta, Acrocalanus gibber, A. gracilis, A. longicornis, Calocalanus pavo, Paracalanus indicus, P. parvus, Calanopia elliptica, Lophothrix frontalis, Scaphocalanus* sp., *Scolecithrix danae, Oithona similis, O. spinirostris, Macrosetella gracilis, Mormonilla minor, Corycaeus catus, C. danae, C. speciosus, Conaea gracilis, Oncaea venusta, Sapphirina nigromaculata* and *S. ovatolanceolata*) occurred during all seasons in the WB.

However, only two of these *viz. Oithona similis* and *Oncaea venusta* were present at all depths and stations. The total number of species occurring decreased below the thermocline (MLD: 137, TT-BT: 145, BT-300 m: 117, 300-500: 112, 500-1000 m: 101). The season-wise variation in the total number of species was also distinct with 59, 151, 128 and 113 species observed respectively during SUM, FIM, WM and SpIM. Stereozoom and light microscopy photographs of some species identified from the Bay are given in Plates 5-8.

### 7.2.5. Dominant species

Least number of species occurred during SUM. Ten species *viz. O. venusta, C. arcuicornis, E. monachus, Acrocalanus gracilis, Phyllopus indicus, Oithona similis, Mormonilla minor, Pleuromamma indica, Corycaeus danae* and *Oithona* sp. contributed to 76.2% of the total copepods identified (Table 7.7). Due to many missing samples, the spatial distribution of the dominant species could not be analyzed for this season.

During FIM again, 10 dominant species (*O. venusta, Paracalanus indicus, P. parvus, Oithona* sp., *Acrocalanus gibber, Lucicutia flavicornis, Pleuromamma indica, Undinula vulgaris, Eucalanus elongatus* and *E. monachus*) contributed to 50% abundance (Table

Table 7.7. Copepod species contributing ≥2% of total abundance (individuals m$^{-2}$) observed in the upper 1000 m of the western Bay during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM)

| **Season** | **Species** | **Abundance in 1000 m (ind. m$^{-2}$)** | **%** |
|---|---|---|---|
| SUM | *Oncaea venusta* | 5582 | 18.3 |
| | *Clausocalanus arcuicornis* | 4222 | 13.8 |
| | *Eucalanus monachus* | 3848 | 12.6 |
| | *Acrocalanus gracilis* | 2813 | 9.2 |
| | *Phyllopus indicus* | 2094 | 6.9 |
| | *Oithona similis* | 1323 | 4.3 |
| | *Mormonilla minor* | 995 | 3.3 |
| | *Pleuromamma indica* | 914 | 3.0 |
| | *Corycaeus danae* | 769 | 2.5 |
| | *Oithona* sp. | 698 | 2.3 |
| FIM | *Oncaea venusta* | 13562 | 18.6 |
| | *Paracalanus indicus* | 6243 | 8.6 |
| | *Oithona* sp. | 2662 | 3.6 |
| | *Paracalanus parvus* | 2483 | 3.4 |
| | *Acrocalanus gibber* | 2128 | 2.9 |
| | *Lucicutia flavicornis* | 1972 | 2.7 |
| | *Pleuromamma indica* | 1941 | 2.7 |
| | *Undinula vulgaris* | 1907 | 2.6 |
| | *Eucalanus elongatus* | 1845 | 2.5 |
| | *Eucalanus monachus* | 1779 | 2.4 |
| WM | *Oncaea venusta* | 14803 | 18.8 |
| | *Clausocalanus arcuicornis* | 7915 | 10.1 |
| | *Oithona similis* | 6028 | 7.7 |
| | *Mormonilla minor* | 5388 | 6.9 |
| | *Paracalanus indicus* | 3659 | 4.7 |
| | *Oncaea mediterranea* | 2356 | 3.0 |
| | *Pleuromamma indica* | 2087 | 2.7 |
| | *Acrocalanus longicornis* | 2004 | 2.6 |
| | *Eucalanus monachus* | 1987 | 2.5 |
| | *Corycaeus catus* | 1913 | 2.4 |
| | *Oithona plumifera* | 1697 | 2.2 |
| SpIM | *Eucalanus monachus* | 47508 | 17.3 |
| | *Oncaea venusta* | 25872 | 9.4 |
| | *Oithona similis* | 22572 | 8.2 |
| | *Clausocalanus arcuicornis* | 18679 | 6.8 |
| | *Pleuromamma indica* | 18103 | 6.6 |
| | *Pleuromamma robusta* | 8743 | 3.2 |
| | *Lucicutia flavicornis* | 8299 | 3.0 |
| | *Centropages furcatus* | 7020 | 2.6 |
| | *Acrocalanus gracilis* | 6152 | 2.2 |

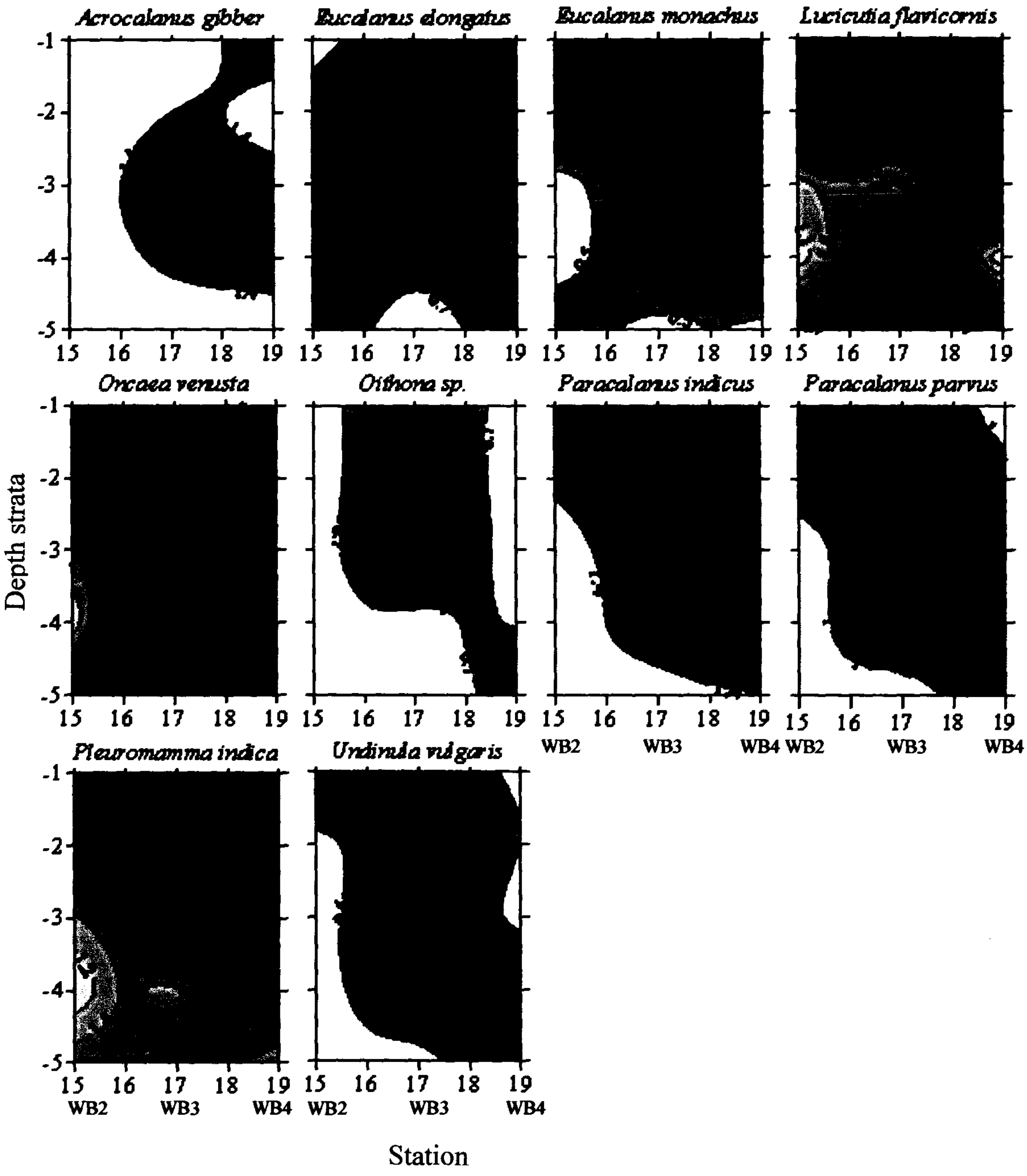


Figure 7.4. Distribution of major copepod species along western Bay during fall inter monsoon. Abundance (number 100m$^{-3}$; on labeled contours) is indicated in log numbers.

Depth strata: -1: Surface-mixed layer depth (mld); -2: top of thermocline (Tl)- Base of thermocline (Bl); -3: Bl- 300m; -4: 300-500m; -5: 500-1000m

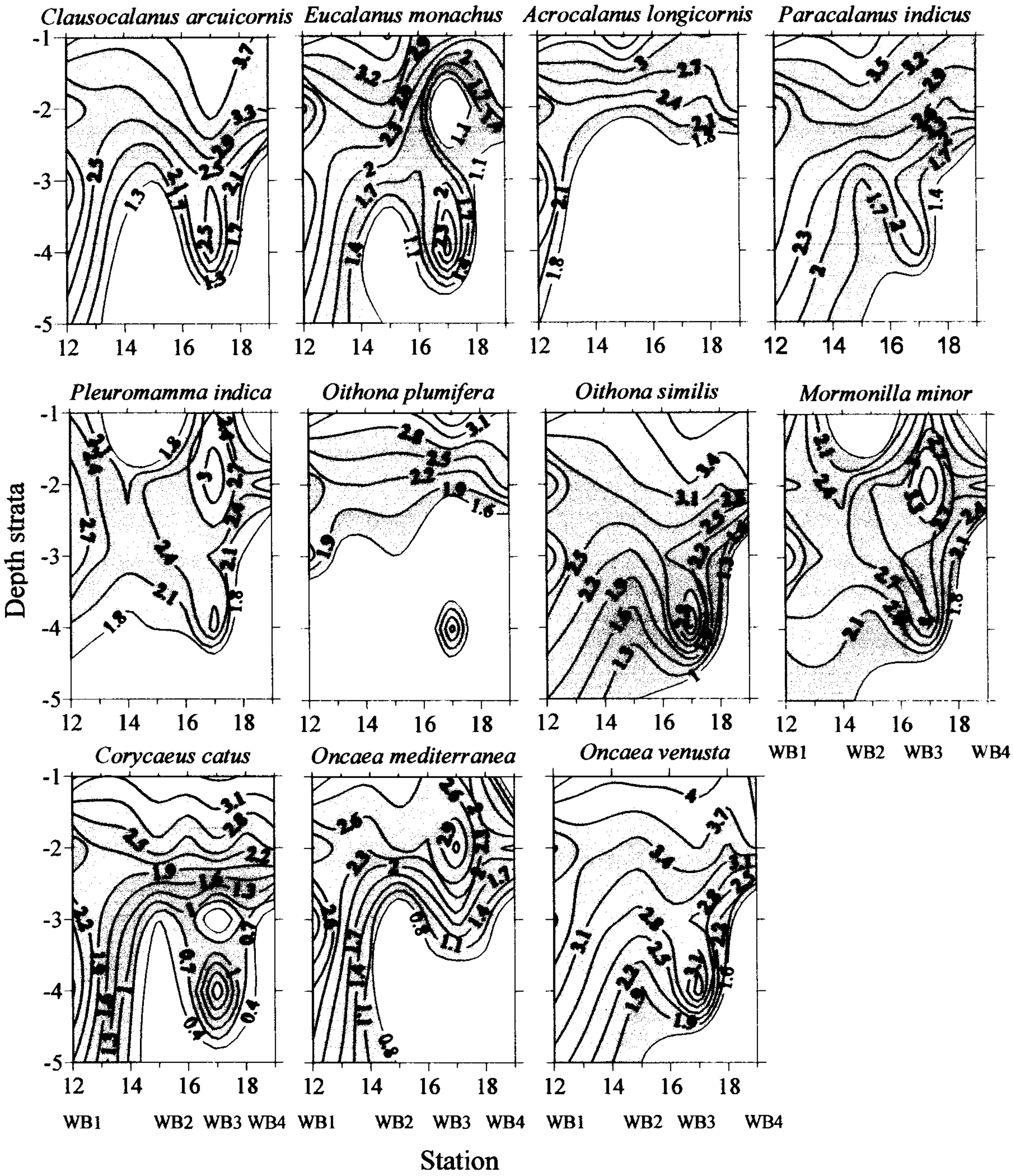


Figure 7.5. Distribution of major copepod species along western Bay during winter monsoon. Abundance (number $100m^{-3}$; on labeled contours) is indicated in log numbers.

Depth Strata: -1: surface - mixed layer depth (mld); -2: top of thermocline (TT) - Base of thermocline (BT); -3: BT - 300m; -4: 300-500m; -5: 500-1000m

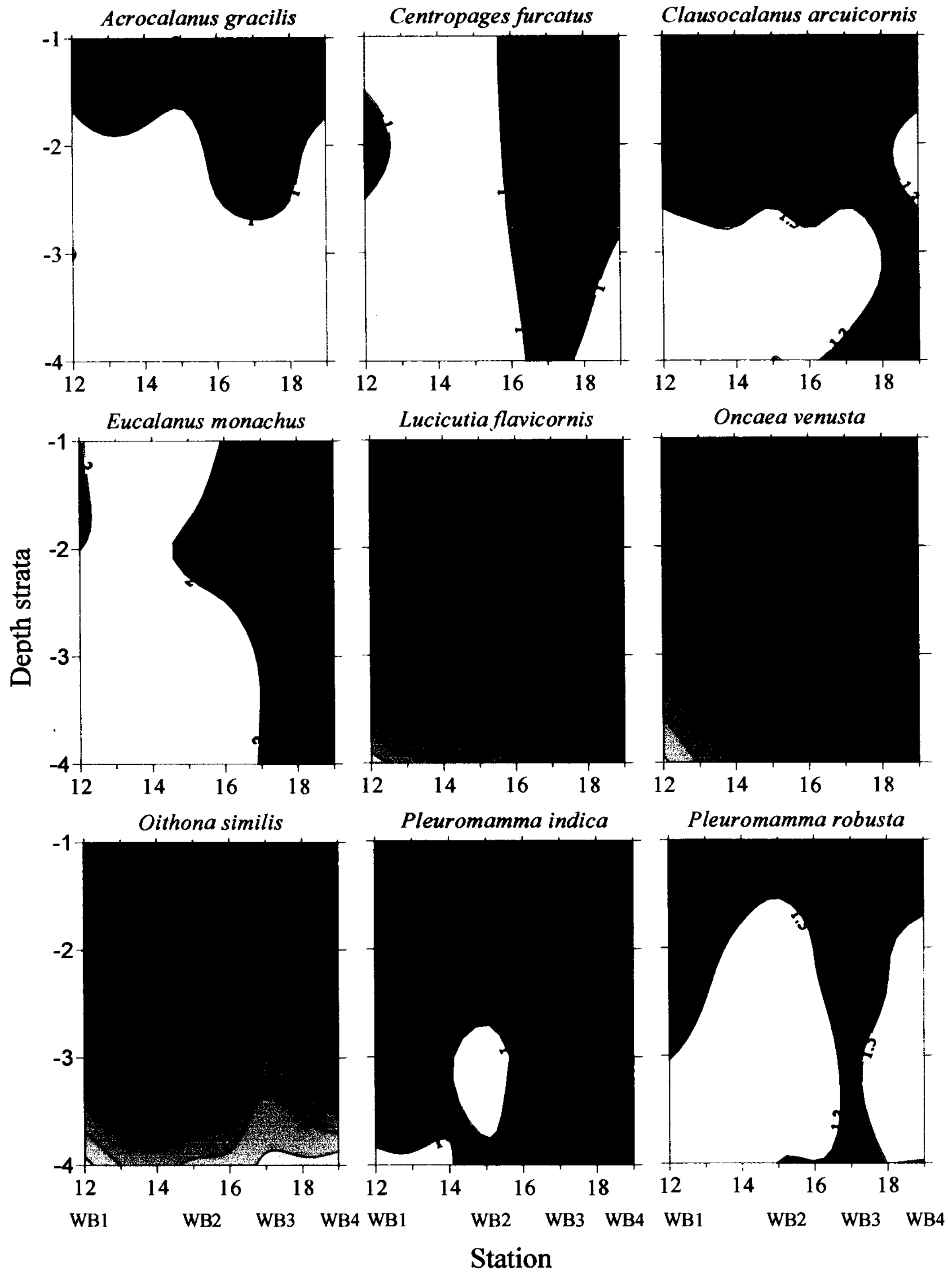


Figure 7.6. Distribution of major copepod species along western Bay during spring inter-monsoon. Abundance (number $100m^{-3}$; on labeled contours) is indicated in log numbers.

Depth strata: -1: Surface-mixed layer depth (mld); -2: top of thermocline (TT)-Base of thermocline (BT); -3: BT-300m; -4: 300-500m

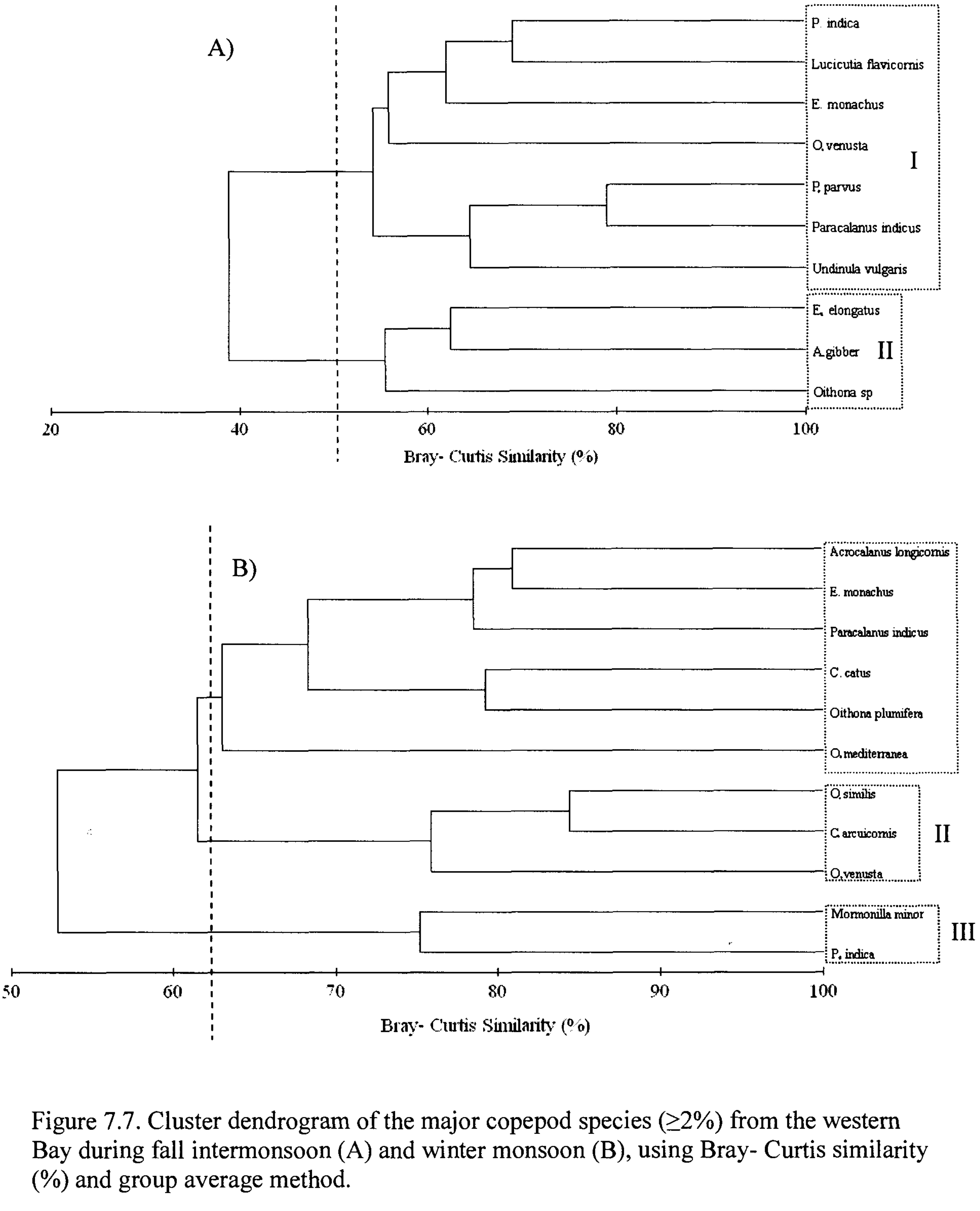


Figure 7.7. Cluster dendrogram of the major copepod species (≥2%) from the western Bay during fall intermonsoon (A) and winter monsoon (B), using Bray- Curtis similarity (%) and group average method.

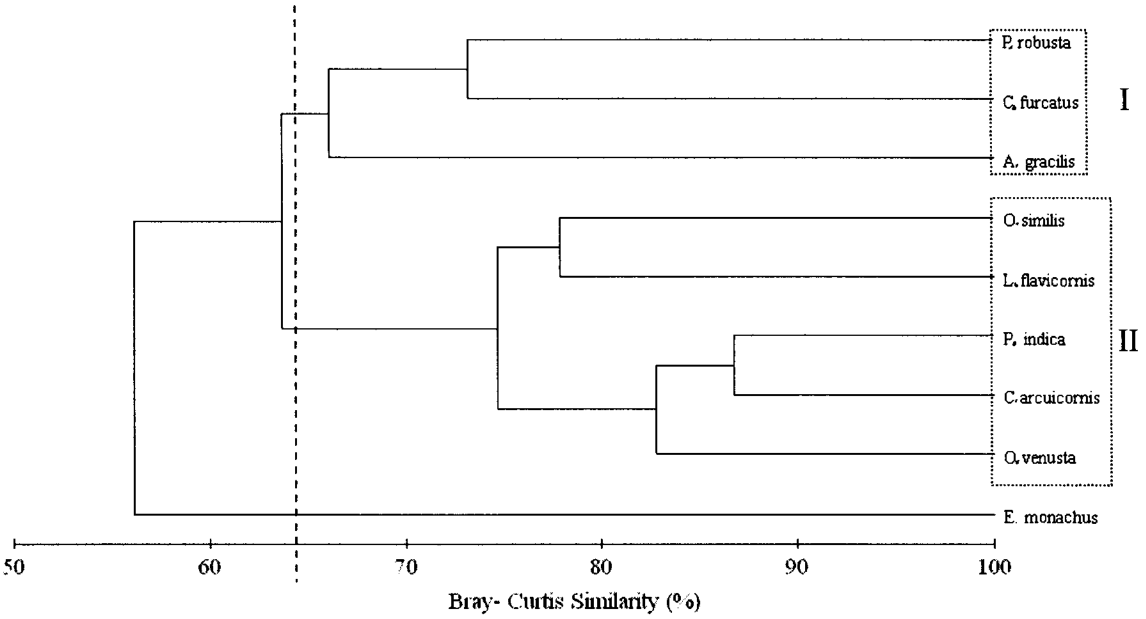


Figure 7.8. Cluster dendrogram of the major copepod species (≥2%) from the western Bay during spring inter monsoon, using Bray- Curtis similarity (%) and group average method.

7.7). *Pleuromamma indica, L. flavicornis, E. monachus, O. venusta, P. parvus, P. indicus* and *U. vulgaris* formed cluster I. They occurred throughout the 1000 m column mostly at WB3 and WB4. Being dominant in the 200-300 m layer at WB3, Group II comprising *E. elongatus, A. gibber* and *Oithona* sp. formed cluster II (Fig. 7.4; Fig. 7.7 A).

During WM, *O. venusta, Clausocalanus arcuicornis, Oithona similis, Mormonilla minor, Paracalanus indicus, Oncaea mediterranea, Pleuromamma indica, Acrocalanus longicornis, E. monachus, Corycaeus catus and Oithona plumifera* in WM accounted for 63.4% of the total copepods (Table 7.7). *Acrocalanus longicornis, E. monachus, P. indicus, C. catus, O. plumifera* and *O. mediterranea* comprising cluster I were abundant in the MLD. They decreased drastically with depth and some were absent below the second or the third stratum at some stations. In cluster II, *O. similis, C. arcuicornis* and *O. venusta* were abundant in the upper two strata but decreased gradually with depth. In cluster III, *M. minor* and *P. indica* were more in the thermocline to 300 m especially at WB1 and WB3 (Fig. 7.5; Fig. 7.7 B).

During SpIM, nine species, *E. monachus, O. venusta, O. similis, C. arcuicornis, P. indica, P. robusta, L. flavicornis, Centropages furcatus* and *Acrocalanus gracilis* were dominant contributing 59% of the total copepods (Table 7.7). *Pleuromamma robusta, C. furcatus* and *A. gracilis* that formed cluster I were observed mostly at WB1 and WB4. While the first two species were observed even in the 500-1000 m stratum at WB3, the last species was confined to the upper two strata only. In cluster II, *O. similis, L. flavicornis, P. indica,* and *O. venusta* were present throughout the 1000 m except that *C. arcuicornis* was absent from the 300-1000 m stratum at WB1 and WB2. *Eucalanus monachus* did not group with any species and was abundant throughout the 1000 m at WB3 and WB4 (Fig. 7.6; Fig. 7.8).

### 7.2.6. Species diversity, evenness and richness

Shannon diversity (*H'*), richness (*d*) and evenness (*J'*) for copepod species varied greatly with depth and stations. The ranges for the three indices during SUM are: *H'* (0.7-4.0), *d* (1.5-4.9), *J'* (0.21-0.94; Fig. 7.9A).

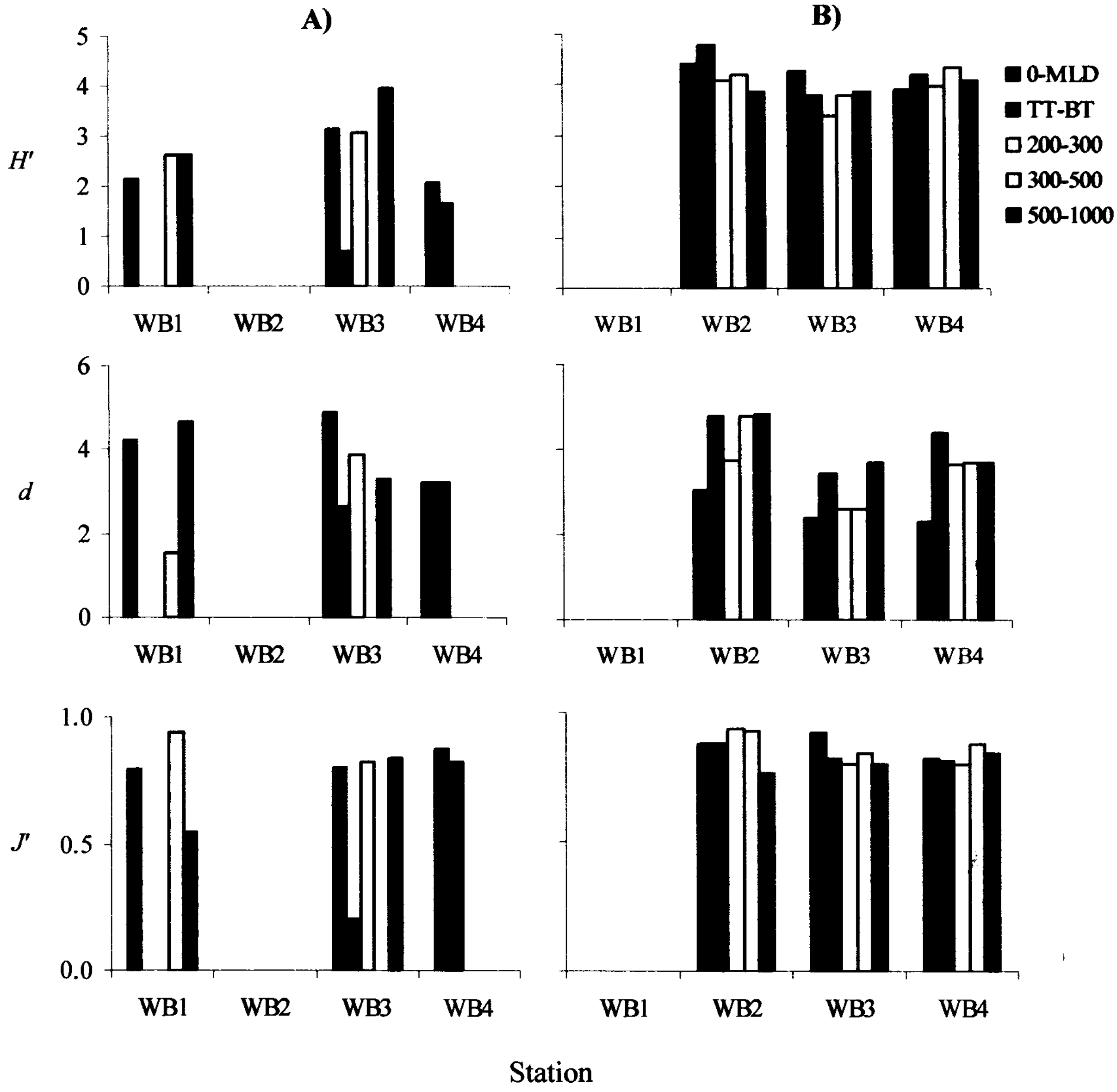


Figure 7.9. Depth-wise variation of copepod species diversity (*H'*), richness (*d*), and evenness (*J'*) at different sampling stations in the western Bay of Bengal during summer monsoon (A) and fall intermonsoon (B)

During FIM, *H'* ranged from 3.4 to 4.8, *d* from 2.3 to 4.8 with their lowest values at WB3. *J'* ranging from 0.76 to 0.93 was higher at WB2. *H'* and *J'* did not vary much with depth. In general, *d* was higher below the MLD (Fig. 7.9B).

*H'* ranged from 3.4 to 4.2 and was higher in the upper two strata during WM. Varying from 2.0 to 3.9, *d* was higher in subsurface depths and seemed to decrease northwards. *J'* varied from 0.72 to 0.88 and was more or less similar over depths and stations (Fig. 7.10 A).

During SpIM, *H'* varying from 1.7 to 4.4, was high in the MLD and also mostly in the lowest strata. It was the lowest in the 200-300 m stratum and increased northwards. Similar distribution trend was observed in case of *d*, which varied from 1.5 to 4.4, with an overall northward decrease. Varying from 0.44 to 0.95, *J'* showed a northward increase in the third stratum (Fig. 7.10 B).

### 7.2.7. Correlation analysis

The mixed layer copepod abundance correlated: a) mostly negatively with temperature; b) positively with salinity during most seasons, and c) positively with chlorophyll (chl) *a* only during FIM. Diversity (*H'*) correlated mostly negatively with total abundance and temperature; mostly positively with chl *a* and salinity. Species richness also correlated negatively with total biomass and abundance except during SUM. It correlated positively with temperature and salinity and, negatively with chl *a*. Evenness was negatively correlated with total biomass, abundance and, temperature. It correlated positively with chl *a* in the monsoons and negatively during inter monsoons (Table 7.8).

## 7.3. Discussion

### 7.3.1. Comparative account of copepod abundance

The following comparative accounts are from different parts of the world oceans mostly from the neritic waters. Spatial variation in their numerical abundance (Nair et al. 1981; Padmavati et al. 1998) ranging from 0.8 to 417920 individuals 100 $m^{-3}$ in the upper 1000 m was also obtained in earlier studies in the Indian Ocean.

In the western Mediterranean, values ranging from 60000-120000 ind. 100 $m^{-3}$ were obtained in the upper 200 m (Fernandez de Puelles et al. 2003). They varied from 1.64 x

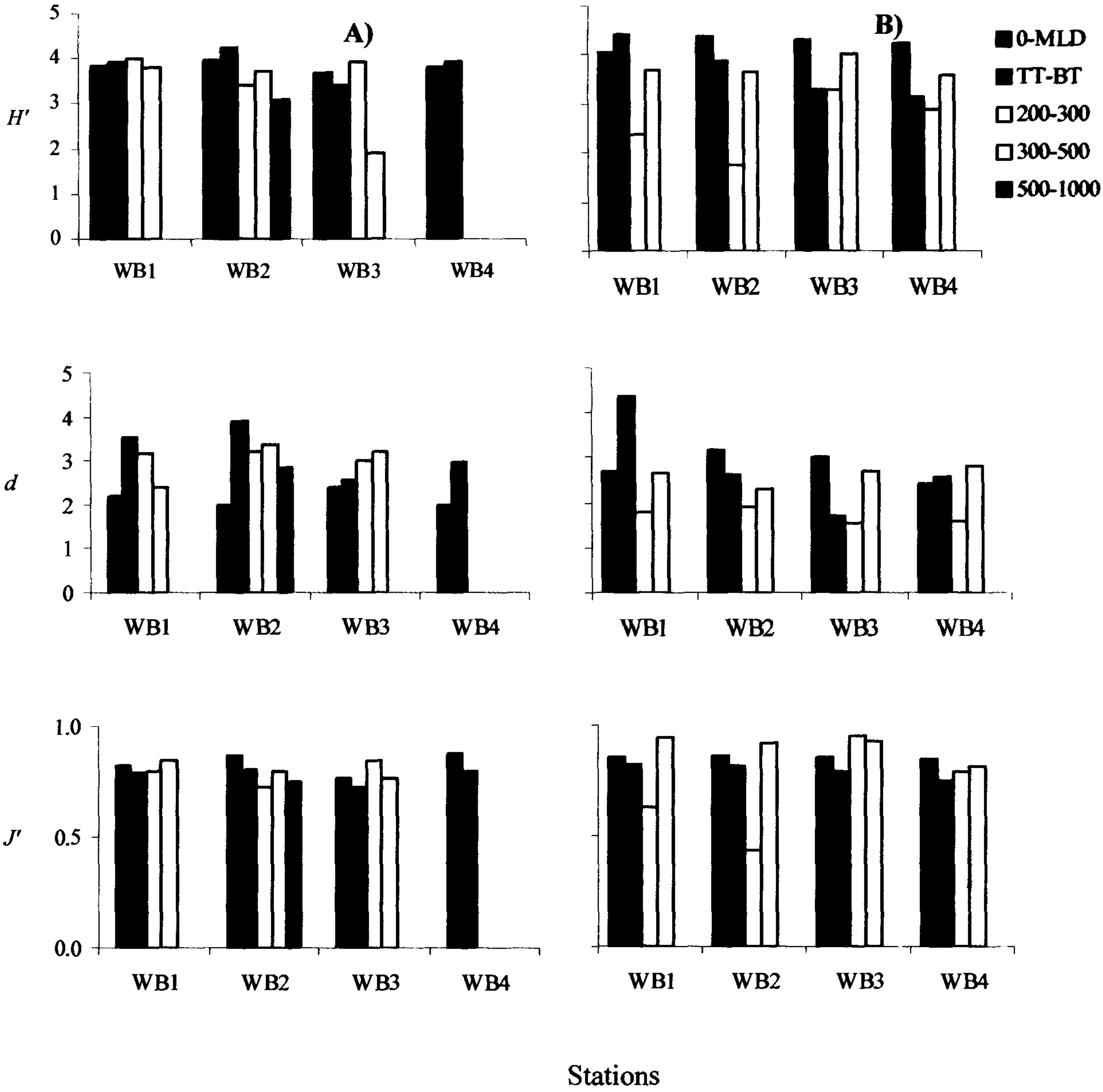


Figure 7.10. Depth-wise variation of copepod species diversity (*H'*), richness (*d*), and evenness (*J'*) at different sampling stations in western Bay of Bengal during winter monsoon (A) and spring intermonsoon (B)

Table 7.8. Correlation coefficients of copepod abundance, species diversity (*H'*), richness (*d*) and evenness (*J'*) with various parameters (total zooplankton biomass, abundance, temperature, salinity, chlorophyll *a* and copepod abundance) in the western Bay during different sampling seasons

| | *Biomass* | *Abundance* | *Temp* | *Sal* | *Chl a* | *Cop_abun* |
|---|---|---|---|---|---|---|
| SUM | | | | | | |
| Cop_abun | **0.998** | 1.000 | 0.001 | 0.358 | -0.716 | 1.000 |
| *H'* | **-0.900** | **-0.925** | 0.377 | 0.021 | 0.399 | **-0.926** |
| *d* | **0.842** | **0.807** | 0.593 | **0.841** | **-0.990** | **0.806** |
| *J* | -0.475 | -0.420 | **-0.909** | **-0.998** | **0.934** | -0.418 |
| FIM | | | | | | |
| Cop_abun | 0.236 | **0.937** | -0.127 | **-0.995** | 0.589 | 1.000 |
| *H'* | 0.080 | -0.781 | -0.191 | **0.977** | **-0.813** | **-0.950** |
| *d* | -0.539 | -1.000 | 0.442 | **0.907** | -0.295 | **-0.946** |
| *J* | 0.778 | **-0.084** | **-0.843** | 0.517 | **-0.982** | -0.426 |
| WM | | | | | | |
| Cop_abun | **0.920** | **0.985** | **-0.996** | **0.957** | -0.182 | 1.000 |
| *H'* | 0.799 | 0.619 | -0.567 | 0.443 | 0.730 | 0.502 |
| *d* | -0.206 | 0.050 | -0.080 | 0.274 | **-0.864** | 0.164 |
| *J* | 0.211 | -0.042 | 0.062 | -0.277 | **0.826** | -0.147 |
| SpIM | | | | | | |
| Cop_abun | **0.908** | 1.000 | -0.200 | 0.577 | 0.005 | 1.000 |
| *H'* | 0.120 | -0.009 | -0.115 | 0.448 | 0.550 | 0.005 |
| *d* | -0.663 | **-0.800** | 0.125 | -0.211 | 0.300 | -0.792 |
| *J* | **-0.771** | **-0.804** | 0.368 | -0.408 | 0.060 | -0.794 |

r values marked in **bold** are significant at $p<0.05$ SUM-summer monsoon; FIM-fall intermonsoon; WM- winter monsoon and, SpIM- spring intermonsoon ; Temp-temperature, Sal-salinity; Chl *a*- chlorophyll *a*; Cope_abun-copepod abundance
All zooplankton related parameters are from mixed layer depth, while the physico-chemical parameters and chl *a* are averages from the upper 120 m.

$10^5$ to 6.40 x $10^7$ ind.100 $m^{-3}$ in the Fukuyama Harbor, an eutrophic inlet of the Inland Sea of Japan (Uye and Liang 1998). Their mean abundance was 12300 ± 6900 ind.100 $m^{-3}$ in the coastal waters off southwestern Taiwan (Lo et al. 2001). Varying seasonally, the abundance ranged from 200 to 18300 ind 100 $m^{-3}$ in the Atlantic coast of southern Morocco (Somoue et al. 2005). Rakhesh et al. (2006) observed high abundance of copepods ranging from 9300 to 14,00400 ind.100 $m^{-3}$ in the shelf waters (50-200 m) of the WB.

As already detailed in Chapter 5, copepods constituted 67-99.7% of the total mesozooplankton standing stocks in the WB. Despite the fact that the stations sampled in this study were in shelf/slope waters (with the maximum depth sometimes exceeding 1000 m), the total number of copepods is comparable to many above listed studies from the near-shore waters. In the upper 100 m, their abundance was in the range of 0.8 to 213540 ind. 100 $m^{-3}$ during SUM, 764 to 114067 ind. 100 $m^{-3}$ during FIM, 394 to 147965 ind. 100 $m^{-3}$ during WM and from 186 to 417920 ind. 100 $m^{-3}$ during SpIM.

### 7.3.2. Influence of hydrography on the abundance and type

Significant differences were observed in abundance between the stations during SUM in particular. The higher abundance in MLD at WB3 during SUM, and WB1 during WM coincided with the existence of cold-core eddies (Chapter 3). In cold-core eddies, enhanced chl *a* was reported earlier in the Bay (Gomes et al. 2000; Prasannakumar et al. 2004, 2007). Increased plankton production in eddies has been observed in many parts of the world oceans (Chapter 6).

As also observed during the IIOE (Panikkar and Rao 1973), rich patches of copepod abundance were observed along the northern Andhra coast during SUM, Orissa coast during intermonsoons and off Madras during the winter monsoon in this study. Off Visakhapatnam, the hydrographical conditions are largely influenced by southerly (August–December, salinity 20.79–32.97 psu) and northerly (January–July, salinity 30.06–34.57) currents, which run skirting the coast. Upwelling during March–May leads to increased phytoplankton production (La Fond 1958; Murty and Varadachari 1968; Rao et al. 1986; Ganapati 1973; Raju 1988; Gomes et al. 2000; Schott and McCreary 2001; Madhupratap et al. 2003;). Chl *a* up to 42 mg $m^{-2}$ was observed at WB3 during SpIM with a dominant diatom community (>90%; Paul 2007). Marked increase in nutrients and salinity at this time of the year compared to offshore waters appears to enhance zooplankton biomass.

As mentioned in Chapter 6, copepod diel vertical migration (DVM; Hays 2003) has been reported from many oceans (Saltzman and Wishner 1997; Smith et al. 1998; Goswami et al. 2000; Jayalakshmy 2000; Madin et al. 2001). However, no significant DVM of copepods was observed in this study except during SpIM. Pronounced oxygen minimum zone (OMZ) in the Bay would have restricted vertical migration of most copepods (Saltzman and Wishner 1997). Highest copepod abundance was always in the MLD, the strata of maximum chlorophyll and primary production (Hobson and Lorenzen 1972; Ortner et al. 1980; Herman 1983, 1989; Roman et al. 1986). Their generally negative correlation with chl *a* in this study appears to be due to their grazing activity. Similar to that in the CB and also in other studies (Wishner and Allison 1986; Padmavati et al. 1998), their numbers decreased with depth. From their relatively higher proportion at deeper depths in the Bay and also in the Arabian Sea (Madhupratap and Haridas 1990), it appears that they are important in waters where food is scarce.

Tropical waters being warmer and relatively stable compared to temperate waters, little seasonal changes are expected in hydrography (Longhurst and Pauly 1987) and in plankton (Blackburn 1981; Moore and Sander 1977). Though some studies in the tropics do find seasonal variability in zooplankton (Calef and Grice 1967), in coastal tropical oceans, such patterns are generally related to variability of annual rainfall (Chisholm and Roff 1990). The North Indian Ocean is unique in this aspect where the seasonal variability is driven primarily by the monsoons. In the WB, highly significant seasonal variation in copepod abundance was observed, with the entire transect becoming more productive during SpIM (36778 ind. 100 $m^{-3}$), followed by WM (33047 ind. 100 $m^{-3}$), FIM (26761 ind. 100 $m^{-3}$) and SUM (16161 ind. 100 $m^{-3}$). Seasonal changes in copepod abundance with a spring maximum have been found in many parts of tropical oceans (Moore 1949; Bsharah 1957; Menzel and Ryther 1961; Madhu et al. 2007). Similar to studies from estuaries on the West coast of India (Pillai et al. 1973; Madhupratap 1987, 1979; Madhu et al. 2007), copepod abundance correlated positively with surface salinity in this study from the East coast of India.

### 7.3.3. Prominent orders and families in the Bay of Bengal

Six orders of Copepoda *i.e.* Calanoida, Cyclopoida, Harpacticoida, Mormonilloida, Poecilostomatoida and Siphonostomatoida identified in this study are all previously reported from the Arabian Sea (Madhupratap and Haridas 1990; Bottger-Schnack 1995). In spite of the seasonal differences in the distribution patterns of these orders in the upper 1000 m, Calanoida was always dominant irrespective of seasons, as has also been reported in all oceans (Pacific: Farran 1936; Atlantic: Deevey and Brooks 1977; Indian Ocean: Madhupratap and Haridas 1990). All the calanoid (Madhupratap et al. 1990; Padmavati et al. 1998; Madhupratap et al. 2001) as well as non-calanoid (Bottger-Schnack 1995) families of copepods observed in this study have been reported previously from the Arabian Sea. Increased percentage of calanoids in the 300-500 m layer during intermonsoons and, in the deepest layer during SUM was largely due to the contribution of low-oxygen- tolerant species of the families Lucicutiidae, Metridinidae, Augaptilidae and Spinocalanidae. The oxygen content in these depths was relatively more during WM.

Only a few families were numerically dominant, contributing ≥5% of the total copepods in a total of 38 families. A clear dominance in their pattern of distribution was evident during all seasons. Sometimes, families such as Megacalanidae, Rataniidae, Clausiidae were so poor in abundance that as less as just one specimen per whole sample was recorded. At least four to nine of such rare families, due to lower abundance were absent from the samples in every season. Vertical partitioning as well as seasonal variation of predominant families was evident from this data.

The abundance of herbivorous calanoids like Paracalanidae, Eucalanidae, Acartiidae and Clausocalanidae is commonly reported in the surface waters in oceans (Stephen and Kunjamma 1987; Kouwenberg 1994; Padmavati et al. 1998; Saltzman and Wishner 1997; Cornils et al. 2007). Metridinidae comprised largely of *Pleuromamma indica,* an omnivorous, low-oxygen tolerant and vertically migrating species (Saraswathy and Iyer 1986) in the Indian Ocean.

Cyclopoida comprising exclusively Oithonidae, though present throughout the column, was mostly abundant in the thermocline. Oithonids are known to be eurythermal, euryhaline and globally occurring omnivorous species. This observation agrees with the studies of Nishida and Marumo (1982) and Padmavati et al. (1998). The warm water families Corycaeidae, Oncaeidae and Sapphirinidae (Raymont 1983) belonging to the second dominant order Poecilostomatoida were also abundant in the MLD and their abundance/occurrence decreased with depth. However, similar to observations of Bottger-Schnack (1995), Oncaeidae mostly increased again in deeper depths. Mormonillidae, the mesopelagic family (Boxshall 1986) was abundant at all depths below MLD. The most abundant species among harpacticoids, *Macrosetella gracilis*, was present throughout the 1000 m as observed by Weikert (1982) was abundant in the 300-500 m stratum (11%) in SUM.

As also demonstrated by Deevey and Brooks (1977), larger copepods occurred mainly in deeper waters with smaller species being more numerous at the surface.

### 7.3.4. First Reports from this study and significance

A total of 201 species were recorded in the present investigation from the WB that covered four different seasons. They are mostly tropical-subtropical with some of them having cosmopolitan and circumglobal distribution (Fleminger and Hulsemann 1973; Table 7.9). Most of these species identified have been recorded in previous studies in the Indian Ocean. However, 11 species from this transect are recorded for the first time in the Indian Ocean. *Aetideopsis tumurosa*, *Chiridius longispinus*, *Amallophora crassirostris*, *A. irritans* and *Pseudoamallothrix ovata* occurred only in the WB. Six species *i.e.* *Euchirella rostromagna*, *Heterorhabdus pacificus*, *Xanthocalanus pectinatus*, *Scottocalanus rotundatus*, *Monacilla gracilis* and *Undinella spinifer* were found in the central transect as well.

The following species are reported previously from the coastal waters of the Bay: *Paracalanus aculeatus*, *Pareucalanus attenuatus*, *Eucalanus crassus*, *E. monachus*, *E. pseudattenuatus*, *Canthocalanus pauper*, *Euchaeta concinna*, *E. marina*, *E. indica*, *Temora discaudata*, *T. turbinata*, *Acartia erythraea*, *Mesocalanus tenuicornis*, *Lucicutia flavicornis*, *Candacia bradyi*, *C. pachydactyla*, *Centropages calaninus*, *C. furcatus*, *C. gracilis*, *Pontellina plumata*, *Undinula vulgaris*, *Cosmocalanus darwini*, *Labidocera acuta*, *L. pavo*, *Calanopia elliptica*, *C. minor*, *Acrocalanus gibber*, *Sapphirina nigromaculata*, *Corycaeus catus*, *C. danae*, *C. speciosus*, *Farranula gibbula*, *Oncaea*

Table 7.9. List of copepod species from the central and western Bay of Bengal recorded during this study. Their previous records and other relevant information also included

| Sr. No | Species | CB av % | WB av % | Previous records |
|---|---|---|---|---|
| 1 | *Acartia amboinensis* Carl, 1907 | 0.013 | 0.048 | Arabian Sea; Malacca strait |
| @2 | *A. centrura* Giesbrecht, 1889 | A | 0.025 | Arabian Sea; BoB |
| @3 | *A. danae* Giesbrecht, 1889 | 0.013 | A | Arabian Sea; BoB |
| @4 | *A. erythraea* Giesbrecht, 1889 | 0.010 | 0.163 | Arabian Sea, BoB |
| @5 | *A. negligens* Dana, 1849 | 0.294 | 0.472 | Arabian Sea; BoB |
| @6 | *A. southwelli* Sewell, 1914 | 0.031 | A | Arabian Sea; BoB |
| @7 | *A. spinicauda* Giesbrecht, 1889 | 0.034 | 0.556 | Arabian Sea; Malacca strait; BoB |
| @8 | *Acartiella sewelli* Steuer, 1934 | 0.012 | A | Arabian Sea; BoB |
| $9 | *Aetideopsis tumurosa* Sars, 1903 | A | 0.024 | Sub-antarctic Pacific |
| 10 | *Aetideus acutus* Farran, 1929 | 0.106 | 0.049 | Trop, sub-trop |
| 11 | *A. armatus* Boeck, 1872 | 0.072 | 0.001 | IO |
| 12 | *A. bradyi* A Scott, 1909 | 0.012 | A | Indo Pacific, IO |
| 13 | *A. giesbrechtii* Cleve, 1904 | A | 0.004 | Trop, sub-trop; IO |
| 14 | *Aetideus* sp. | 0.026 | A | |
| $15 | *Chiridius longispinus* Tanaka, 1957 | A | 0.015 | W Pacific |
| $16 | *Chiridiella* sp. | 0.014 | A | Atlantic |
| 17 | *Chirundina streetsi* Giesbrecht, 1895 | A | 0.005 | SW Pacific; IO |
| 18 | *Euchirella amoena* Giesbrecht, 1888 | 0.056 | 0.006 | SW Pacific; IO |
| 19 | *E. bella* Giesbrecht, 1888 | 0.003 | A | Arabian Sea |
| 20 | *E. bitumida* With, 1915 | 0.077 | 0.046 | N Atlantic; SW Pacific, IO |
| 21 | *E. curticauda* Giesbrecht, 1888 | 0.007 | 0.006 | I, A, P |
| 22 | *E. galeata* Giesbrecht, 1888 | 0.063 | 0.040 | N Pacific, IO |
| 23 | *E. indica* Vervoort, 1949 | 0.231 | 0.154 | Trop, sub-trop; Indo Pacific |
| 24 | *E. latirostris* Farran, 1929 | A | 0.0001 | Warm Sub-antarctic waters; IO |
| 25 | *E. maxima* Wolfenden, 1905 | 0.002 | A | Atlantic; IO |
| 26 | *E. messinensis* Claus, 1863 | 0.008 | A | Trop, sub- trop; temperate; IO |
| 27 | *E. rostrata* Claus, 1866 | 0.035 | A | I, A, P |
| $28 | *E. rostromagna* Wolfenden, 1911 | 0.020 | 0.004 | Antarctic convergence |
| 29 | *E. similis* Wolfenden, 1911 | 0.017 | A | I, A, P |
| $30 | *E. speciosa* Grice and Hulsemann, 1968 | 0.024 | A | Sub-tropical Pacific |
| 31 | *E. truncata* Esterly, 1911 | 0.029 | A | SW Pacific, IO |
| 32 | *E. venusta* Giesbrecht, 1888 | 0.010 | 0.002 | Indo Pacific |
| @33 | *Euchirella* sp. | 0.147 | 0.195 | Bay of Bengal |
| 34 | *Psedochirella dentata* A. Scott, 1909 | 0.001 | A | Indo Pacific |
| 35 | *P. mawsoni* Vervoort, 1957 | 0.005 | A | IO, Pacific |
| 36 | *Gaetanus arminger* Giesbrecht, 1888 | 0.020 | A | I, A, P |
| 37 | *G. kruppii* Giesbrecht, 1903 | 0.071 | 0.0002 | I, A, P |
| 38 | *G. miles* Giesbrecht, 1888 | 0.080 | 0.010 | Trop, sub-trop; temp; I, A, P |
| 39 | *G. minor* Farran, 1905 | 0.062 | 0.015 | SW Pacific, IO |
| 40 | *G. pileatus* Farran, 1903 | 0.007 | 0.015 | I, A, P |
| 41 | *Gaidius pungens* Giesbrecht, 1895 | 0.032 | A | All oceans 200-1000m |
| 42 | *Undeuchaeta major* Giesbrecht, 1888 | 0.005 | A | SW Pacific; IO |
| 43 | *U. plumosa* Lubbock, 1856 | 0.098 | 0.009 | Trop, sub-trop, temp; I, A, P |
| 44 | *Undeuchaeta* sp. | 0.002 | 0.017 | |
| 45 | *Valdiviella brevicornis* Sars, 1905 | A | 0.041 | IO; N Atlantic; bathypelagic |
| 46 | *Arietellus giesbrechtii* Sars, 1905 | 0.004 | 0.017 | NW Atlantic; eq Pac; IO |
| 47 | *A. setosus* Giesbrecht, 1892 | 0.001 | A | Trop Atlantic, IO |
| 48 | *Arietellus* sp. | 0.006 | A | |
| 49 | *Augaptilus glacialis* Sars, 1900 | 0.001 | A | N Atlantic; Arctic; Pacific; IO |
| 50 | *Augaptilus* sp. | 0.081 | A | Arabian Sea |
| 51 | *Centraugaptilus rattrayi* T. Scott, 1894 | 0.011 | A | I, A, P |
| 52 | *C. horridus* Farran, 1908 | 0.084 | A | Arabian Sea, Pacific |
| 53 | *Centraugaptilus* sp. | 0.003 | A | |
| 54 | *Euaugaptilus angustus* Sars, 1905 | 0.001 | 0.036 | Atlantic, Arabian Sea |
| 55 | *E. bullifer* Giesbrecht, 1889 | 2.020 | 0.013 | I, A, P, Arabian Sea |

| | | | | |
|---|---|---|---|---|
| 56 | *E. facilis* Farran, 1908 | 0.046 | A | N Atlantic, Arabian Sea |
| 57 | *E. hecticus* Giesbrecht, 1889 | 0.013 | 0.431 | I, A, P; Arabian Sea |
| 58 | *E. laticeps* Sars, 1905 | 0.026 | 0.0002 | Atlantic; Arabian Sea |
| 59 | *E. longimanus* Sars, 1905 | 0.002 | A | Temp; Atlantic; Pacific; W IO |
| 60 | *E. magnus* Wolfenden, 1904 | 0.004 | A | N Atlantic, Antarctic; IO |
| \$61 | *E. mixtus* Brodsky, 1950 | 0.008 | A | Bering Sea; Pacific; Med |
| 62 | *E. nodifrons* Sars, 1905 | 0.002 | A | N Atlantic; IO |
| 63 | *E. oblongus* Sars, 1905 | 0.067 | 0.001 | N Atlantic; IO; Arabian Sea |
| 64 | *E. rigidus* Sars, 1907 | 0.008 | 0.016 | Pacific; IO |
| @65 | *Haloptilus acutifrons* Giesbrecht, 1892 | 0.183 | A | IO; Med; Arabian Sea; BoB |
| 66 | *H. longicornis* Claus, 1863 | 0.415 | 0.198 | Med; Arabian Sea; USSR |
| 67 | *H. mucronatus* Claus, 1863 | 0.001 | A | S Atlantic; Mediterranean |
| 68 | *H. ornatus* Giesbrecht, 1892 | 0.011 | 0.039 | Atlantic; Med; W IO; Malay |
| 69 | *H. spiniceps* Giesbrecht, 1892 | 0.042 | 0.010 | Warm currents of I, A, P |
| \$70 | *Pseudhaloptilus abbreviatus* Sars, 1905 | 0.034 | A | N Atlantic |
| 71 | *P. eurygnathus* Sars, 1920 | 0.003 | A | N Atlantic; Arabian Sea |
| 72 | *P. pacificus* MW Johnson, 1936 | 0.007 | 0.0002 | N Pacific; Japanese coast; W IO |
| @73 | *Canthocalanus pauper* Giesbrecht, 1888 | 0.132 | 0.840 | I, A, P; BoB |
| @74 | *Cosmocalanus darwinii* Lubbock, 1860 | 0.006 | 0.137 | Trop, sub-trop Oceans; IO; BoB |
| @75 | *Mesocalanus tenuicornis* Dana, 1849 | 0.023 | 0.031 | Trop, sub-trop oceans; IO; BoB |
| @76 | *Nannocalanus minor* Claus, 1863 | 0.012 | A | Trop, sub-trop oceans; IO; BoB |
| @77 | *Undinula vulgaris* Dana, 1849 | 0.728 | 1.650 | Neretic; trop; IO; BoB |
| @78 | *Candacia ethiopica* Dana, 1849 | A | 0.003 | Cosmopotitan; trop; IO, BoB |
| @79 | *C. bispinosa* Claus, 1863 | 0.001 | A | IO; BoB |
| @80 | *Candacia bradyi* A Scott, 1902 | 0.218 | 0.396 | Trop; IO; BoB |
| @81 | *C. catula* Giesbrecht, 1889 | 0.023 | 0.006 | Trop; IO; BoB |
| @82 | *C. discaudata* A Scott, 1909 | 0.031 | 0.237 | Trop; IO; BoB |
| @83 | *C. pachydactyla* Dana, 1849 | 0.043 | 0.064 | Cosmopolitan; trop; IO; BoB |
| @84 | *Paracandacia truncata* Dana, 1849 | 0.357 | 0.615 | IO; BoB |
| @85 | *P. simplex* Giesbrecht, 1889 | 0.002 | A | IO; BoB |
| 86 | *Candacia* sp. | 0.174 | 0.272 | |
| 87 | *Centropages alcocki* Sewell, 1912 | 0.009 | 0.018 | Trop |
| @88 | *C. calaninus* Dana, 1849 | 0.085 | 0.051 | Cosmopolitan; trop; BoB |
| @89 | *C. dorsispinatus* Thompson & Scott, 1903 | 0.048 | A | Trop; BoB |
| @90 | *C. furcatus* Dana, 1849 | 0.186 | 0.974 | Trop; BoB |
| @91 | *C. gracilis* Dana, 1849 | 0.020 | 0.005 | Trop; BoB |
| 92 | *C. orsinii* Giesbrecht, 1889 | 0.040 | A | IO; Malacca strait |
| 93 | *Centropages* sp. | 0.077 | 0.010 | |
| 94 | *Clausocalanus arcuicornis* Dana, 1849 | 4.491 | 3.568 | Cosmopolitan; trop, IO |
| 95 | *C. furcatus* Brady, 1883 | 1.257 | 1.327 | Cosmopolitan; trop, sub-tropic |
| 96 | *C. pergens* Farran, 1926 | 0.201 | 0.100 | Trop; sub-trop |
| 97 | *Clausocalanus* sp. | 0.090 | 0.009 | |
| 98 | *Drepanopsis frigidus* Wolfenden, 1911 | 0.008 | 0.025 | IO |
| \$99 | *D. orbus* sp. | 0.006 | A | Sagami Bay; Japan |
| @100 | *E. crassus* Giesbrecht, 1888 | 0.680 | 0.294 | BoB |
| @101 | *E. subcrassus* Giesbrecht, 1888 | 0.073 | A | BoB |
| @102 | *E. elongatus* Dana, 1849 | 1.939 | 0.968 | W Atlantic; Arabian Sea; BoB |
| @103 | *E. monachus* Giesbrecht, 1888 | 2.206 | 6.535 | W Atlantic; Gulf of Mexico; BoB |
| 104 | *E. mucronatus* Giesbrecht, 1888 | 0.546 | 0.231 | Florida current; Arabian Sea |
| @105 | *E. pseudattenuatus* Sewell, 1947 | 0.057 | 0.0003 | BoB |
| 106 | *Eucalanus* sp. | 0.281 | 0.371 | |
| @107 | *Pareucalanus attenuatus* Dana, 1849 | 0.446 | 0.377 | SW Pacific; BoB |
| 108 | *Subeucalanus crassus* Giesbrecht, 1888 | 0.020 | A | IO; Arabian Sea |
| @109 | *Euchaeta concinna* Dana, 1849 | 0.074 | 0.241 | IO; Pacific |
| @110 | *E. indica* Wolfenden, 1905 | 0.163 | 0.187 | Malay; Maldives archipelago; IO |
| @111 | *E. marina* Prestandrea, 1833 | 0.898 | 0.815 | I, A, P; BoB |
| 112 | *E. media* Giesbrecht, 1888 | 0.004 | A | I, A, P |
| 113 | *E. plana* Mori, 1937 | 0.016 | A | Arabian Sea |
| 114 | *Euchaeta* sp. | 0.535 | 0.134 | |

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|---|---|---|---|---|
| 115 | *Pareuchaeta malayensis* Sewell, 1929 | 0.006 | A | Arabian Sea |
| 116 | *Temoropia mayumbaensis* T. Scott, 1894 | 0.440 | 0.420 | NW Atlantic, Arabian Sea |
| 117 | *Disseta palumboi* Giesbrecht, 1889 | 0.001 | A | I, A, P |
| 118 | *Hemirhabdus grimaldi* Richard, 1893 | A | 0.006 | I, A, P, Arabian Sea |
| 119 | *Heterorhabdus abyssalis* Giesbrecht, 1889 | 0.156 | 0.079 | I, A, P |
| 120 | *H. fistulosus* Tanaka, 1964 | A | 0.003 | NW Pacific; IO |
| [\$]121 | *H. pacificus* Brodsky, 1950 | 0.021 | 0.028 | NW Pacific |
| 122 | *H. papilliger* Claus, 1863 | 0.548 | 0.282 | All oceans |
| 123 | *H. spinifrons* Claus, 1863 | 0.184 | 0.239 | All oceans |
| 124 | *H. subspinifrons* Tanaka, 1964 | 0.000 | A | S IO; S Atlantic; NW Pacific |
| 125 | *H. vipera* Giesbrecht, 1889 | 0.015 | A | I, A, P |
| 126 | *Heterorhabdus* sp. | 0.164 | 0.049 | |
| 127 | *Paraheterorhabdus robustus,* Farran 1908 | 0.081 | 0.068 | Atlantic; Antarctic; Indo Pacific |
| 128 | *Heterostylites longicornis* Giesbrecht 1889 | 0.076 | 0.091 | I, A, P; Arabian Sea; Malay |
| 129 | *H. major* F. Dahl, 1894 | 0.002 | A | Atlantic; IO; Antarctic; USSR |
| 130 | *Lucicutia bicornuta* Wolfenden, 1905 | 0.002 | A | Atlantic; IO; Malay; Antarctic |
| [@]131 | *L. flavicornis* Claus, 1863 | 4.823 | 3.251 | Trop I, A, P; Arabian Sea; BoB |
| 132 | *L. longispina* Tanaka, 1963 | 0.003 | A | W Pacific; IO |
| 133 | *L. lucida* Farran, 1908 | 0.007 | 0.038 | Atlantic; Pacific; IO |
| 134 | *L. magna* Wolfenden, 1903 | 0.003 | 0.028 | Atlantic; Med; Antarctic; IO |
| 135 | *L. maxima* Steuer, 1904 | 1.050 | 0.916 | IO; Malay |
| 136 | *L. ovalis* Giesbrecht, 1889 | 0.169 | 0.170 | I, A, P |
| 137 | *Mecynocera clausii* Thompson, 1888 | 0.196 | 0.171 | Trop, sub-trop, temp; epipelagic; IO |
| 138 | *Megacalanus princeps* Brady, 1883 | 0.002 | 0.035 | I, A, P; Antarctic |
| [@]139 | *Gaussia princeps* T. Scott, 1894 | 0.151 | 0.025 | Pacific; USSR; IO; BoB |
| 140 | *Metridia brevicauda* Giesbrecht, 1889 | 0.544 | 0.625 | Atlantic; IO; Malay |
| 141 | *M. cuticauda* Giesbrecht, 1889 | 0.092 | 0.155 | Pacific; Atlantic; Malay; IO |
| [\$]142 | *M. pacifica* Brodsky, 1950 | 0.008 | A | N Pacific; Atlantic |
| 143 | *M. princeps* Giesbrecht, 1889 | 0.176 | 0.005 | Atlantic; IO; Malay |
| 144 | *Metridia* sp. | 0.147 | 0.002 | |
| 145 | *Pleuromamma abdominalis* Lubbock 1856 | 0.145 | A | I, A, P |
| 146 | *P. gracilis* Claus, 1863 | 1.032 | 0.736 | I, A, P |
| [@]147 | *P. indica* Wolfenden, 1905 | 6.529 | 6.244 | Indo Pacific; BoB |
| 148 | *P. quadrangulata* F. Dahl, 1893 | 0.144 | 0.001 | IO |
| 149 | *P. robusta* F. Dahl, 1893 | 0.389 | 0.822 | IO |
| 150 | *P. xiphias* Giesbrecht, 1889 | 0.186 | 0.010 | IO |
| 151 | *Pleuromamma* sp. | 0.151 | 0.199 | |
| 152 | *Nullosetigera bidentata* Brady, 1883 | 0.040 | A | Arabian Sea |
| 153 | *Nullosetigera* sp. | 0.004 | 0.037 | |
| 154 | *Bestiolina similis* Sewell 1914 | 0.005 | A | W IO; SW Pacific; Malacca strait |
| [@]155 | *A. gibber* Giesbrecht, 1888 F,M | 0.444 | 0.823 | SW Pacific; BoB |
| [@]156 | *A. gracilis* Giesbrecht, 1888 | 0.825 | 1.027 | Tropical oceans; Bay of Bengal |
| [@]157 | *A. longicornis* Giesbrecht, 1888 | 0.735 | 1.433 | SW Pacific; Malacca strait; BoB |
| [@]158 | *A. monachus* Giesbrecht, 1888 | 0.019 | 0.026 | SW Pacific; BoB |
| 159 | *Calocalanus longispinus* Shmeleva, 1978 | 0.001 | A | SW Pacific; IO |
| [@]160 | *C. pavo* Dana, 1849 | 0.721 | 0.653 | Trop, sub-trop, temp; BoB |
| 161 | *C. pavoninus* Farran, 1936 | 0.015 | 0.035 | Trop I, A, P |
| 162 | *C. plumulosus* Claus, 1863 | 0.209 | 0.199 | Trop, sub-trop, temp; Med |
| 163 | *Paracalanus indicus* Wolfenden, 1905 | 4.341 | 5.581 | Trop, sub-trop, temp; Med; W IO |
| [@]164 | *P. aculeatus* Giesbrecht, 1888 | 0.503 | 1.026 | Arabian Sea; IO; BoB |
| [@]165 | *P. crassirostris* Dahl, 1894 | 0.269 | A | SW Pacific; IO; BoB |
| [@]166 | *P. parvus* Claus, 1863 | 0.415 | 1.159 | Arabian Sea; IO; BoB |
| [\$]167 | *Amallophora conifer* sp. | 0.018 | A | 400-600m W Pacific |
| [\$]168 | *A. crassirostris* sp. | A | 0.051 | 0-1000m W Pacific |
| [\$]169 | *A. irritans* sp. | A | 0.055 | 0-1000m W Pacific |
| [\$]170 | *A. oculata* sp. | 0.016 | A | 0-1000m W Pacific |
| 171 | *Cephalophanes frigidus* Wolfenden, 1911 | A | 0.012 | IO, Atlantic; Antarctic |
| 172 | *Onchocalanus affinis* With, 1915 | A | 0.059 | N Atlantic; Arabian Sea |
| 173 | *Phaenna spinifera* Claus, 1863 | A | 0.123 | I, A, P; Med; Arabian Sea |

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|---|---|---|---|---|
| $174 | *Xanthocalanus pectinatus* sp. | 0.005 | 0.107 | 0-1000m W Pacific |
| 175 | *Xanthocalanus* sp. | 0.004 | A | |
| 176 | *Calanopia aurivilli* Cleve, 1901 | 0.026 | A | NW Atlantic; Arabian Sea |
| @177 | *C. elliptica* Dana, 1849 | 0.114 | 0.123 | NW Atlantic; Arabian Sea; BoB |
| @178 | *C. minor* A. Scott, 1902 | 0.027 | 0.010 | NW Atlantic; Arabian Sea; BoB |
| @179 | *Labidocera acuta* Dana, 1849 | 0.058 | 0.107 | C Atlantic; oceanic or coastal; BoB |
| @180 | *L. minuta* Giesbrecht, 1889 | A | 0.018 | IO; BoB |
| @181 | *L. pectinata* Thompson and Scott, 1903 | A | 0.015 | IO; BoB |
| @182 | *L. pavo* Giesbrecht, 1889 | 0.004 | 0.071 | IO; BoB |
| @183 | *Pontellina plumata* Dana, 1849 | 0.325 | 0.206 | IO; BoB |
| 184 | *Pontellopsis scotti* Sewell, 1932 | A | 0.024 | IO |
| @185 | *Rhincalanus cornutus* Dana, 1849 | 0.393 | 0.251 | Atlantic; IO; BoB |
| @186 | *R. nasutus* Giesbrecht, 1888 | 0.146 | 0.000 | Atlantic; IO; BoB |
| 187 | *R. rostrifrons* Dana, 1849 | 0.237 | 0.007 | Indo Pacific |
| 188 | *Amallothrix arcuata* Sars, 1920 | 0.006 | 0.000 | I, A, P; Arabian Sea |
| 189 | *A. gracilis* Sars, 1905 | 0.115 | 0.171 | Atlantic; Arabian Sea; Indo Pacific |
| 190 | *Pseudoamallothrix emarginata* Farran 1905 | 0.001 | A | Pacific; IO; Arabian Sea |
| $191 | *P. ovata* Farran, 1905 | A | 0.008 | S Pacific; Antarctic; Cosmopolitan |
| 192 | *Lophothrix frontalis* Giesbrecht, 1895 | 0.355 | 0.263 | I, A, P, |
| 193 | *L. humilifrons* Sars, 1905 | 0.014 | A | Arabian Sea; Pacific |
| 194 | *Scaphocalanus echinatus* Farran, 1905 | 0.036 | 0.038 | Atlantic; W Pacific; Arabian Sea |
| 195 | *S. elongatus* A. Scott, 1909 | 0.008 | A | IO; Malay |
| 196 | *S. longifurca* Giesbrecht, 1888 | 0.010 | A | N Pacific; IO |
| 197 | *S. magnus* T. Scott, 1894 | 0.006 | 0.037 | W Pacific; IO |
| 198 | *S. major* T. Scott, 1894 | A | 0.004 | I, A, P |
| 199 | *Scaphocalanus* sp. | 0.039 | 0.077 | |
| 200 | *Scolecithricella abyssalis* Giesbrecht, 1888 | 0.007 | A | Atlantic; Pacific; Med; Malay |
| 201 | *S. bradyi* Giesbrecht, 1888 | 0.119 | A | Trop, sub-trop, I, A, P |
| 202 | *S. dentata* Giesbrecht, 1892 | 0.007 | 0.039 | I, A, P |
| 203 | *S. vittatta* Giesbrecht, 1892 | 0.020 | 0.005 | Atlantic; Med; IO |
| 204 | *Scolecithricella* sp. | 0.346 | 0.080 | |
| @205 | *Scolecithrichopsis ctenopus* Giesbrecht1888 | 0.159 | 0.055 | IO; S Pac; Malay; BoB |
| 206 | *Scolecithrix bradyi* Giesbrecht, 1888 | 0.045 | 0.012 | Trop, sub-trop, oceans; IO |
| @207 | *S. danae* Lubbock, 1856 | 0.529 | 0.396 | IO; BoB |
| 208 | *S. nicobarica* Sewell, 1929 | 0.014 | 0.021 | IO; Pacific |
| 209 | *Scolecithrix* sp. | 0.077 | 0.010 | |
| 210 | *Scottocalanus dauglishi* Sewell, 1929 | 0.005 | A | IO |
| 211 | *S. helenae* Lubbock, 1856 | 0.165 | 0.001 | I, A, P; Arabian Sea; Malay |
| $212 | *S. rotundatus* sp. | 0.0001 | 0.021 | W Pacific |
| $213 | *Monacilla gracilis* Wolfenden, 1911 | 0.293 | 0.390 | W Pacific |
| 214 | *M. tenera* Sars, 1907 | 0.528 | 0.113 | Bathypelagic; Atlantic; IO |
| 215 | *M. typica* Sars, 1905 | 0.023 | 0.386 | I, A, P |
| 216 | *Spinocalanus angusticeps* Sars, 1920 | A | 0.003 | Atlantic; IO |
| 217 | *S. longipes* Tanaka, 1956 | A | 0.126 | W Pacific; IO |
| 218 | *S. magnus* Wolfenden, 1904 | 0.011 | 0.007 | I, A, P |
| 219 | *S. spinosus* Farran, 1908 | 0.002 | A | Deep water; all oceans |
| 220 | *Spinocalanus* sp. | 0.023 | 0.003 | |
| @221 | *Temora turbinata* Dana, 1849 | 0.029 | 0.202 | IO; BoB |
| @222 | *T. discaudata* Giesbrecht, 1889 | 0.041 | 0.420 | IO; BoB |
| 223 | *T. stylifera* Dana, 1849 | 0.059 | 0.238 | Atlantic; IO; Malacca strait |
| $224 | *Tharybis* sp. | 0.002 | A | W Pacific |
| 225 | *Undinella brevipes* Farran, 1908 | 0.015 | A | Upper 1000 m; N Atlantic; IO |
| $226 | *U. spinifer* sp. | 0.025 | 0.005 | Upper 1000 m; N Atlantic; |
| 227 | *Undinella* sp. | 0.012 | A | Arabian Sea |
| @228 | *Oithona brevicornis* Giesbrecht, 1891 | 0.140 | 0.196 | IO; Malacca strait; BoB |
| @229 | *O. plumifera* Baird, 1843 | 0.851 | 0.943 | Epipelagic; all oceans; BoB |
| 230 | *O. setigera* Dana, 1849 | 0.116 | 0.568 | Atlantic; IO |
| @231 | *O. similis* Claus, 1866 | 5.884 | 7.081 | IO; BoB |
| 232 | *O. spinirostris* Claus, 1863 | 0.461 | 0.251 | IO |

|  |  |  |  |  |
|---|---|---|---|---|
| 233 | *Oithona* sp. | 0.147 | 0.552 |  |
| 234 | *Aegisthus aculeatus* Giesbrecht, 1891 | 0.002 | 0.010 | NW Atlantic; IO |
| 235 | *A. mucronatus* Giesbrecht, 1891 | 0.146 | 0.102 | NW Atlantic; IO |
| @236 | *Clytemnestra scutellata* Dana, 1848 | 0.401 | 0.209 | NW Atlantic; IO; BoB |
| @237 | *Microsetella norveigica* Boeck, 1864 | 0.005 | 0.004 | NW Atlantic; IO; BoB |
| @238 | *M. rosea* Dana, 1848 | 0.114 | 0.143 | Atlantic; IO; Malacca strait; BoB |
| @239 | *Euterpina acutifrons* Dana, 1848 | 0.064 | 0.999 | IO; BoB |
| @240 | *Macrosetella gracilis* Dana, 1848 | 1.341 | 1.283 | Atlantic; IO; BoB |
| @241 | *Miracia efferata* Dana, 1849 | 0.041 | 0.072 | NW Atlantic; IO; BoB |
| 242 | *Oculosetella gracilis* Dana, 1852 | 0.011 | 0.0001 | NW Atlantic; IO |
| 243 | *Mormonilla minor* Giesbrecht, 1891 | 8.977 | 5.848 | N Atlantic; Arabian Sea |
| 244 | *M. phasma* Giesbrecht, 1891 | 0.106 | 0.197 | IO |
| 245 | *Corycaeus agilis* Dana, 1849 | A | 0.005 | IO; Malacca strait |
| 246 | *C. asiaticus* F. Dahl, 1894 | 0.013 | 0.022 | IO; Malacca strait |
| @247 | *C. catus* F. Dahl, 1894 | 1.457 | 1.367 | Atlantic; IO; BoB |
| @248 | C. *danae* Giesbrecht, 1891 | 1.299 | 2.141 | Atlantic; IO; BoB |
| 249 | *C. longistylis* Dana, 1849 | 0.053 | 0.048 | IO |
| @250 | *C. speciosus* Dana, 1849 | 0.496 | 1.066 | Atlantic; IO; BoB |
| 251 | *C. typicus* Krøyer, 1849 | 0.116 | 0.318 | Atlantic; IO |
| 252 | *Corycaeus* sp. | 0.163 | 0.167 |  |
| 253 | *Farranula carinata* Giesbrecht, 1891 | 0.051 | 0.014 | IO |
| @254 | *F. gibbula* Giesbrecht, 1891 | 0.021 | 0.022 | IO; BoB |
| 255 | *Sapphirella tropica* Wolfenden, 1905 | 0.004 | A | Atlantic; IO |
| 256 | *Lubbockia aculeata* Giesbrecht, 1891 | 0.017 | 0.025 | Atlantic; IO |
| 257 | *L. squillimana* Claus, 1863 | 0.023 | 0.005 | Atlantic; IO |
| 258 | *Lubbockia* sp. | 0.033 | A |  |
| 259 | *Conaea gracilis* Dana | 4.851 | 2.507 | Atlantic; AS |
| 260 | *Oncaea mediterranea* Claus, 1863 | 0.574 | 1.059 | Atlantic; IO |
| 261 | *O. notopus* Giesbrecht, 1891 | 0.161 | A | Atlantic; IO |
| @262 | *O. venusta* Philippi, 1843 | 15.806 | 14.115 | Atlantic; IO; Malacca strait; BoB |
| 263 | *Oncaea* sp. | 0.057 | 0.056 |  |
| 264 | *Pachos punctatum* Claus, 1863 | A | 0.0002 | Atlantic; IO |
| 265 | *Triconia conifera* Giesbrecht, 1891 | 0.517 | 0.254 | Atlantic; IO |
| 266 | *Copilia longistylis* Mori, 1932 | 0.002 | 0.060 | IO |
| @267 | *C. mirabilis* Dana, 1849 | A | 0.140 | Atlantic; IO; BoB |
| 268 | *C. quadrata* Dana, 1849 | 0.180 | 0.282 | Atlantic; IO; Malacca strait |
| 269 | *C. vitrea* Haeckel, 1864 | 0.017 | 0.093 | Atlantic; IO |
| 270 | *Sapphirina auronitens* Claus, 1863 | 0.059 | 0.058 | IO |
| 271 | *S. intestinata* Giesbrecht, 1891 | 0.016 | 0.003 | IO |
| 272 | *S. metallina* Dana, 1849 | 0.023 | A | Atlantic; IO; Malacca strait |
| @273 | *S. nigromaculata* Claus, 1863 | 0.018 | 0.212 | Atlantic; IO; BoB |
| 274 | *S. opalina* Dana, 1849 | 0.002 | A | Atlantic; IO |
| @275 | *S. ovatolanceolata* Dana, 1849 | 0.049 | 0.090 | Atlantic; IO; BoB |
| 276 | *Sapphirina* sp. | 0.171 | 0.195 |  |
| 277 | *Vettoria granulosa* Giesbrecht, 1891 | A | 0.003 | Atlantic; IO |
| @278 | *Ratania flava* Giesbrecht, 1892 | A | 0.011 | N Atlantic; IO; BoB |
|  | Total species identified | 251 | 201 |  |
|  | Total Genera identified | 83 | 82 |  |

$: first records from the Indian Ocean (IO); @: reported previously from the Bay of Bengal (BoB); N: North; NW: Northwest; W: West; S: South; C: central; I, A, P: Indian, Atlantic, Pacific, oceans; trop: tropical; sub-trop: subtropical; eq Pac: equatorial Pacific; Med: Mediterranean; Malay: Malay archipelago waters *venusta, Euterpina acutifrons, Microsetella norveigica, Macrosetella gracilis, Miracia efferata* (Nair et al. 1981; Rakhesh et al. 2006), *Acrocalanus gracilis, Clytemnestra scutellata,* (Pati 1980), *Eucalanus elongatus, Calocalanus pavo, Sapphirina ovatolanceolata* (Krishnamurty 1967), *Rhincalanus nasutus, Oithona plumifera* (Subbaraju and Krishnamurty 1972), *Paracandacia truncata, Candacia catula, C. discaudata* (Lawson 1977), *Microsetella rosea, Oithona similis, Paracalanus parvus, Acrocalanus longicornis, Acartia spinicauda,Oithona brevicornis* (Godhantaraman 1994) and *Acartia centrura* (White et al. 2006).

Other than these 54 species, the remaining species identified in this study are the first-time reports from the western Bay of Bengal. Since only 40 out of 201 species in the WB were present in all seasons, a significant number of species occurred only seasonally. Various possible reasons for their seasonal occurrence are detailed in Chapter 6.

### 7.3.5. Dominant species

As described in Chapter 6, the apparent predominance of *O. venusta* during most part of the year in both CB and also in WB might suggest a continuous breeding throughout the year (Hopkins 1977). In other oligotrophic regions such as the Sargasso Sea too, a predominance of *Oncaea* was observed (Deevey 1971). During SpIM, *E. monachus* was the predominant species. The occurrence of *E. monachus* in large numbers coinciding with spring blooms in temperate seas or upwelling events in the tropical zone is well documented (Gapishko 1980; Heinrich 1986; Smith 1995). As an adaptation to intermittent food supply, the species diapause at mesopelagic depths at lower latitudes (Boucher 1984; Heinrich 1986; Smith 1992) and the massive lipid storage by pre-adult resting stages fuels respiration (Conover 1988). It may be presumed that episodic new production as indicated by the higher populations of the large sized opportunistic coarse filter feeding *E. monachus* would have contributed appreciably to the total biomass during SpIM.

The other dominant species with ≥2% of the total populations also displayed a wide range of distribution patterns, such as preponderance in the shallow, intermediate and /or deep-water distribution. *Eucalanus elongatus*, the mesopelagic resident (Deevey and Brooks 1977) was always in deeper depths irrespective of seasons in this warm tropical basin. The species *C. arcuicornis*, *Acrocalanus gracilis, O. mediterranea P. indicus, Eucalanus monachus*, *C. catus*, *C. danae* and *O. similis* were common along this transect as well as in the CB. *Paracalanus* spp. known to obtain sufficient food at the low food concentrations (Paffenhofer and Stearns 1988) were also preponderant in this transect. Compared to the other abundant species in WB such as *Paracalanus* spp., *Clausocalanus* spp., *Oithona* spp. and *Oncaea* spp., the relatively large and warm water species *Centropages furcatus* constituted a significant part of the zooplankton biomass as also reported for other coastal areas especially the South east Atlantic coast (Turner 1987; Turner and Tester 1989). As Ikeda (1974) and Anraku and Omori (1963) suggest, the omnivorous–carnivorous character allows the successful maintenance of this species allowing it to compensate for seasonal variations of phytoplankton abundance.

Similar to that in the CB and many previous observations (Bigelow 1926; Rose 1929, 1933; Wilson 1942; Sewell 1947), *Oithona similis* and *Oncaea venusta* were ubiquitous in this study with mostly higher abundances in top 200 m. *Lucicutia flavicornis* and *Pleuromamma indica* as seen in this study, are reported to occur throughout the water column of over 1000 m (Saltzman and Wishner 1997). *Pleuromamma indica*, *Eucalanus elongatus* and *M. minor* seem to tolerate low oxygen concentrations (Saltzman and Wishner 1997) since they were observed in higher proportion at subsurface depths.

### 7.3.6. Diversity

Estimating diversity in the pelagic realm is particularly relevant when examining relationships between hydrography and the pelagic biota. Similar to observations of Deevey and Brooks (1977), diversity was high in the MLD and the deeper depths in the WB. Padmavati et al. (1998) attributed the high diversity in the deepest layer to the stable environment there. Overall, *H'* did not show much latitudinal variation in the WB. On an average, diversity was very high during FIM as was also seen in the CB. A very stable water column in this season of marked chemical and physical gradients, providing a structured environment but with low input of nutrients for phytoplankton production could be a reason for high diversity (Angel 1993). As Lasserre (1994) suggest, the high diversity in the phytoplankton community in the Bay (Paul et al. 2007) appear to be a mechanism generating diversity among zooplankton.

The details of evenness and species richness in the WB were not very different from those already discussed in Chapter 6 but for minor deviations. Copepod diversity showed a negative correlation with chl *a* indicating inverse relation with primary production (Huston 1994).

### 7.3.7. Compositional differences in WB and CB

Undoubtedly, the Bay of Bengal is a copepod-dominated biome. Collectively, the copepod population in low latitudes has its intense breeding activity during July and October. But, individual species may reach their maximum densities in different months of the year (Reeve 1964; Raymont 1983), a characteristic feature of the warm seas. Though the average abundance in the WB was greater than in the CB, there was no significant difference between coastal and oceanic waters but for one season (SUM). This is probably because the stations in WB were mostly in depths over 1000 m.

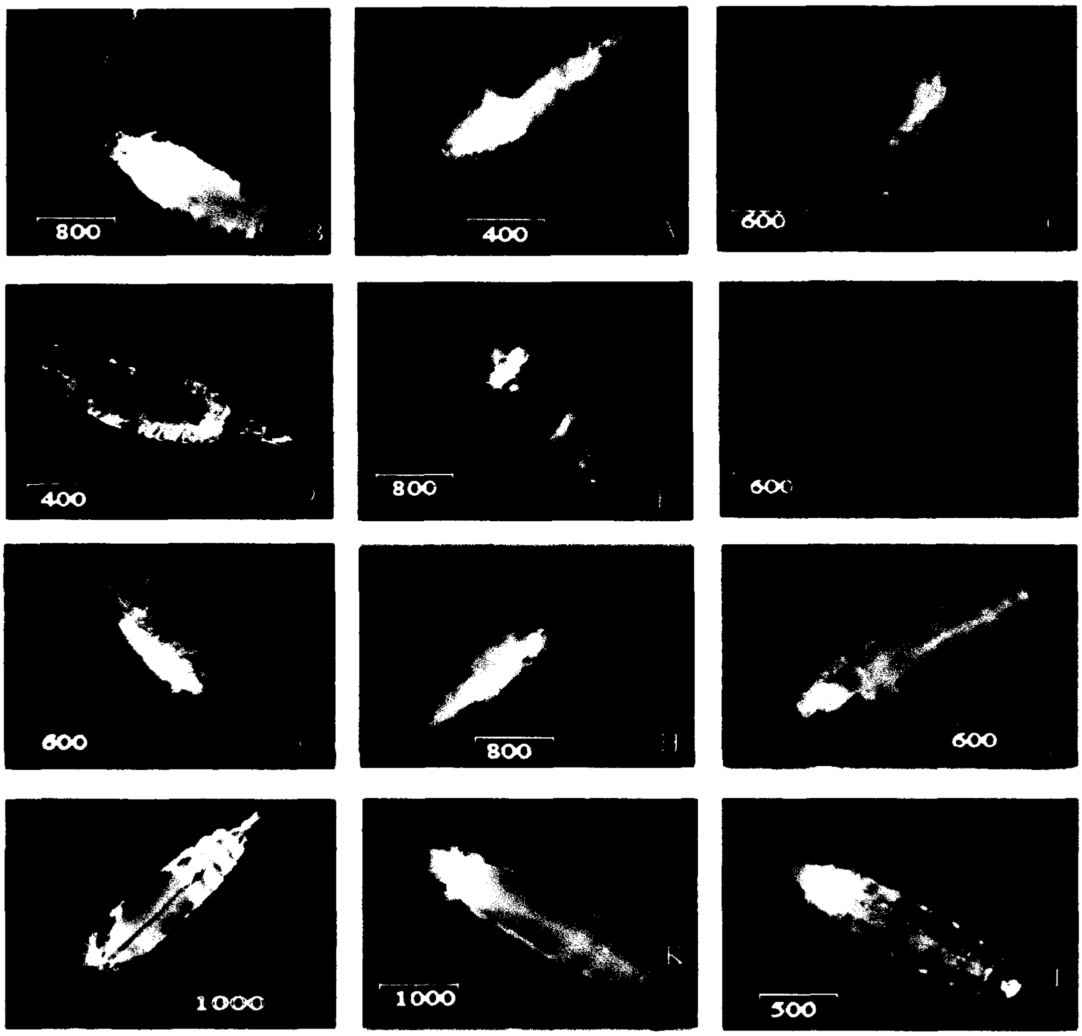
The WB was significantly more productive than the CB only during SUM. Such difference in the inshore and offshore waters was also observed with the seasonally reversing monsoons in the Arabian Sea (Smith et al. 1998; Stelfox et al. 1999). One additional order, Siphonostomatoida comprising a member of family Rataniidae was identified only in the WB. The number of genera (82) and species (201) observed in the WB were lower compared to CB (83 genera and 251 species). Species diversity was higher in the CB. While *Paracalanus parvus, Acrocalanus gibber, A. longicornis, O. plumifera* and *Centropages furcatus* were the dominant epipelagic species in the WB, *Macrosetella gracilis, Paracalanus aculeatus*, *P. crassirostris, Corycaeus speciosus* and *Clausocalanus furcatus* were in the CB, suggesting that dominant epipelagic assemblages vary in coastal and oceanic waters.

Though Calanoida was the dominant order, the poecilostomatoid, *O. venusta* formed the key species in most seasons, depths and stations along both transects. With only a moderate chl *a* regime in the Bay, this carnivore-omnivore seems to be well adapted for survival in the environmental variabilities oscillating in the Bay under the influences of physics (monsoonal currents and wind forcing), chemistry (salinity and nutrient changes) and biology (chl *a*; primary production).

Vertical partitioning of food and space resources is evident with different families dominating different zones of the upper 1000 m water column and only a few ubiquitous forms like *Oithona* and *Oncaea* seeming to be versatile. The wide distribution of *Oithona* species is partly due to the fact that some of them have euryhaline (Torres-Sorando et al. 2003 and Hansen et al. 2004), and eurythermal characteristics (Turner 2004), in addition to low respiration and metabolic rates (Paffenhofer 1993). Fransz and Gonzalez (1995) report that egg production of *Oithona* is spread over the seasons than reported for calanoid copepods. They also seem to be spawning and hatching throughout the water column (Fernandez de Puelles et al. 1996) as observed from the occurrence of copepod eggs and nauplii (Chapter 5) at all sampling depths. According to Kellermann (1987), *Oithona* adults are important food items for fish larvae ("visual hunters"), so that the adults prefer to stay in deeper water layers supposedly to avoid predators. *Pleuromamma indica* showed a significant positive correlation with salinity and phosphate and a negative relationship with dissolved oxygen in the Bay of Bengal and Arabian Sea (Saraswathy 1986). Being able to adapt readily to OMZ in the northern Indian Ocean in particular, its increased abundance over the past thirty years is suggestive of the growing size and/or intensity of the OMZ in the Arabian Sea (Smith and Madhupratap 2005).

This study has brought out the occurrence of a large number of copepod species (>200) not reported so far from the BoB. High diversity not only in the deep but also in the surface is a significant observation of this study. Besides being useful to notify such diversity of copepods from the Bay of Bengal, it is also reflecting the distribution pattern of predominant species (*e.g. O. venusta*), from this least studied region. The fact that the deep-strata sampling was carried out systematically for the first time which is the main reason for revealing such a lot of new records (20 species are new to the Indian Ocean) of copepod species, need to be kept in the fore. This was possible mainly because of the sampling from deeper than the usual 200 m column. In addition, the extensive and careful analysis of all the collected samples led to such discoveries. It is certain that there are far more number of zooplankton in the deeper realms of the BoB unknown to marine biologists. Notwithstanding the meagerness of the least abundant species, another highlight from this study is that there is more to know of copepods from the Bay of Bengal.

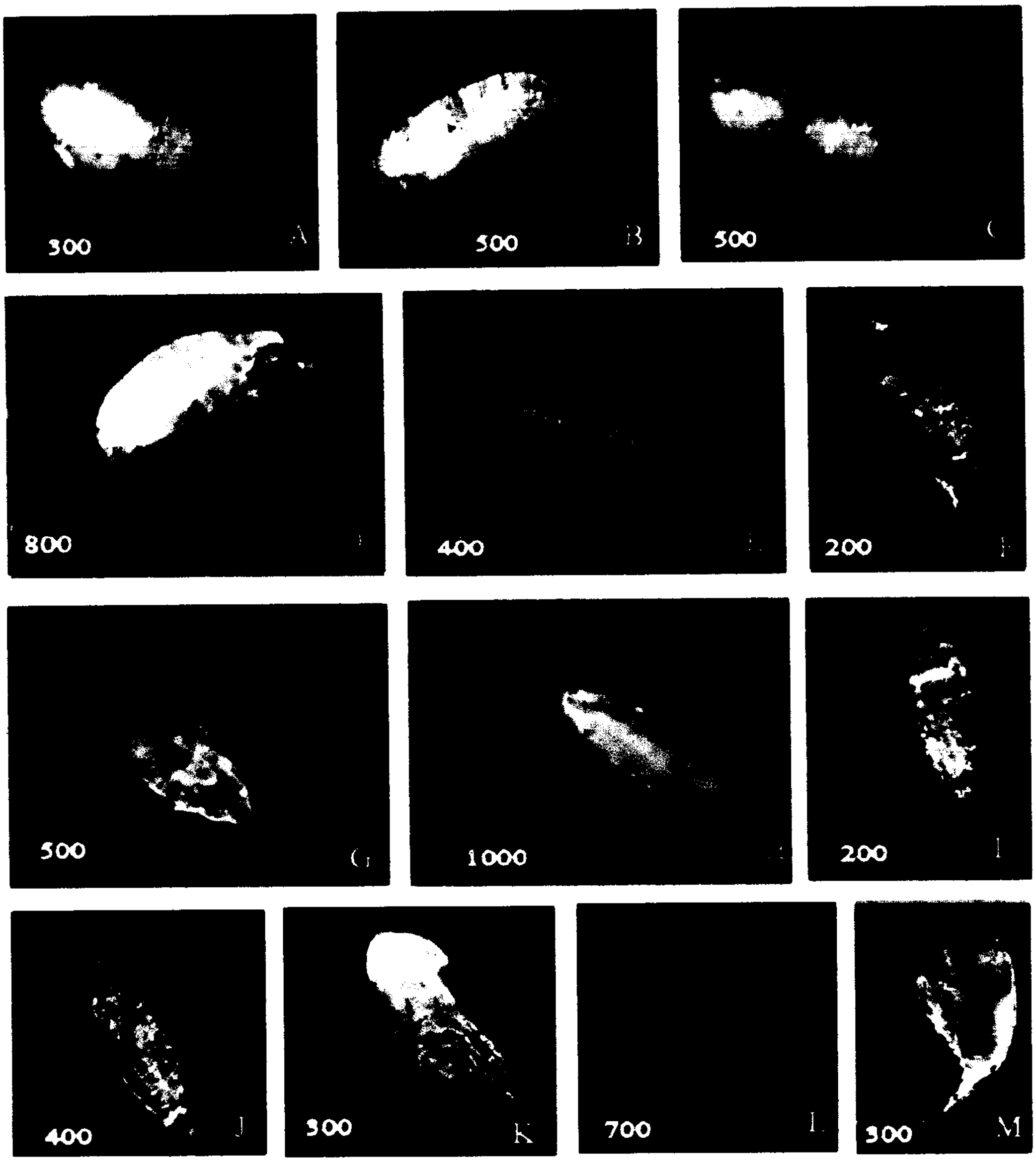
# Plate 5



Photographs of some epipelagic calanoid copepod species (scale is in micrometer) from the Bay of Bengal

Key:
A: *Labidocera pavo*; B: *L. acuta*; C: *Pontella* sp.; D: *Candacia catula*; E: *C. pachydactyla*:F. G: *Candacia* sp.; H: *Eucalanus crassus*; I: *E. mucronatus*; J: *Eucalanus elongatus*; K: *Pareucalanus attenuatus*; L: *Rhincalanus cornutus*

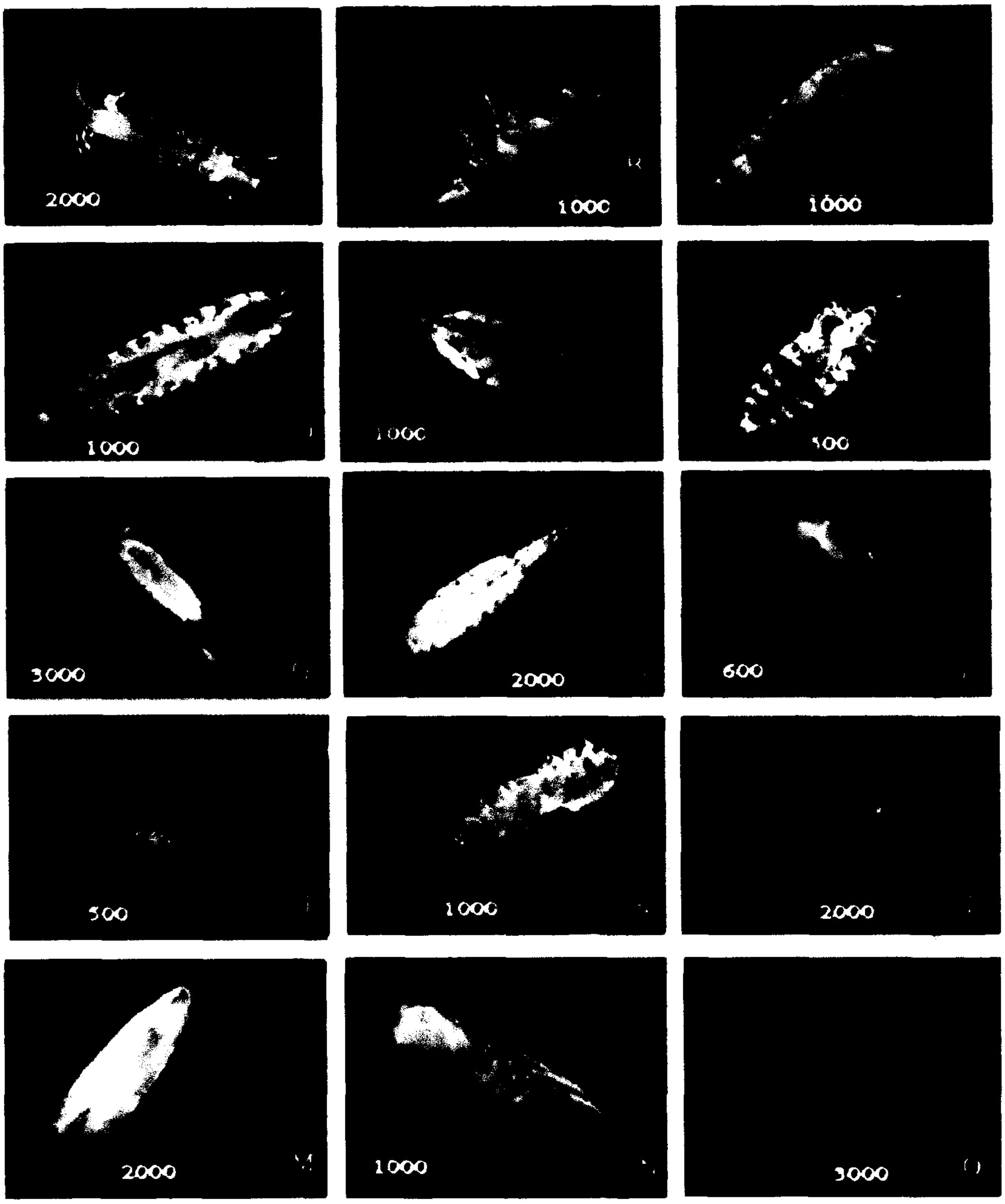
# Plate 6



Photographs of some epipelagic calanoid copepod species (scale is in micrometer) from the Bay of Bengal

Key:
A: *Acrocalanus longicornis*; B: *Undinula vulgaris*; C: *Cosmocalanus darwinii*;
D: *Scolecithrix danae*; E: *Calocalanus pavo*; F: *Acartia spinicauda*;
G: *Aetideus acutus*; H: *Euchaeta marina*; I: *Clausocalanus furcatus*;
J: *Centropages furcatus*; K: *Canthocalanus pauper*; L: *Temora discaudata*;
M: *Paracalanus indicus*

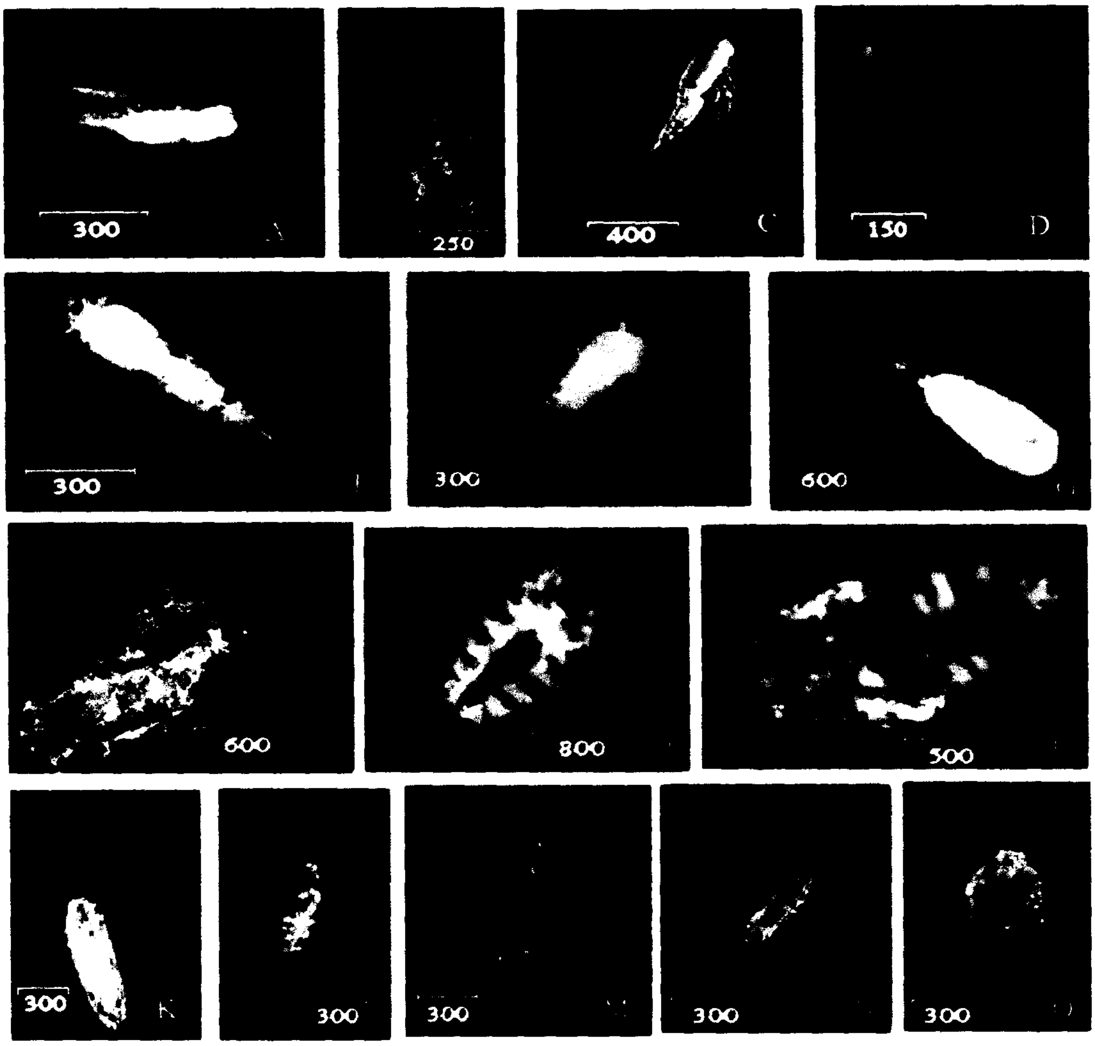
# Plate 7



Photographs of some mesopelagic copepod species (scale is in micrometer) from the Bay of Bengal

Key:
A: *Euchirella bitumida*; B: *Euchirella* sp.; C: *Gaetanus miles*; D: *Euaugaptilus facilis*;
E: *Euaugaptilus* sp.; F: *Haloptilus longicornis*; G: *Gaussia princeps*; H: *Metridia princeps*;
I: *Metridia brevicauda*; J: *Pleuromamma indica*; K: *P. xiphias*; L: *Lucicutia maxima*;
M: *Lophothrix frontalis*; N: *Scottocalanus helenae*; O: *Megacalanus princeps*

# Plate 8



Photographs of some non- calanoid copepod species (scale is in micrometer) from the Bay of Bengal

Key:
A: *Aegisthus mucronatus*; B: *Euterpina acutifrons*; C: *Microsetella rosea*;
D: *M. norvegica*; E: *Mormonilla minor*; F: *Corycaeus catus*; G: *Corycaeus* sp.;
H: *Sapphirina ovatolanceolata*; I: *Sapphirina* sp.; J: *Pachos punctatum*;
K: *Lubbockia aculeata*; L: *Conaea gracilis*; M: *Oncaea venusta*; N: *Oithona similis*;
O: *Ratania flava*

# Chapter 8

# Chapter 8

## *Measurements of Vital Rates of Copepods in the Bay*

There is a growing awareness of the important contribution of mesozooplankton to carbon cycling in the ocean (Zhang and Dam 1997; Steinberg et al. 2000). The transfer of primary production to secondary producers not only involves ingestion of phytoplankton, but also the respiratory demand of zooplankton that utilizes a large proportion of the ingested matter (Hernandez- Leon and Ikeda 2005). The ubiquitous distribution, high abundance and trophic importance of copepods form important criteria for estimating their vital rates in the elucidation of marine carbon cycling (Aristegui et al. 2005; Hernandez- Leon and Ikeda 2005; Buitenhuis et al. 2006). The activities of planktonic copepods range from occasional motion to continuous, rapid swimming (Gauld 1966; Paffenhofer et al. 1996; Mazzocchi and Paffenhofer 1999). According to modeling studies, increased motion results in increased metabolic expenditures (Klyashtorin and Yarzombek 1973).

Zooplankton grazing is an important process controlling phytoplankton populations in the oceans (Banse 1994). However, studies on zooplankton carried out in the open ocean are concerning mostly their distribution (Finenko et al. 2003). During the last decade, investigations on zooplankton grazing have been carried out in more productive coastal areas (Morales et al. 1991; Pakhomov and Perissinotto 1997; Gowen et al. 1999). Although the vast oligotrophic regions contribute up to 80% of the global ocean production and 70% of the total export production (Karl et al. 1996), information on zooplankton vital rates in general, is lacking from these ecosystems (Dam et al.1995; Zhang et al. 1995).

Method of Gut fluorescence as a measure of chlorophyll pigments was developed by Yentsch and Menzel (1963). The fundamental factor in estimation of the ingestion rate is the careful measurement of the gut evacuation rate (Peterson et al.1990). The gut evacuation rate constant (k) is usually derived from a model of exponential decrease in gut fluorescence over time, assuming that a constant proportion of the gut content is evacuated per unit time (Baars and Oosterhuis 1984; Kiorboe et al. 1985, Christoffersen and Jespersen 1986).

From studies of Campbell and Vaulot (1993), Letelier et al. (1993) and Campbell et al. (1994, 1997), it is evident that warm oligotrophic regions support a complex planktonic community with pico-sized (0.2–2 μm) phytoplankton and, auto- and heterotrophic bacteria dominating the community biomass. Such organisms are reported to be largely unavailable to direct utilization by the Crustacea-dominated mesozooplankton because of size constraints on feeding mechanisms (Rassoulzadegan and Etienne 1981; Conover 1982; Berggreen et al. 1988; Hansen et al. 1994). Nonetheless, they are linked in principle to higher order animals by the cascading influences of mesozooplankton grazing on consumers of intermediate size (Sherr et al. 1986; Sherr and Sherr 1988; Wikner and Hagstrom 1988).

Oxygen consumption of copepods has been related to body mass, temperature (Ikeda 1985; Hiromi et al. 1988; Castellani et al. 2005), feeding behavior (Klekowski et al. 1977), and to diel cycles (Pavlova 1994). In the subtropical to tropical open-ocean, abundances of potential food organisms for planktonic copepods are usually low compared to neritic regions (Paffenhofer et al. 2003). This is indicative that their metabolic and growth demands may not always be met (Dam et al. 1995; Roman and Gauzens 1997). Most of the organic matter originated through primary production in the surface layers is fated to mineralize through planktonic respiration *in situ* or during the course of sinking. Only a small fraction is buried in the ocean floor. Recently Del Giorgio and Duarte (2002) provided an assessment of respiration in the ocean. From this, it appears that respiration consumes more organic matter than seems to be produced in the ocean.

Mesozooplankton respiration can be calculated as the product of their specific respiration rates and biomass. Specific respiration rates have been shown to vary with temperature and body mass, with relatively modest or no taxonomic differences (Ikeda 1985). Zooplankton biomass in the epipelagic zone of a given water mass being highly variable in space and time by one to three orders of magnitude (Huntley and Lopez 1992), the subsequent respiration rates are likely to vary concurrently.

Metabolic processes of zooplankton such as grazing, respiration and growth in the open ocean waters have received growing attention in recent years, particularly in the Pacific and Atlantic (Dam et al. 1995; Zhang et al. 1995; Le Borgne and Rodier 1997; Roman and Gauzens 1997; Zhang and Dam 1997; Roman et al. 2002; Le Borgne and Landry 2003; Le Borgne 1977, 1981, 1982; Welschmeyer and Lorenzen 1985; Harrison et al. 2001; Huskin et al. 2001 a, b; Woodd-Walker et al. 2002).

Respiration measurements were carried out in the early 1930s mainly on the copepod *Calanus finmarchicus* (Marshall et al. 1935, Clarke and Bonnet 1939). To date there has not been a single documented report of respiration rate from the Bay of Bengal. Assessing the magnitude of respiration by the preponderant epipelagic copepods in the warm, moderately productive waters of the Bay of Bengal is essential for relating their organic matter requirement *vis a vis* its production through photosynthetic process. This set of measurements was thus aimed at not only obtaining information on zooplankton respiration rate but also to calculate the carbon consumption rates using relevant respiration quotients available in literature.

To understand the grazing pressure of different trophic levels on phytoplankton, nutrient enrichments of size-fractionated seawater have been carried out in microcosm experiments in oligotrophic eastern Mediterranean (Kress et al. 2005; Zohary et al. 2005) and at Hawaiian Ocean time-series station (HOTS; Calbet and Landry 1999). In tropical ecosystems such as the Bay of Bengal (BoB), the upper waters are mostly devoid of any nutrients due to almost perennial warm pool and low saline lens in the upper 30 m (Prasannakumar et al. 2002, 2007). The thermohaline stratification causes nutrient limitation and keeps the Bay low to moderate in chl *a* levels throughout the year. In the present study, the effect of nutrient enrichment on the dynamics of chlorophyll *a*, phytoplankton cell numbers, microzooplankton and the mesozooplankton abundance was investigated in microcosm experiments. The main objective of this experiment was to evaluate mesozooplankton grazing or ingestion effect on phytoplankton under natural sea water-, nutrient altered- and, size fractionated- microcosms set up onboard.

Zooplankton growth-rate measurements *in situ* in open waters have been carried out as early as 1963 (Cushing and Tungate 1963), but they are extremely time-consuming. Shipboard incubation techniques have been used for growth estimates for individual copepod species based on molting frequency (Miller et al. 1984) and egg production (Kiorboe and Johansen 1986; Berggreen et al. 1988). But these techniques are subject to a variety of containment effects and are of limited value for overall copepod community growth estimates in tropical seas where the species diversity of copepods is great (Grice and Hart 1962; Timonin 1971).

Another approach to estimating copepod growth is based on regression models that use temperature (McLaren and Corkett 1981; Huntley and Lopez 1992), resource concentration (Vidal 1980; Berggreen et al. 1988) or temperature and body size (McLaren 1965; Ikeda and Motoda 1975; Hirst and Sheader 1997; Hirst and Lampitt 1998) to predict copepod growth rates. These models assume that all copepod species of the same size grow at the same rate at a given temperature.

Using a regression equation, growth rates for the 200-500 μm fraction of copepods have been estimated during this study from the upper mixed layer.

## 8.1. Materials and Methods

These sets of microcosm and rate measurement experiments were carried out onboard during the winter monsoon cruise (November 26, 2005 to January 7, 2006) of FORV *Sagar Sampada.*

### 8.1.1. Collection of zooplankton samples

A Bongo (two-nets set; mouth area 0.28 $m^2$ of each net; mesh size 300 μm; Hydrobios) net was hauled obliquely at 2 knots speed for 10-15 min for collecting surface (0-5 m) zooplankton at all the nine stations shown in Fig. 3.1 in Chapter 3. The initial and final digital flowmeter (FMR; Hydrobios Model 438 110) readings were noted in order to calculate the volume of water filtered. The volume of water filtered was calculated using: $V (m^3) = A \times R \times K$; Where, A= mouth area (for circular net, $A = \pi \times r^2$ where r is the radius of the net, $\pi = 3.14$); R = flow meter reading; K = calibration constant; V = Volume of water filtered.

### 8.1.2. Measurement of gut fluorescence

This technique was carried out by following the available methods (Mackas and Bohrer 1976; Baars and Oosterhuis 1984; Kiorboe et al. 1985, Christoffersen and Jespersen 1986; Dam et al. 1995). Upon retrieval of the net, the contents of one net were used to measure the biovolume and preserved as described in Chapter 4 for enumerating the mesozooplankton and total copepods. The contents of the second net were immediately transferred into 1litre 0.45-µm filtered seawater taken from 10 m depth. This was done to avoid crowding and undue stress. At zero time itself, 25 ml of this diluted zooplankton sample was transferred into a wide petridish to pick up actively moving copepods. Under dim light, ~30 medium sized copepods were picked with a dropper and filtered onto GF/C filter paper and added to 8 ml of 90 % acetone. Similar procedure was carried out for the rest of the zooplankton samples every 15 min generally for 150 min. The samples were kept for extraction at zero degree in the freezer for 24 h in the dark. After extraction, the sample was thawed for half an hour and chlorophyll (chl) *a* was measured using Fluorometer (AU-10 Turner designs, USA).

Concentrations of chl *a* and phaeopigments (phaeo) in the copepod guts were calculated using the following equations (Parsons et al. 1984 ):

$$\text{Chl } a\ (\mu\text{g ind}^{-1}) = (T/(T-1)) * (Rb - Ra) * Fd * \text{Vol ex} / \text{no of individuals}$$

$$\text{Phaeo}\ (\mu\text{g ind}^{-1}) = (T/(T-1)) * ((T*Ra) - Rb) * Fd * \text{Vol ex} / \text{no of individuals}$$

where; T = acidification coefficient (Rb/Ra obtained through the calibration of the fluorometer); Rb = reading before acidification; Ra = reading after acidification
Fd = flourometer calibration factor (µg liter$^{-1}$); Vol ex = volume of extraction (ml);

The Gut content was calculated as: $G = (1.51 \times \text{conc. of phaeopigment}) + \text{conc. of chl a}$

The gut evacuation rate constant (k) was calculated from the equation: $Gt = G_0 \times e^{-kt}$
Where; Gt = pigment concentration at time t; $G_0$ = pigment concentration at time $t_0$

The ingestion rate was then calculated as: $I = G * k$ (ICES 2000)

Copepod egestion (fecal pellet production; E) was estimated by assuming that 70% of the ingested material (I) was partitioned to growth and respiration and 30% was egested as fecal pellets (Conover 1978).

The amount of chl *a* grazed daily by copepods was estimated by multiplying their numerical abundance in a tow (ind $m^{-3}$) with the corresponding ingestion rate. The phytoplankton carbon ingested was calculated by applying a carbon to chl *a* ratio as 50 (Banse 1988).

### 8.1.3. Measurement of respiration rates

The respiration or oxygen consumption rate was measured following essentially Mayzaud and Dallot (1973). From the assortment of mesozooplankton collected from the oblique hauls, mostly copepods were separated and transferred to a beaker with 0.22 μm filtered seawater (FSW) and allowed to acclimatize for one hour. Five sets of bottles of 125 ml capacity (in duplicate) were used in the experiment as follows:

A set of two bottles was filled gently with 0.20 μm FSW avoiding air bubble formation. These were used for measuring initial concentration of dissolved oxygen (DO) by fixing it immediately with Winkler A and B reagents. Copepods (~30 $l^{-1}$) and streptomycin (50 mg $l^{-1}$) were added to the experimental bottles filled with 0.20 μm FSW. The antibiotic was added to arrest uptake by bacteria. Another set of two bottles was incubated with copepods (~30 $l^{-1}$) without the antibiotic to derive the oxygen consumption both by bacteria and copepods (positive control). One more set of two bottles with streptomycin but without copepods (negative controls) were used to check whether the addition of streptomycin is contributing to any DO consumption. A final set of two bottles served as negative controls and, was without copepods and antibiotics to examine if FSW itself contributed to any variation in DO concentration.

But for the bottles initially fixed, the other sets of bottles were topped up with FSW to the brim and covered with aluminium foil and incubated for 12 h at RT. After 12 h, the bottles were fixed with Winkler A and B and dissolved oxygen estimated by the standard Winkler method (Grasshoff et al. 1983; using 665 Dosimat Metrohm, Switzerland). After the experiment, the contents of the incubation bottles were filtered over 200-μm mesh and the retained plankton counted using a magnifying lens.

Oxygen consumption rate was calculated by using the equation (Omori and Ikeda 1984):

$$R = ((C_o-C_t)-(C_o-C_{t'})) \times (V_e-V_z)/ (t \times N)$$

Where $C_0$ = Oxygen concentration at time 0, $C_t$ = oxygen concentration in experimental bottle, Ct' = oxygen concentration in control, $V_e$ = volume of experimental bottle, $V_z$ = volume of zooplankton, t = incubation time, N = number of copepods.

A respiration quotient of 1.0 provided by Baars and Franz (1984) was used to convert oxygen consumption into carbon mineralization. The derived respiration rates at each sampling location were applied to calculate the total copepod respiration in the mixed layer using the copepod abundance data presented in Chapters 6 and 7.

### 8.1.4. Evaluation of responses of plankton assemblages to nutrient amendments

The experiment was conducted at three locations (CB1, CB5 and WB2) in the BoB. The first location was the southernmost station in the open waters, the second the northernmost and the last, in the western Bay. At these locations, over 200 l of seawater was collected from 10 m depth by several casts of 30 l Go Flo bottles. After collecting the water, zooplankton were collected as described in section 8.1.1., transferred in 0.45μm-filtered seawater to considerably thin down the concentration and held for an hour before using in the experiments below.

#### *Set up of Microcosms*

Ten transparent polythene tubs of 20 litre capacity were used as microcosms. In brief, the experimental set up and nutrient amendments is as follows:

*Microcosm 1*:Twenty litres of whole seawater (WSW)- Normal control

*Microcosm 2*: WSW (20 l) amended with nutrients ($NO_3$: 15 μM, $SiO_3$: 5μM and $PO_4$: 1μM). Such nutrient concentrations were usually deep-seated at ~40-80 m, where deep chlorophyll maxima form in the Bay of Bengal. Thus, the amendment was done to examine the response of phytoplankton to increased nutrient levels without the added population of grazers, *i.e.* copepods.

*Microcosm 3* was the same as the above but with added copepods at a concentration of 10 ind. $l^{-1}$ to check the effect of grazing on phytoplankton under nutrient enrichment.

*Microcosm 4:* Twenty litres of 200 μm filtered seawater (FSW) and added nutrients at the concentrations in microcosms 2 and 3. Passing through 200 μm was done for excluding mesozooplankton grazers while still retaining the microzooplankton. These alterations were made to check out whether the phytoplankton population increased and, grew rapidly without the mesozooplankton grazing pressure, or decreased owing to overwhelming microzooplankton grazing pressure.

*Microcosm 5* consisted of 200 μm FSW sans addition of nutrients and grazers. This was done to observe the effect of natural community of micro-zooplankton grazers on the natural phytoplankton population.

*Microcosm* 6 consisted of 100 μm FSW and added nutrients, in order to see the response of phytoplankton and consequently of the smaller fraction of the microzooplankton when nutrient concentrations are increased.

*Microcosm* 7 had 20 l 100 μm FSW sans added nutrients to serve as control to microcosm 6.

*Microcosm* 8 was set up with 20 l 20 μm FSW to check the grazing effect of nanozooplankton if any on phytoplankton fraction < 20μm.

*Microcosm* 9 had 20 l 20 μm FSW with added nutrients. This microcosm was set up to examine the response of the HNF if the nanophytoplankton increased as consequence of added nutrients.

*Microcosm* 10 was with 20 l 20 μm FSW, and copepods. In this treatment, it was aimed at finding out whether the <20μm phyto-fraction can support the survival of mesozooplankton grazers or not.

All the microcosms were maintained at shipboard temperature (~26°C) under 12:12 h light (1000 lux = ~200 μE): dark cycle for a period of 7 days. Samples were drawn daily for seven days and, nine different parameters were measured from all the microcosms. These were: nutrients- nitrate ($NO_3$), silicate ($SiO_3$) and phosphate ($PO_4$), phytoplankton (PCC), microzooplankton (Mzp), mesozooplankton (MsZP), total bacterial abundance (BA), chlorophyll (chl) *a* and phaeopigments (phaeo). Everyday, the water samples were collected around the same time, analysed soon after collection or, fixed appropriately and stored for later analyses in the laboratory. The parameters measured are as follows:

*Nutrients*

100 ml water sample from each microcosm was filled in clean plastic bottles and frozen at 0°C until analyses. Nutrients ($NO_3$-N, $PO_4$-P and $SiO_4$-Si) were analyzed as soon as the experiment was terminated, using a SKALAR autoanalyser following the procedures given in Grasshoff et al. (1983).

*Phytoplankton/Microzooplankton*

From all the 10 microcosms, 250 ml of water sample was fixed in Lugol's iodine (1% w/v), 3% formaldehyde and 2 mg $l^{-1}$strontium sulphate, and stored in dark until taken up for analyses. A settling and siphoning procedure was followed to concentrate samples from 250 ml to 10 ml (Utermohl 1958). A few replicates of one-ml concentrated aliquots were taken into a Sedgwick-Rafter plankton counting chamber and examined microscopically at 200–400X magnification. Some taxa of phytoplankton were identified to generic level by referring to various keys (Tomas 1997; ICES 2000).

*Mesozooplankton abundance*

Another 250 ml of water sample from each microcosm was collected and fixed with formalin to a final concentration of 4% and stored. In the laboratory, the water was siphoned out to keep behind ~10 ml, which was poured into Bogorov chamber and total mesozooplankton were counted (UNESCO 1968; ICES 2000).

*Chlorophyll a and phaeopigments*

Samples of 500 ml of water were collected dailyfor measurement of these pigments.Their measurements were carried out following the JGOFS Protocols (UNESCO 1994) described in Chapter 3.

*Bacterial Abundance*

From each microcosm, 10 ml samples were fixed with 0.22 µm pre-filtered formaldehyde (final concentration of 3.7%) and stored at 4°C in dark as per JGOFS Protocols (UNESCO 1994) until analysis. The procedure followed for enumerating bacterial counts was according to Parsons et al. (1984). Three milliliter of each sample was stained with acridine orange (final concentration 0.01%) for 3 min, filtered onto 0.22 μm black Nuclepore filters, mounted on glass slides using non-fluorescent oil and observed under 100X oil immersion objective of epifluorescence microscope (E400 Nikon, Japan). The slides were viewed using a blue excitation (450-490 nm) filter, 510 nm beam splitter and a 520 nm emission filter. Bacterial cells in ca. 25 microscopic fields were counted, mean cell numbers per field calculated and used for estimating total abundance by using the formula detailed in Parsons et al. (1984):

Bacterial cells $ml^{-1} = X_b \times C_t / V$; where

$X_b$ = mean bacteria per field

$C_t$ = conversion factor (filtration area/grid area)

V = volume of sample filtered (ml)

### 8.1.5. Derivation of growth rates

The regression equation of Hirst and Sheader (1997) given below, was used to calculate the potential growth rate of mesozooplankton. This equation uses published data on copepod growth rates, a wide range of body weights (0.002–43 μM C) and habitat temperatures (0-29.8°C).

$G = 0.0732 \times 10^{0.0246T} / W_c^{\ 0.2962}$

where,

$g$ ($d^{-1}$) = intrinsic growth rate; $T$; °C = temperature and $W_c$; μg C individual$^{-1}$ = copepod carbon weight

Temperature data obtained from CTD at each sampling location were averaged from the upper 120 m in the central (CB) and western Bay of Bengal (WB). It was assumed that the predominant copepods (70 to 90%) comprised all of the measured mesozooplankton biomass. Individual copepod weight for the 200-500 μm fraction was taken as 2.04 μg C (Roman et al. 2000).

Copepod production was derived using:

$P$ (mg C $m^{-2}$ $d^{-1}$) = $B \, x \, g$,

where $B$ is biomass (mM C $m^{-2}$).

Biomass values of zooplankton collected during four different seasons (summer monsoon: SUM; fall intermonsoon: FIM; winter monsoon: WM; spring intermonsoon: SpIM) during this study from the Bay were used for deriving the copepod production.

## 8.2. Results

### 8.2.1. Composition of Copepoda

The predominant copepods differed at each station sampled in both transects (Table 8.1). At CB1, the dominant copepods were *Undinula vulgaris* (17.2%), *Corycaeus longistylis* and *C. speciosus* (10.3%). At CB2, *Sapphirina* spp. (18%), *Undinula vulgaris* (11%) and *Acrocalanus* spp. (9.4%) were dominant. At CB3, *U. vulgaris* (31.5%), *Sapphirina* spp. (11%) and *Candacia bradyi* (9.3%) were abundant. At CB4, *U. vulgaris*, *Pleuromamma indica* (22.7%) and *C. bradyi* (13.6%) were dominant. At CB5, *Temora stylifera* (28%), *Oncaea* spp. (17%), *Candacia* sp. (13.2%) and *Scottocalanus helenae* (9.4%) were the dominant species.

In the WB, *Acrocalanus longicornis* (17.7%), *Temora discaudata* (11.3%) and *T. stylifera* (9.7%) were the dominant species at WB1 (Table 8.1). At WB2, *Oithona* spp. (24.4%), *T. stylifera* and *A. longicornis* (16.3%) were dominant. At WB3, *Oithona* spp. (15.2%), *T. stylifera* and *Centropages furcatus* (12.1%) were dominant. At WB4, *Temora stylifera* (26.1%) was the most abundant.

### 8.2.2. Gut evacuation, ingestion and egestion rates of copepods

The initial chl *a* concentrations in copepod guts from the measurements of gut fluorescence at various stations were found to be varying from 2 to 14 ng per individual (Fig. 8.1). Similarly, the phaeopigment concentration varied from 0.2 to 6.6 ng per individual. In the gut evacuation experiment, the copepod gut chl *a* decreased rapidly in the experimental duration of 150 min. The decline was rapid especially in the first hour. A conspicuous feature observed was the steady-state to steep increase in phaeopigments towards the end of the experiment. Minor peaks could also be noticed in the chl *a* after the first 30-60 mins.

Copepod abundance varying from 72 to 2736 ind. m$^{-3}$ were higher in the WB (Fig. 8.2). The gut evacuation rate constant varied only narrowly from 4.02 to 4.08 h$^{-1}$ between

Table 8.1. Distribution of Copepod species at different stations in the central and western Bay of Bengal

| | **% abundance at different stations** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Species** | **CB1** | **CB2** | **CB3** | **CB4** | **CB5** | **WB1** | **WB2** | **WB3** | **WB4** |
| *Acrocalanus longicornis* | **7.69** | | | | 7.55 | **17.74** | **16.28** | | |
| *Acrocalanus* spp | | **9.37** | 3.70 | | 1.89 | | | 3.03 | 4.35 |
| *Calanopia elliptica* | | | | | | 1.61 | | | |
| *Calaocalanus pavo* | | | | 4.55 | 1.89 | | 1.16 | 6.06 | 4.35 |
| *Candacia bradyi* | | 6.25 | **9.26** | **13.64** | | 1.61 | | | |
| *Candacia pachydactyla* | **7.69** | 3.12 | | | | | | | |
| *Candacia* spp. | | 1.56 | | | **13.21** | 3.23 | 4.65 | | |
| *Canthocalanus pauper* | 3.85 | 7.81 | 1.85 | | | | | | |
| *Centropages calaninus* | 3.85 | | 1.85 | | | 1.61 | 2.33 | | |
| *Centropages furcatus* | | 3.12 | 1.85 | | | | | **12.12** | 4.35 |
| *Clausocalanus* spp. | | 1.56 | | | 3.77 | | 1.16 | | 4.35 |
| *Copilia quadrata* | | | | 4.55 | | | | | |
| *Copilia* sp. | | 1.56 | 1.85 | | 1.89 | 3.23 | 3.49 | | |
| *Corycaeus catus* | 3.85 | | | | | | | | 4.35 |
| *Corycaeus danae* | | 4.69 | | 4.55 | | 1.61 | | | |
| *Corycaeus longistylis* | **11.54** | 4.69 | 3.70 | | 1.89 | 1.61 | | | |
| *Corycaues speciosus* | **11.54** | | | | | | | 3.03 | |
| *Corycaeus* spp. | | | 1.85 | 4.55 | 1.89 | 1.61 | 2.33 | | 4.35 |
| *Cosmocalanus darwinii* | | | 1.85 | | | 1.61 | | 9.09 | 4.35 |
| *Eucalanus crassus* | | | | | | 8.06 | 6.98 | 3.03 | |
| *E elongatus* | | | 1.85 | | | 1.61 | 1.16 | | |
| *E mucronatus* | | | | | | 1.61 | | | |
| *E pseudoattenuatus* | | | | | | 1.61 | | | |
| *Pareucalanus attenuatus* | 3.85 | 1.56 | 1.85 | | | 1.61 | | 3.03 | 4.35 |
| *Euchaeta indica* | | 1.56 | 1.85 | | 1.89 | 1.61 | 1.16 | | |
| *Euchaeta marina* | | 1.56 | 1.85 | | | | | 6.06 | 4.35 |
| *Euchaeta* spp. | | 4.69 | 1.85 | | 1.89 | 1.61 | | | |
| *Farrannula carinata* | | | 1.85 | | | | | | |
| *Labidocera pavo* | | 1.56 | | | 1.89 | | | | 4.35 |
| *Macrosetella gracilis* | | | 1.85 | | | | | | |
| *Oithona* spp. | | | 1.85 | 4.55 | | 3.23 | **24.42** | **15.15** | |
| *Oncaea* sp. | 3.85 | | | | **16.98** | 6.45 | 3.49 | 9.09 | 8.70 |
| *Oncaea venusta* | **7.69** | 4.69 | 7.41 | | 3.77 | 1.61 | | 3.03 | 8.70 |
| *Paracalanus indicus* | | | | | | | 2.33 | 3.03 | |
| *Paracalanus parvus* | 3.85 | | | | | | | | 4.35 |
| *Paracalanus* spp. | 3.85 | 3.12 | | | | 4.84 | | 3.03 | |
| *Pleuromamma indica* | | | | **22.73** | 1.89 | 1.61 | 2.33 | | 4.35 |
| *Pleuromamma* sp. | | | | | | 1.61 | | | |
| *Pontellina plumata* | | 1.56 | 1.85 | 4.55 | | 1.61 | 1.16 | | 4.35 |
| *Rhincalanus cornutus* | | | | | | 1.61 | | | |
| *Sapphirina* sp. | 3.85 | **18.75** | **11.11** | 4.55 | | | | 6.06 | |
| *Scolecithrix danae* | | 1.56 | 5.56 | 4.55 | | | | | |
| *Scottocalanus helenae* | | 1.56 | | | 9.43 | 1.61 | 3.49 | 3.03 | |
| *Temora discaudata* | | | | | | **11.29** | 4.65 | | |
| *Temora stylifera* | | 3.12 | | 4.55 | **28.30** | **9.68** | **16.28** | **12.12** | **26.09** |
| *Undinula vulgaris* | **19.23** | **10.94** | **31.48** | **22.73** | | | | | |
| Total ind 100 $m^{-3}$ | 4232 | 24896 | 14428 | 6741 | 53341 | 857274 | 221464 | 72265 | 37720 |
| Number of species | 14 | 23 | 22 | 12 | 16 | 28 | 18 | 16 | 16 |

Dominant copepods at each station are marked **bold**

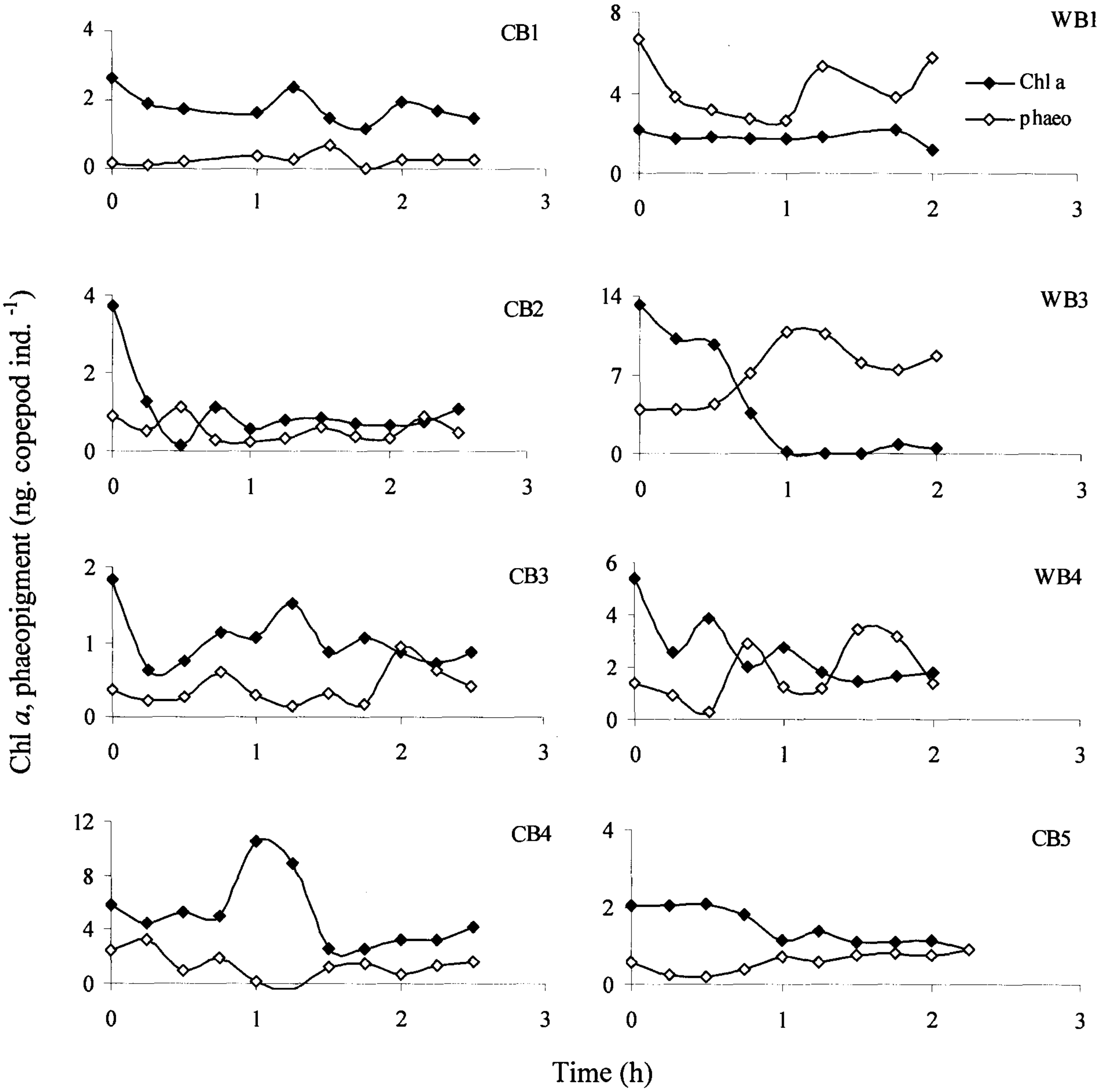


Figure 8.1. Variation in copepod gut pigments (ng. chl *a* and phaeopigments. copepod ind$^{-1}$) with increasing starvation time

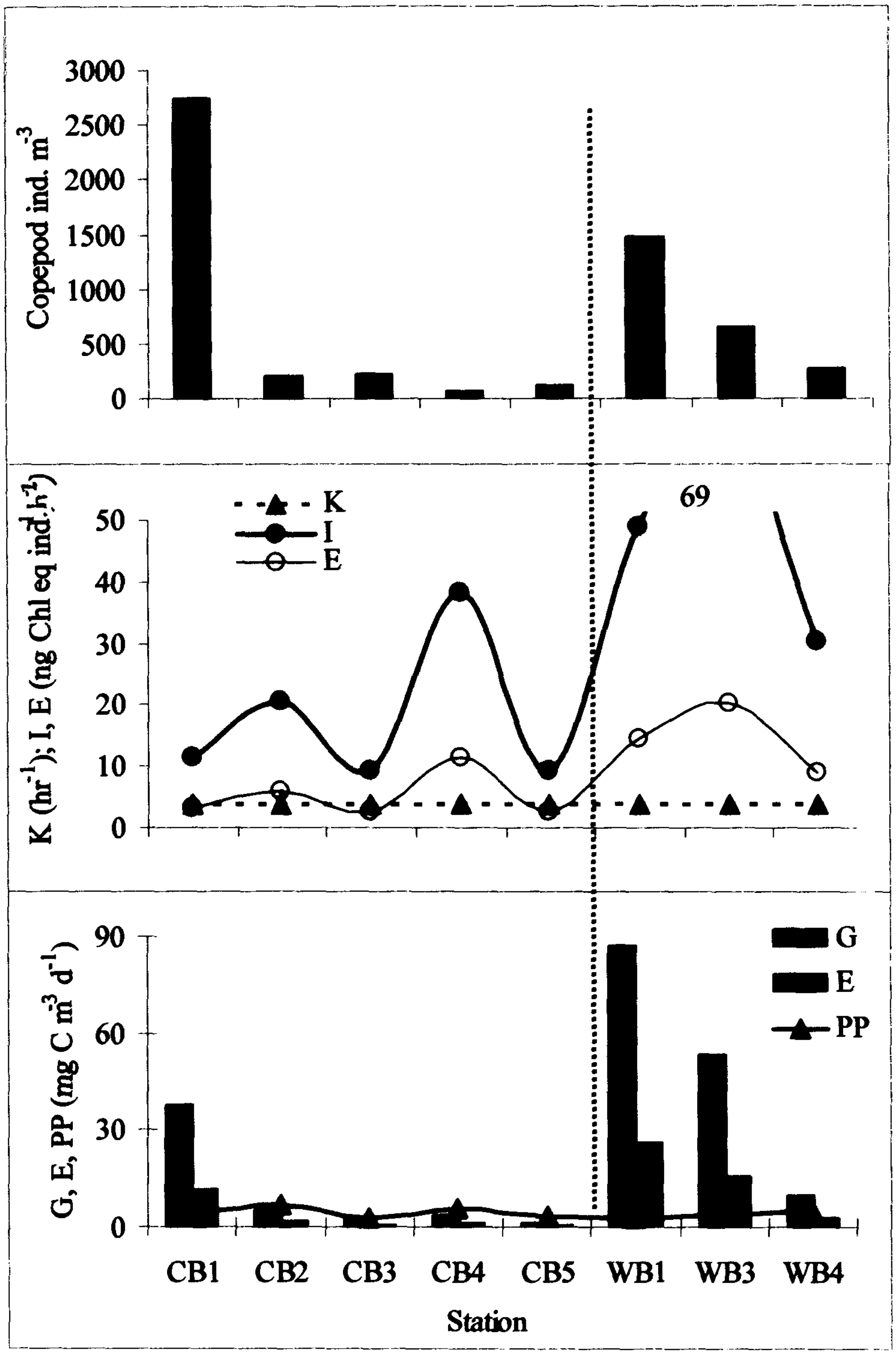


Figure 8.2. Copepod abundance (individuals 100 $m^{-3}$); their gut evacuation rate constant (K), ingestion (I), egestion (E; fecal pellet production) and, grazing rate (G) and primary production (PP) in the mixed layer

stations. Using these values, the gut clearance time was estimated to be 14.7-14.9 min. Ingestion rates on chlorophyll ranging from 9.5 to 68.5 ng chl eq. ind$^{-1}$ h$^{-1}$ were the highest at WB3, followed by WB1. Egestion of fecal pellets, which is assumed to be 30% of ingestion varied from 2.9 to 20.6 ng chl eq. ind$^{-1}$ h$^{-1}$.

The calculated ingestion rates corresponded to a daily grazing rate of 1.3-87 mg C m$^{-3}$ d$^{-1}$ in the mixed layer depth (MLD; Fig. 8.2). Similarly, the carbon lost through their fecal pellets ranged from 0.4 to 26.1 mg C m$^{-3}$ d$^{-1}$. Both grazing and egestion rates were higher in the WB. The grazing rate ranged from 39 to >100% of the daily primary production (PP) in the MLD. The grazing rate exceeded the daily PP at all the stations in WB.

### 8.2.3. Respiration rate

Respiratory oxygen consumption (RO) rates for the 200-500 μm fraction of surface living copepods varied from 0.15 to 0.38 μl $O_2$ ind$^{-1}$ h$^{-1}$ (Fig. 8.3) at different stations. The corresponding body carbon respired (RC) was 79-205 ng C ind$^{-1}$ h$^{-1}$. The total copepod community at various stations contributed to daily respiration rates (RD) of 0.3- 5.2 mg C m$^{-3}$ d$^{-1}$. This accounted for 6-141% of the daily primary production (PP). It exceeded that of PP at CB1 and WB1.

Seasonally, the carbon loss due to mesozooplankton respiration in the MLD ranged from 0.08 to 96.14 mg C m$^{-2}$ d$^{-1}$ during SUM, 6.92 to 209.11 mg C m$^{-2}$ d$^{-1}$ during FIM, 9.25 to 190.34 mg C m$^{-2}$ d$^{-1}$ during WM and 1.26 to 349.45 mg C m$^{-2}$ d$^{-1}$ during SpIM (Fig. 8.4). The highest rates were during SpIM and the lowest during SUM. On an average, the daily respiration rates were 22, 15, 36 and 63% of the daily PP in upper 40 m during SUM, FIM, WM and SpIM respectively.

### 8.2.4. Responses of plankton assemblages to nutrient amendments

*Variation of the chemical and biological factors with time*

The following is a brief account of quantitative details of chemical and biological parameters in whole seawater used in the experiments. The variations during the experimental period are presented in Fig. 8.5-8.10.

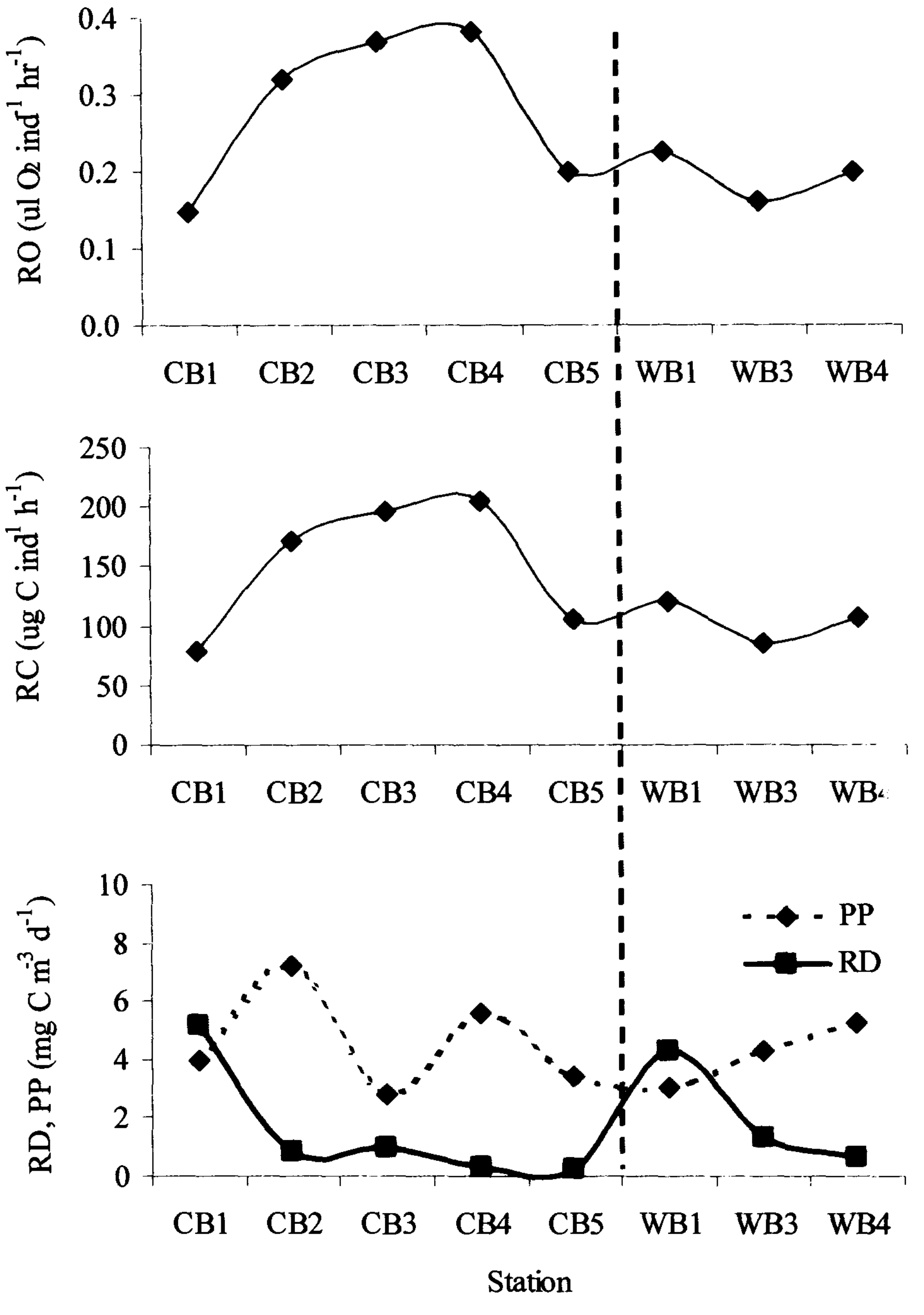


Figure 8.3. Station-wise variation in the rates of oxygen consumption (RO), body carbon respired (RC), daily carbon respiration (RD) and daily primary production (PP) in the central and western Bay of Bengal.

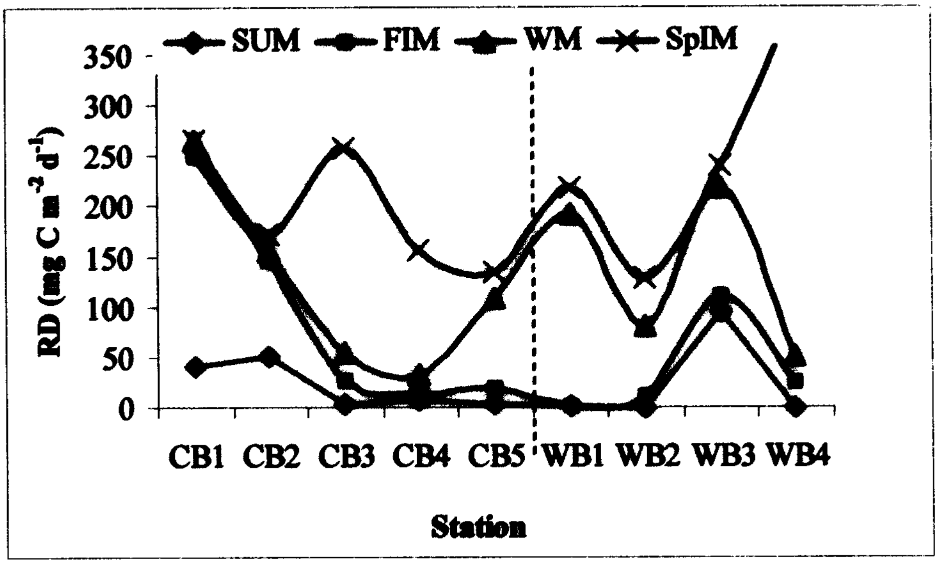


Figure 8.4. Station-wise variation in the rates of daily carbon equivalent of zooplankton respiration (RD) in mixed layer depth during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and Spring intermonsoon (SpIM) in the central and western Bay of Bengal

The ambient nutrient concentrations in seawater were below detection limit for $NO_3$; 2 µM of $SiO_3$, and 1 µM of $PO_4$ at CB1. At CB5, their concentrations were 0.3, 4.7 and 0.3 µM respectively. At WB2, the respective concentrations were 2.2, 4.8 and 1.6 µM. Phytoplankton abundance in whole seawater ranged from 0.32 x $10^3$ cells $l^{-1}$ at CB1, 0.1 x $10^4$cells $l^{-1}$ at CB5 to 0.36 x $10^3$ cells $l^{-1}$ for respective locations on day zero. Microzooplankton numbers varied from 12 ind. $l^{-1}$ at CB1 to 8 ind. $l^{-1}$ each at CB5 and WB2. Similarly, mesozooplankton numbers on day zero at CB1, CB5 and WB1 were 4, 4 and 8 individuals $l^{-1}$. Bacterioplankton numbers (no.x $10^9$ cells $l^{-1}$) were 0.03, 0.1 and 0.2 at CB1, CB5 and WB2 respectively. Chl *a* concentration varied from 0.14 at CB1, 0.3 at CB5 to 0.26 mg $m^{-3}$ at WB2. Phaeopigment values were 0.04, 0.03 and 0.15 mg $m^{-3}$ at the same stations.

Phytoplankton abundance differed considerably ($p<0.05$) between the experimental treatments (different size fractionated water) with the lowest numbers in the microcosms with 20 µm filtered seawater. Bacterial numbers were significantly higher in microcosms containing added zooplankton. Chlorophyll *a* and phaeo-pigment concentrations decreased in the smaller size fractions. While numbers of mesozooplankton significantly reduced in the <200 µm fraction of seawater, that of microzooplankton were negligible in the 20 µm fractionated seawater (Table 8.2).

Between the nutrient-amended and non-amended microcosms, most of the measured biological parameters did not not show a significant difference except for chl *a* and phaeopigments at all stations and microzooplankton at CB5 and WB2. The 7-day variation of the measured parameters in treatments with and without nutrient additions is described below.

*Observations from microcosms without nutrient addition*

At CB1, from day zero to day seven, nutrients generally showed a significant variation in most microcosms. In WSW (Microcosm 1), the phytoplankton cell counts ranging from 0.08 to 0.48 (x $10^3$ cells $l^{-1}$) remained high between day zero and day four and drastically decreased later (Fig. 8.5). However, the decrease in chl *a* concentration ranging from 0.1 to 0.19 mg $m^{-3}$ was not drastic. The phaeopigment concentration seemed to increase from 0.03 to 0.06 mg $m^{-3}$ with increasing number of days. Micro- (4-12 ind. $l^{-1}$) and meso-( 4-8

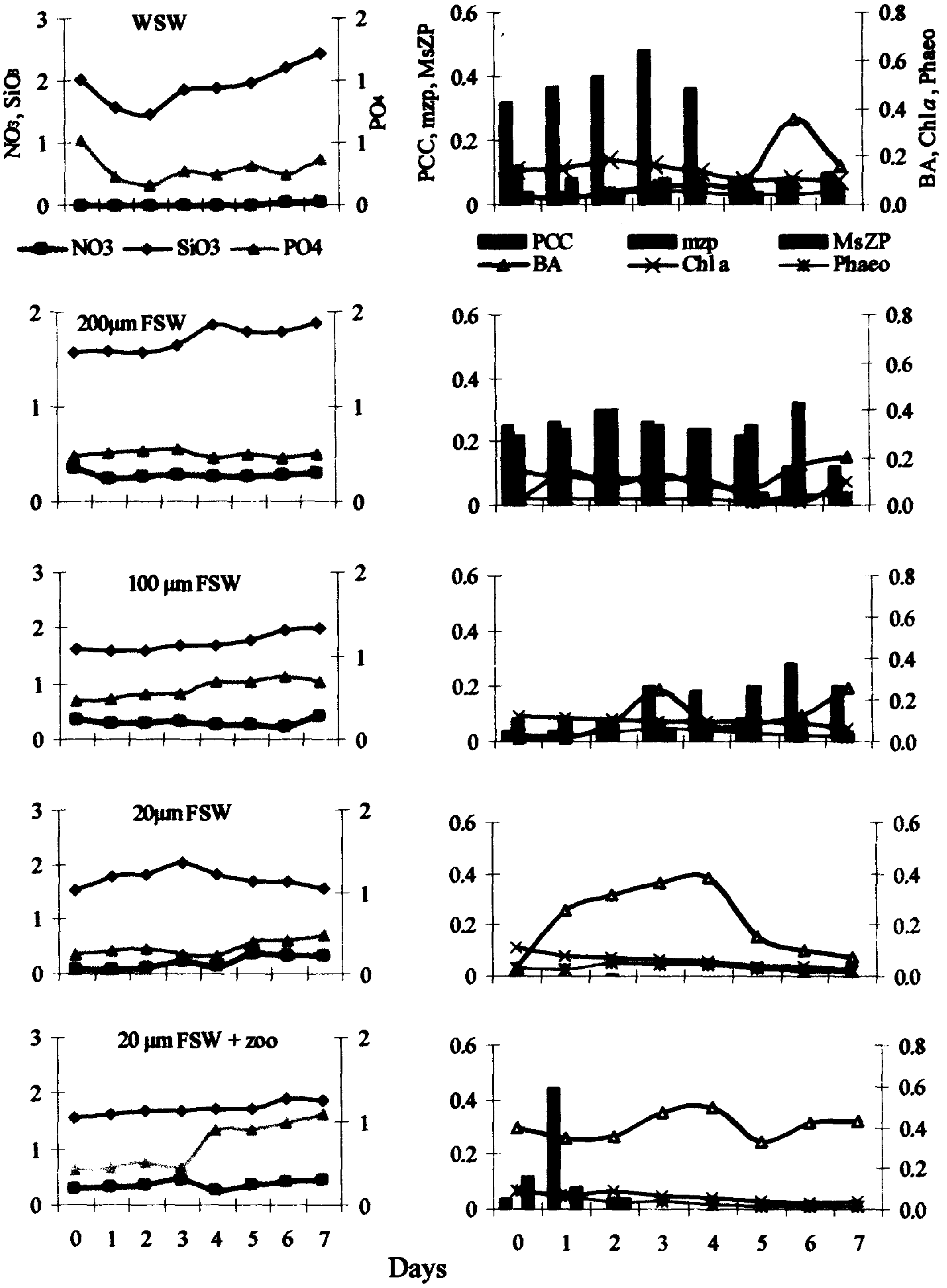


Figure 8.5. Variation of nitrate ($NO_3$), silicate ($SiO_3$) and phosphate ($PO_4$) concentrations (µM), phytoplankton cell counts (PCC; $10^3$ cells $l^{-1}$), microzooplankton (mzp; $10^2$ ind. $l^{-1}$), mesozooplankton (MsZP; $10^2$ ind. $l^{-1}$), bacteria (BA; $10^9$ cells $l^{-1}$), chlorophyll *a* (chl *a*; mg $m^{-3}$) and phaeopigments (phaeo; mg $m^{-3}$) in the microcosms with different size fractions of nutrient un-amended seawater over a 7-day period at CB1. (WSW: whole seawater, FSW: filtered seawater, Zoo: zooplankton).

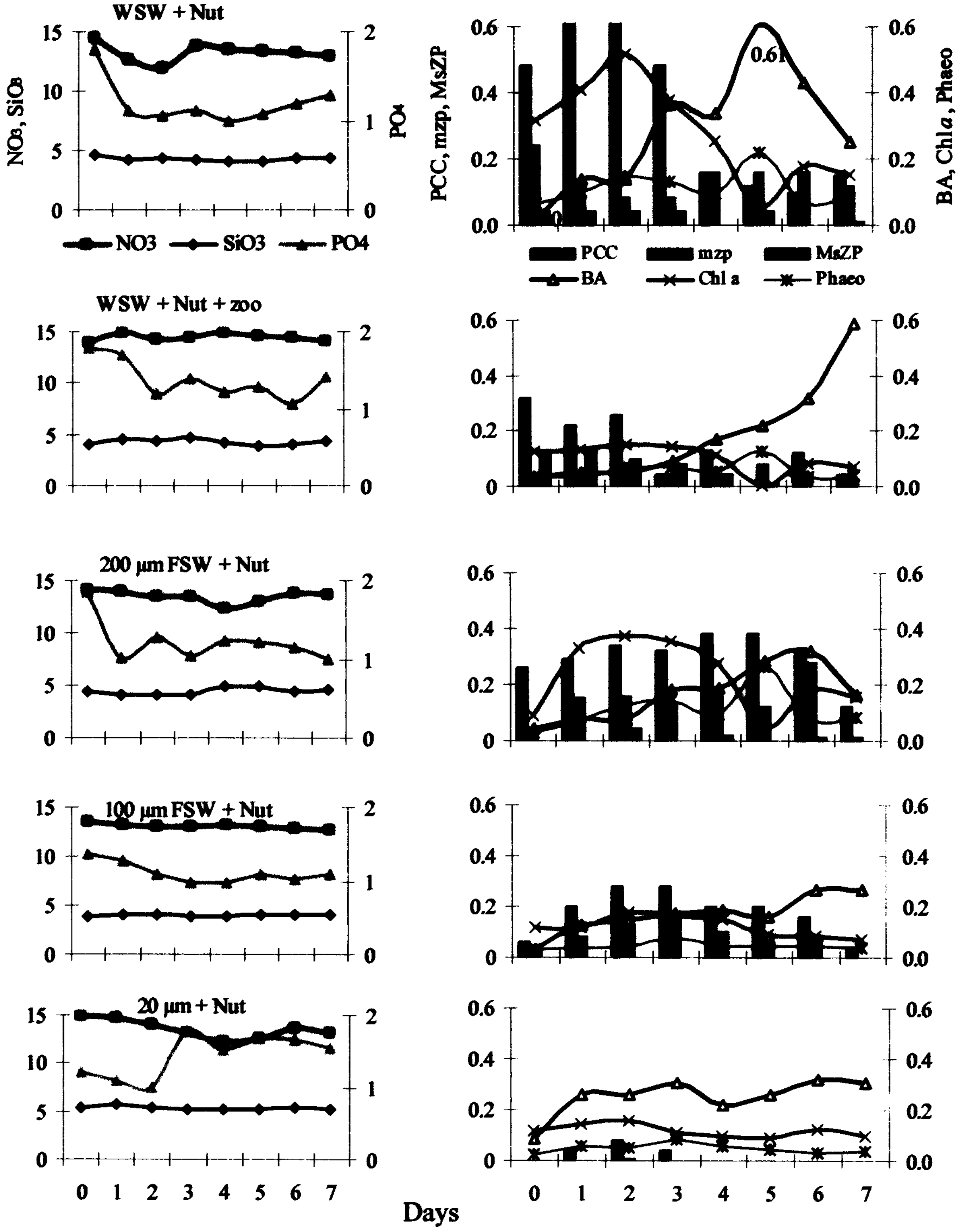


Figure 8.6. Variation of nitrate ($NO_3$), silicate ($SiO_3$) and phosphate ($PO_4$) concentrations (μM), phytoplankton cell counts (PCC; $10^3$ cells $l^{-1}$), microzooplankton (mzp; $10^2$ ind. $l^{-1}$), mesozooplankton (MsZP; $10^2$ ind. $l^{-1}$), bacteria (BA; $10^9$ cells $l^{-1}$), chlorophyll *a* (chl *a*; mg $m^{-3}$) and phaeopigments (phaeo; mg $m^{-3}$) in the microcosms with different size fractions of nutrient amended seawater over a 7-day period at CB1. (WSW: whole seawater, FSW: filtered seawater, Zoo: zooplankton, Nut: nutrients).

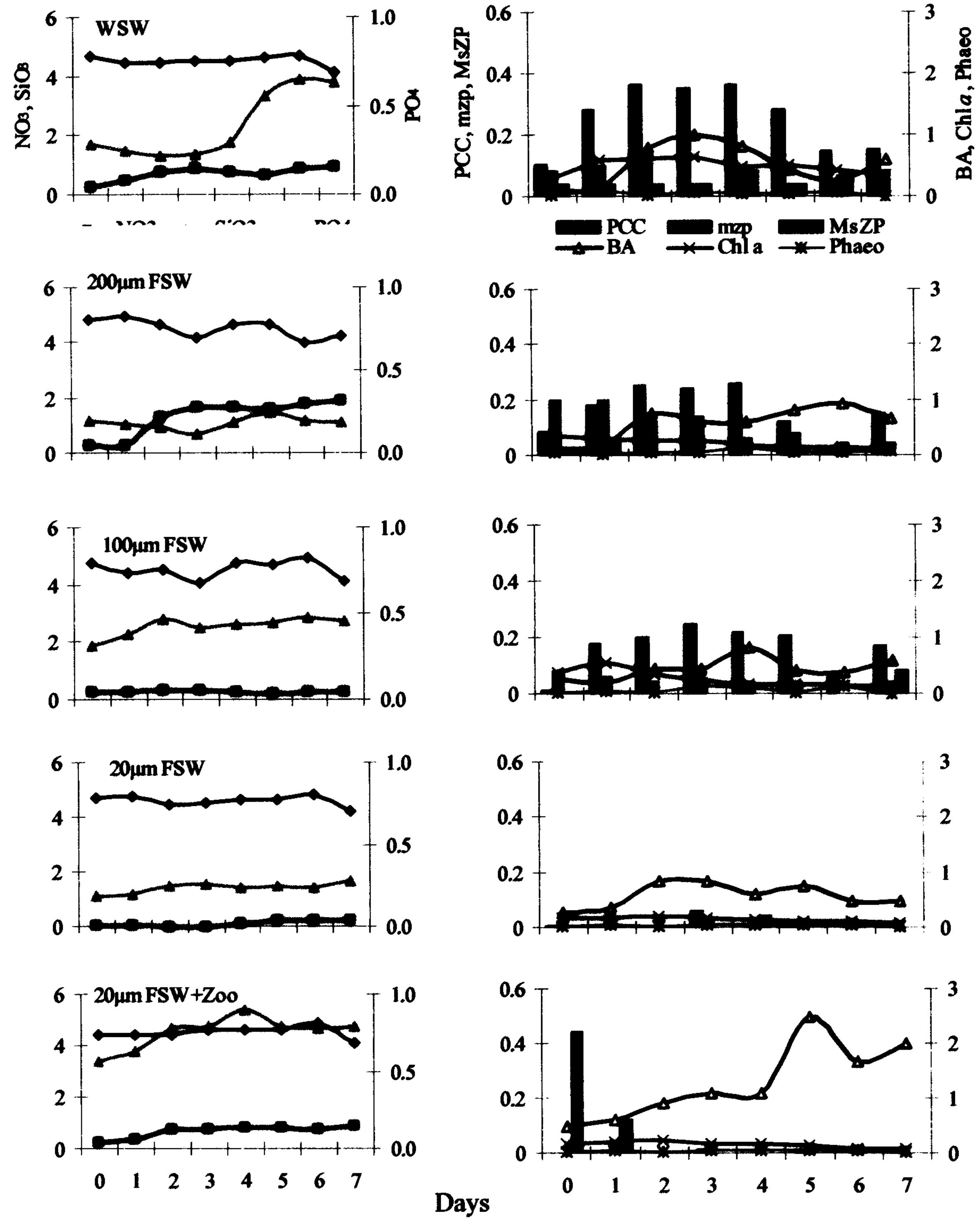


Figure 8.7. Variation of nitrate ($NO_3$), silicate ($SiO_3$) and phosphate ($PO_4$) concentrations (µM), phytoplankton cell counts (PCC; $10^4$ cells $l^{-1}$), microzooplankton (mzp; $10^2$ ind. $l^{-1}$), mesozooplankton (MsZP; $10^2$ ind. $l^{-1}$), bacteria (BA; $10^9$ cells $l^{-1}$), chlorophyll *a* (chl *a*; mg $m^{-3}$) and phaeopigments (phaeo; mg $m^{-3}$) in the microcosms with different size fractions of nutrient un-amended seawater over a 7-day period at CB5. (WSW: whole seawater, FSW: filtered seawater, Zoo: zooplankton)

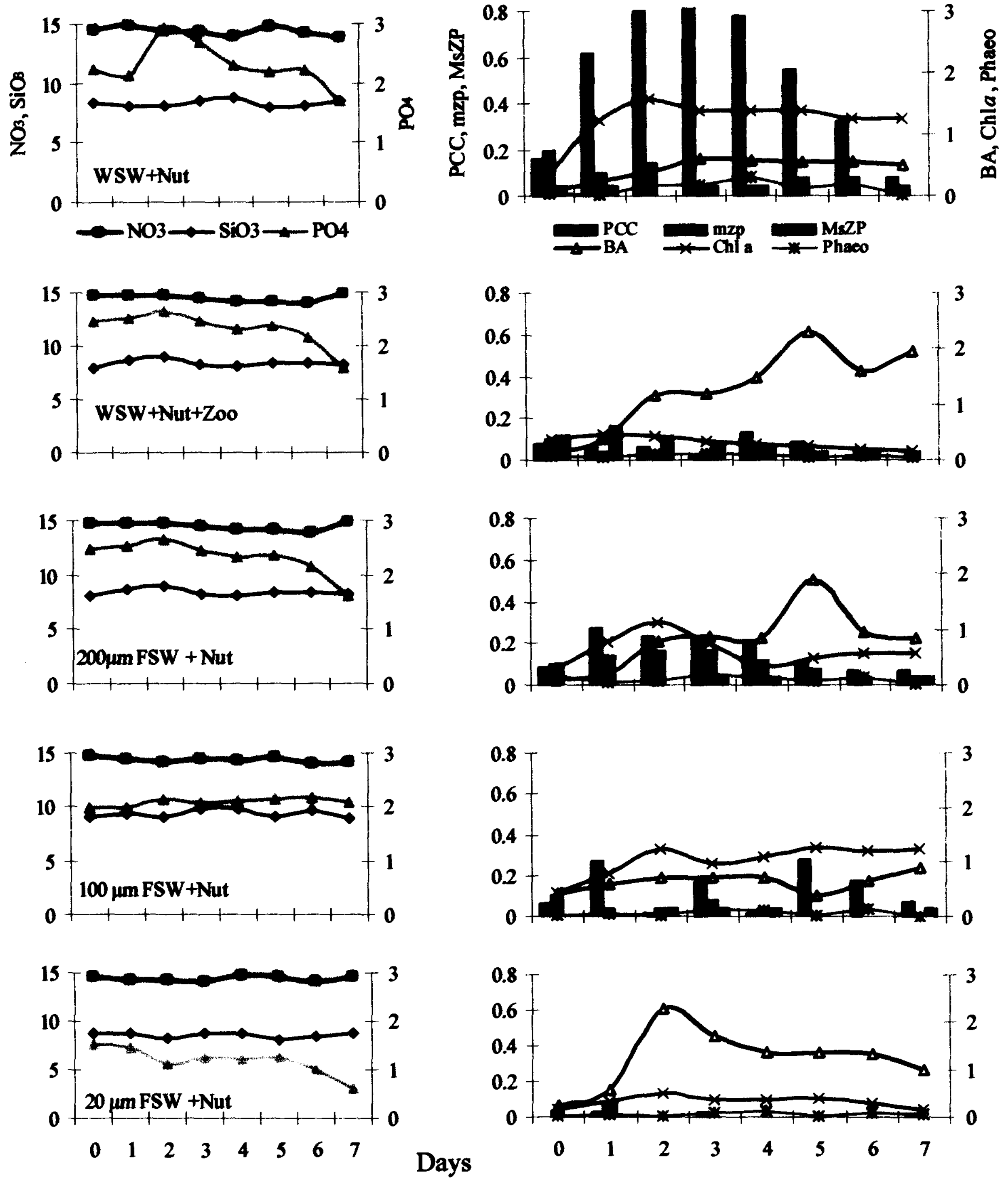


Figure 8.8. Variation of nitrate ($NO_3$), silicate ($SiO_3$) and phosphate ($PO_4$) concentrations (µM), phytoplankton cell counts (PCC; $10^4$ cells $l^{-1}$), micro zooplankton (mzp; $10^2$ ind. $l^{-1}$), mesozooplankton (MsZP; $10^2$ ind. $l^{-1}$), bacteria (BA; $10^9$ cells $l^{-1}$), chlorophyll a (chl *a*; mg $m^{-3}$) and phaeopigments (phaeo; mg $m^{-3}$) in the microcosms with different size fractions of nutrient amended seawater over a 7-day period at CB5. (WSW: whole seawater, FSW: filtered seawater, Zoo: zooplankton, Nut: nutrients)

ind. $l^{-1}$) zooplankton were present throughout. Bacterial numbers (0.03-0.36 x $10^9$ cells $l^{-1}$) increased by an order of magnitude with increasing number of days.

The 200 µm filtered seawater (Microcosm 5) was devoid of mesozooplankton. Thus, microzooplankton ranging from 4 to 32 (ind. $l^{-1}$) were abundant on all days. Phytoplankton concentrations were lower, and varied from 0.12 to 0.3 (x $10^3$ cells $l^{-1}$). The chl *a* concentration reduced from a maximum of 0.14 on day zero to 0.01 mg $m^{-3}$ by day six. Similar trend was noticed in the phaeopigment concentrations (0.01-0.04 mg $m^{-3}$). Bacterial numbers increased by an order from 0.02 to 0.2 (x $10^9$ cells $l^{-1}$) by day seven.

In the 100 µm fraction (Microcosm 7), both microzooplankton (3-20 ind. $l^{-1}$) and PCC (0.04-0.28 x $10^3$ cells $l^{-1}$) were much less. Chl *a* varied from 0.07 to 0.13 mg $m^{-3}$ and phaeopigments from 0.03 to 0.07 mg $m^{-3}$. As chl *a* decreased, a slight increase was observed in the phaeopigment concentrations. Bacteria varying from 0.02 to 0.25 (x $10^9$ cells $l^{-1}$) showed two peaks, one on day three and the other on day seven.

In the 20 µm passed fraction (Microcosm 8), microzoo-, mesozoo- and microphytoplankton were absent. Bacterial numbers varied from 0.03 to 0.38 (x $10^9$ cells $l^{-1}$). Chl *a* varying from 0.03 to 0.12 mg $m^{-3}$, decreased with time. Phaeopigments varied from 0.02 to 0.05 mg $m^{-3}$ and was higher during day two to day five.

In the 20 µm passed seawater fraction (Microcosm 10), the extra zooplankton which were added did not survive after day 2. The number of bacteria varying from 0.4 to 0.5 (x $10^9$ cells $l^{-1}$) did not change much till the seventh day. Chl *a* concentrations varying from 0.04 to 0.09 mg $m^{-3}$ were the lowest among the non-amended microcosms. Phaeopigment concentrations varied from 0.02 to 0.09 mg $m^{-3}$. The concentrations of both decreased with time.

*Observations from nutrient added microcosms*

Upon nutrient addition to the whole seawater (Microcosm 2), a prominent increase in phytoplankton cells ( 0.1-0.64 x $10^3$ cells $l^{-1}$) and chl *a* (0.06-0.52 mg $m^{-3}$) was observed on the second day, decreasing drastically by the seventh day (Fig. 8.6). Phaeo-pigments varying from 0.07 to 0.15 mg $m^{-3}$, were found to peak at the chl *a* minimum. Micro-(8-24 ind. $l^{-1}$) and meso-(0-4 ind. $l^{-1}$) zooplankton grazers were present throughout the

Table 8.2. Two-way anova of various parameters measured in the experiments carried out in different microcosms incubated at ship temperature over a period of seven days.

| | | Source of variation | |
|---|---|---|---|
| Variables | CB1 | CB5 | WB2 |
| | | Between experimental treatments | |
| Nitrate | $F_{(9, 79)}=1277$; **$p<0.05$** | $F_{(9, 79)}=363.5$; **$p<0.05$** | $F_{(9, 79)}=449$; **$p<0.05$** |
| Silicate | $F_{(9, 79)}=352$; **$p<0.05$** | $F_{(9, 79)}=27.5$; **$p<0.05$** | $F_{(9, 79)}=617$; **$p<0.05$** |
| Phosphate | $F_{(9, 79)}=25.6$; **$p<0.05$** | $F_{(9, 79)}=28.6$; **$p<0.05$** | $F_{(9, 79)}=57$; **$p<0.05$** |
| Phytoplankton | $F_{(9, 79)}=7.03$, **$p<0.05$** | $F_{(9, 79)}=17$; **$p<0.05$** | $F_{(9, 79)}=14.5$; **$p<0.05$** |
| Microzooplankton | $F_{(9, 79)}=7.19$; **$p<0.05$** | $F_{(9, 79)}=6.5$; **$p<0.05$** | $F_{(9, 79)}=6.1$; **$p<0.05$** |
| Mesozooplankton | $F_{(9, 79)}=7.5$; **$p<0.05$** | $F_{(9, 79)}=1.49$; $p>0.05$ | $F_{(9, 79)}=5.0$; **$p<0.05$** |
| Bacteria | $F_{(9, 79)}=2.4$; **p<0.05** | $F_{(9, 79)}=7.6$; **$p<0.05$** | $F_{(9, 79)}=9.3$; **$p<0.05$** |
| Chlorophyll *a* | $F_{(9, 79)}=13.07$, **$p<0.05$** | $F_{(9, 79)}=42.2$; **$p<0.05$** | $F_{(9, 79)}=8.5$; **$p<0.05$** |
| Phaeopigments | $F_{(9, 79)}=7.9$; **$p<0.05$** | $F_{(9, 79)}=4.8$; **$p<0.05$** | $F_{(9, 79)}=3.7$; **$p<0.05$** |
| | | Between nutrient amended and the non-amended | |
| Phytoplankton | $F_{(1, 78)}=3.6$; $p>0.05$ | $F_{(1, 78)}=0.17$; $p>0.05$ | $F_{(1, 78)}=2.4$; $p>0.05$ |
| Microzooplankton | $F_{(1, 78)}=3.2$; $p>0.05$ | $F_{(1, 78)}=4.9$; **$p<0.05$** | $F_{(1, 78)}=4.0$; **$p<0.05$** |
| Mesozooplankton | $F_{(1, 78)}=1.3$; $p>0.05$ | $F_{(1, 78)}=0.1$; $p>0.05$ | $F_{(1, 78)}=0.28$; $p>0.05$ |
| Bacteria | $F_{(1, 78)}=1.5$; $p>0.05$ | $F_{(1, 78)}=2.1$; $p>0.05$ | $F_{(1, 78)}=0.75$; $p>0.05$ |
| Chlorophyll *a* | $F_{(1, 78)}=10.9$; **$p<0.05$** | $F_{(1, 78)}=29.7$; **$p<0.05$** | $F_{(1, 78)}=8.3$; **$p<0.05$** |
| Phaeopigment | $F_{(1, 78)}=13.3$; **$p<0.05$** | $F_{(1, 78)}=15.8$; **$p<0.05$** | $F_{(1, 78)}=5.4$; **$p<0.05$** |
| | | Between Days | |
| Nitrate | $F_{(7, 79)}=1.2$; $p>0.05$ | $F_{(7, 79)}=11.57$; **$p<0.05$** | $F_{(7, 79)}=7.4$; **$p<0.05$** |
| Silicate | $F_{(7, 79)}=11.54$; **$p<0.05$** | $F_{(7, 79)}=18.6$; **$p<0.05$** | $F_{(7, 79)}=3.09$; **$p<0.05$** |
| Phosphate | $F_{(7, 79)}=6.61$; **$p<0.05$** | $F_{(7, 79)}=9.8$; **$p<0.05$** | $F_{(7, 79)}=5.37$; **$p<0.05$** |
| Phytoplankton | $F_{(7, 79)}=2.6$; **$p<0.05$** | $F_{(7, 79)}=4.2$; **$p<0.05$** | $F_{(7, 79)}=7.6$; **$p<0.05$** |
| Microzooplankton | $F_{(7, 79)}=2.8$; **$p<0.05$** | $F_{(7, 79)}=4.0$; **$p<0.05$** | $F_{(7, 79)}=4.5$; **$p<0.05$** |
| Mesozooplankton | $F_{(7, 79)}=1.7$; $p>0.05$ | $F_{(7, 79)}=1.0$; $p>0.05$ | $F_{(7, 79)}=2.0$; $p>0.05$ |
| Bacteria | $F_{(7, 79)}=2.6$; **$p<0.05$** | $F_{(7, 79)}=8.2$; **$p<0.05$** | $F_{(7, 79)}=9.5$; **$p<0.05$** |
| Chlorophyll *a* | $F_{(7, 79)}=10$, **$p<0.05$** | $F_{(7, 79)}=5.3$; **$p<0.05$** | $F_{(7, 79)}=38.7$; **$p<0.05$** |
| Phaeopigments | $F_{(7, 79)}=4.8$; **$p<0.05$** | $F_{(7, 79)}=5.0$; **$p<0.05$** | $F_{(7, 79)}=5.8$; **$p<0.05$** |
| | | Between experiments | |
| | | $F_{(2, 1439)}=103$; **$p<0.05$** | |

Significant results are marked **bold**

experiment. The dwindling chl *a* and phytoplankton cells were accompanied by a rise in bacterial numbers.

In the microcosms where nutrients and zooplankton were added to whole seawater (Microcosm 3), PCC (0.04-0.32 x $10^3$ cells $l^{-1}$) and chl *a* concentrations (0.006-0.126 mg $m^{-3}$) were found to be lower and without a prominent peak. Phaeopigments showed a peak near the chl *a* minimum. Bacterial numbers increased quite a lot from 0.03 to 0.6 (x $10^9$ cells $l^{-1}$) by day five.

In the 200 µm passed seawater (Microcosm 4), without mesozooplankton and amended with nutrients, it was seen that phytoplankton cells (0.12-0.38 x $10^3$ cells $l^{-1}$), chl *a* (0.05-0.38 mg $m^{-3}$) and phaeopiments (0.03-0.27 mg m¯3) nearly doubled when compared to the microcosm No.7 containing whole sea water, extra nutrients and extra mesozooplankton. Bacterial counts which also increased from 0.05 to 0.32 (x $10^9$ cells $l^{-1}$) were lower than in the amended whole seawater (microcosm No. 7). While mesozooplankton were hardly observed, microzooplankton ranged from 4 to 28 ind. $l^{-1}$.

In the nutrient amended 100 µm passed seawater(Microcosm 6), the increase in phytoplankton cells (0.04-0.28 x $10^3$ cells $l^{-1}$), chl *a* ( 0.07-0.18 mg $m^{-3}$) and phaeopigments (0.04-0.08 mg $m^{-3}$) was smaller. Microzooplankton ranged in abundance from 4-10 ind. $l^{-1}$. Bacteria increased in abundance from 0.03 to 0.27 ( x $10^9$ cells $l^{-1}$) by the end of the experiment.

In the 20 µm passed fraction (Microcosm 9), chl *a* concentration remained stable throughout the experimental period while bacteria showed a steady increase as the experiment progressed. Phaeopigment concentration was ~50% of the chl *a* concentration.

Akin to this experiment, the measured parameters were almost similar in their quantitative comparison in the other two experiments at CB5 (Fig. 8.7, 8.8) and WB2 (Fig. 8.9, 8.10). However, the response of large phytoplankton and the chl *a* to the nutrient amendments was significant ($p<0.05$) at CB5.

*Correlation analyses*

Phytoplankton cell counts (PCC) correlated significantly positively with chl *a*, phaeopigments and microzooplankton at all the stations from where these experiments

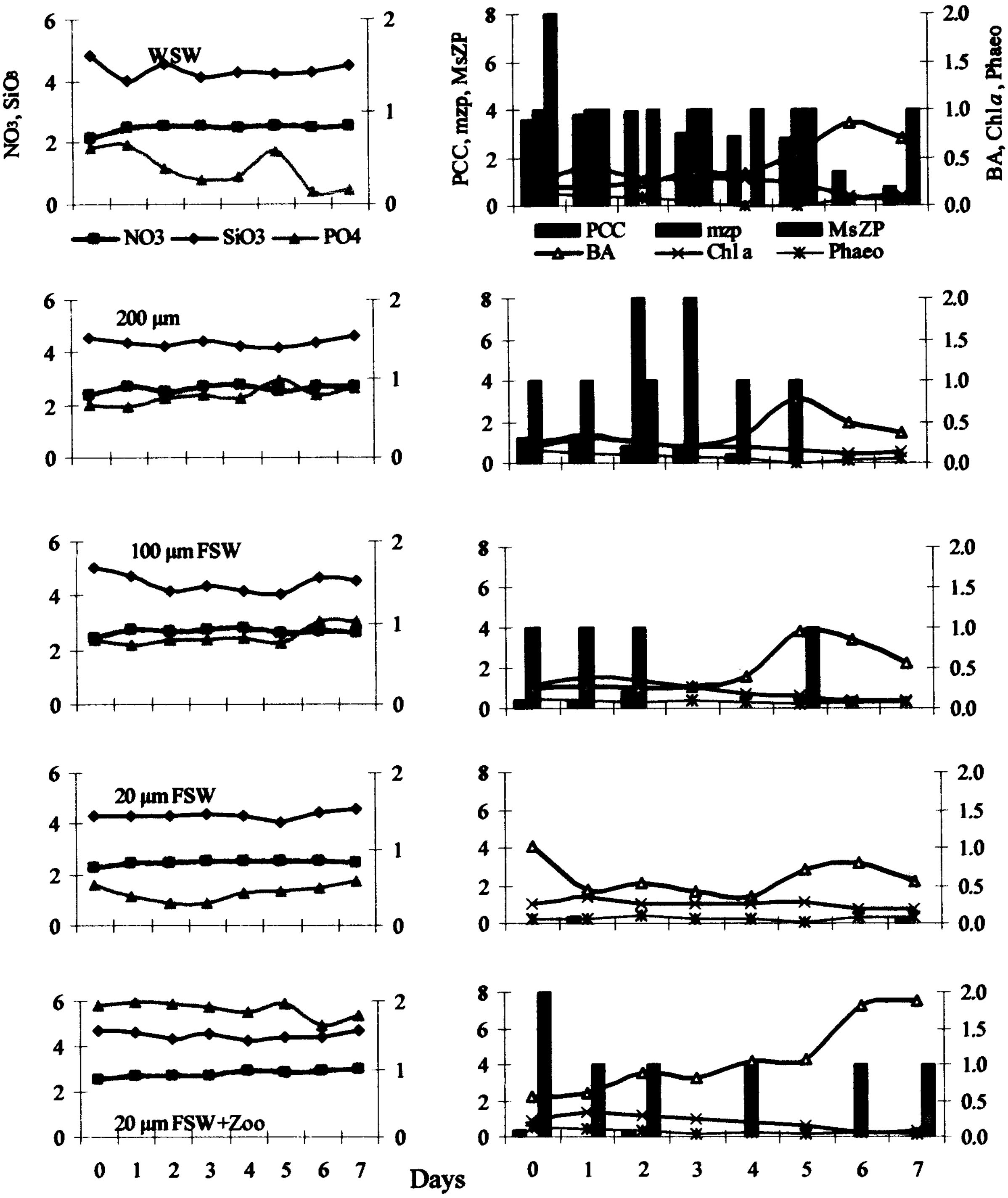


Figure 8.9. Variation of nitrate ($NO_3$), silicate ($SiO_3$) and phosphate ($PO_4$) concentrations (µM), phytoplankton cell counts (PCC; $10^2$ cells $l^{-1}$), micro zooplankton (mzp; ind. $l^{-1}$), mesozooplankton (MsZP; ind. $l^{-1}$), bacteria (BA; $10^9$ cells $l^{-1}$), chlorophyll a (chl *a*; mg $m^{-3}$) and phaeopigments (phaeo; mg $m^{-3}$) in the microcosms with different size fractions of nutrient un-amended seawater over a 7-day period at WB2. (WSW: whole seawater, FSW: filtered seawater, Zoo: zooplankton)

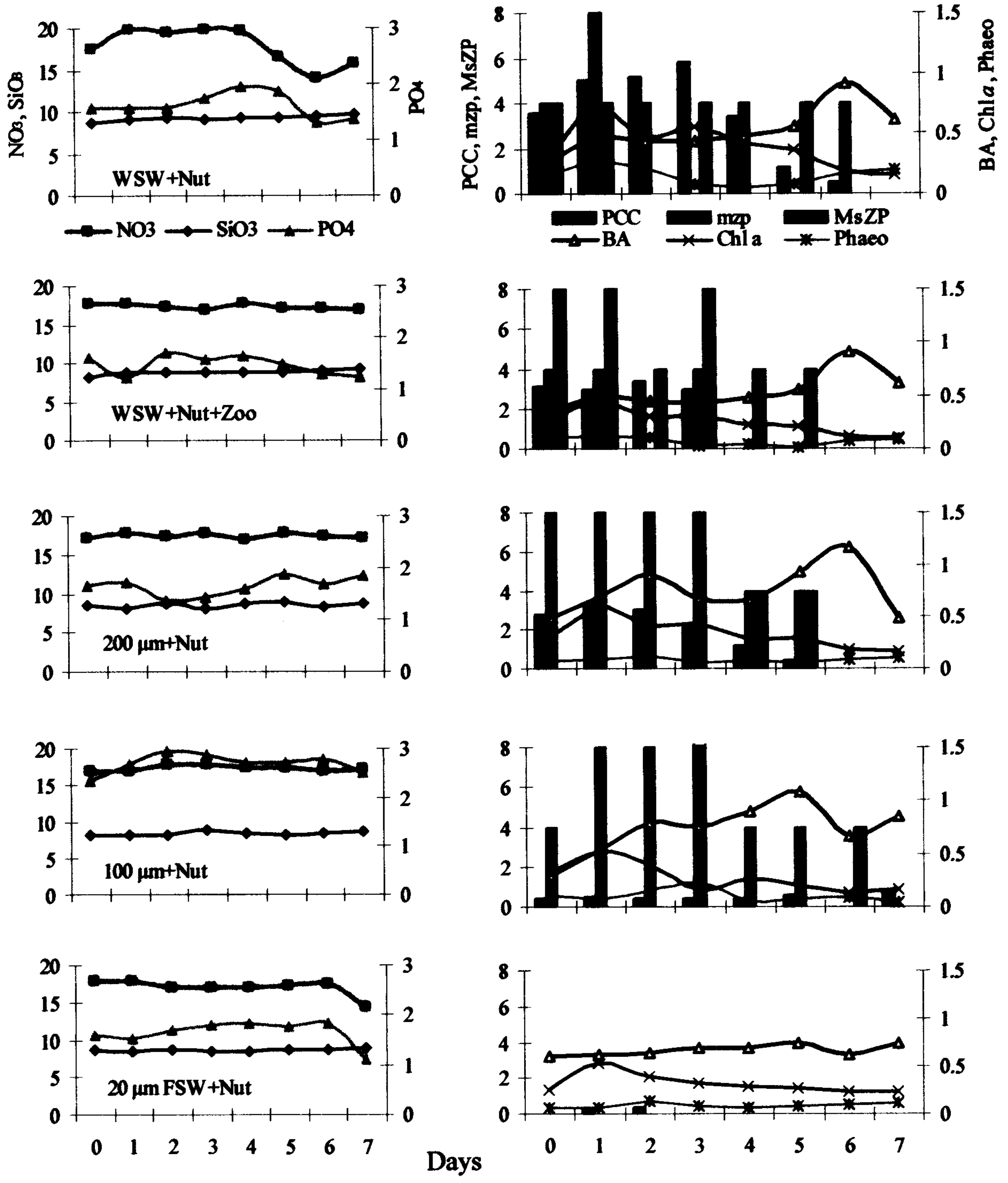


Figure 8.10. Variation of nitrate (NO$_3$), silicate (SiO$_3$) and phosphate (PO$_4$) concentrations (µM), phytoplankton cell counts (PCC, $10^2$ cells $l^{-1}$), microzooplankton (mzp; ind. $l^{-1}$), mesozooplankton (MsZP; ind. $l^{-1}$), bacteria (BA; $10^9$ cells $l^{-1}$), chlorophyll a (chl *a*; mg $m^{-3}$) and phaeopigments (phaeo; mg $m^{-3}$) in the microcosms with different size fractions of nutrient amended seawater over a 7-day period at WB2. (WSW: whole seawater, FSW: filtered seawater, Zoo: zooplankton, Nut: nutrients)

Table 8.3. Spearman correlation coefficient (R) of the various parameters measured in the experiments.

| Pair of Variables | N | R | t(N-2) | *p* | R | t(N-2) | *p* | R | t(N-2) | *p* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CB1 | | | CB5 | | | WB2 | | |
| PCC & chl *a* | 80 | 0.61 | 6.71 | **0.00** | 0.70 | 8.68 | **0.00** | 0.54 | 5.71 | **0.00** |
| PCC & phaeo | 80 | 0.42 | 4.12 | **0.00** | 0.30 | 2.80 | **0.01** | 0.24 | 2.16 | **0.03** |
| PCC & mzp | 80 | 0.58 | 6.25 | **0.00** | 0.61 | 6.77 | **0.00** | 0.60 | 6.70 | **0.00** |
| PCC & MsZP | 80 | 0.22 | 1.96 | **0.05** | 0.32 | 2.99 | **0.00** | 0.52 | 5.34 | **0.00** |
| PCC & BA | 80 | -0.41 | -2.95 | **0.01** | -0.31 | -2.85 | **0.01** | -0.44 | -4.29 | **0.00** |
| PCC & $PO_4$ | 80 | 0.08 | 0.75 | 0.46 | 0.22 | 2.01 | **0.05** | -0.14 | -1.29 | 0.20 |
| mzp & chl *a* | 80 | 0.45 | 4.40 | **0.00** | 0.45 | 4.44 | **0.00** | 0.37 | 3.51 | **0.00** |
| mzp & phaeo | 80 | 0.48 | 4.81 | **0.00** | 0.20 | 1.84 | 0.07 | 0.11 | 1.00 | 0.32 |
| mzp & BA | 80 | -0.16 | -1.43 | 0.16 | -0.34 | -3.24 | **0.00** | -0.33 | -3.04 | **0.00** |
| mzp & MsZP | 80 | 0.15 | 1.36 | 0.18 | 0.31 | 2.86 | **0.01** | 0.37 | 3.48 | **0.00** |
| MsZP & $NO_3$ | 80 | 0.02 | 0.14 | 0.89 | 0.38 | 3.59 | **0.00** | 0.03 | 0.24 | 0.81 |
| MsZP & $PO_4$ | 80 | 0.03 | 0.30 | 0.76 | 0.30 | 2.75 | **0.01** | -0.07 | -0.65 | 0.52 |
| MsZP & phaeo | 80 | 0.48 | 4.81 | **0.00** | 0.14 | 1.20 | 0.23 | 0.12 | 1.11 | 0.27 |
| MsZP & BA | 80 | -0.12 | -1.08 | 0.28 | -0.17 | -1.5 | 0.14 | -0.24 | -2.21 | **0.03** |
| BA & chl *a* | 80 | -0.25 | -2.28 | **0.03** | -0.07 | -0.65 | 0.52 | -0.37 | -3.49 | **0.00** |
| BA & phaeo | 80 | 0.23 | 2.10 | **0.04** | 0.12 | 1.08 | 0.29 | 0.20 | -1.84 | 0.07 |
| BA & $NO_3$ | 80 | 0.14 | 1.28 | 0.21 | 0.20 | 1.84 | 0.07 | 0.23 | 2.08 | **0.04** |
| BA & $SiO_3$ | 80 | 0.24 | 2.17 | **0.03** | 0.07 | 0.63 | 0.53 | 0.14 | 1.21 | 0.23 |
| BA & $PO_4$ | 80 | 0.04 | 0.38 | 0.71 | 0.20 | 1.78 | 0.08 | 0.46 | 4.57 | **0.00** |
| chl *a* & phaeo | 80 | 0.47 | 4.74 | **0.00** | 0.35 | 3.32 | **0.00** | 0.21 | 1.93 | 0.06 |
| chl *a* & $NO_3$ | 80 | 0.15 | 1.35 | 0.18 | 0.38 | 3.59 | **0.00** | 0.26 | 2.41 | **0.02** |
| chl *a* & $SiO_3$ | 80 | 0.20 | 1.77 | 0.08 | 0.37 | 3.50 | **0.00** | 0.14 | 1.23 | 0.22 |
| chl *a* & $PO_4$ | 80 | 0.16 | 1.46 | 0.15 | 0.44 | 4.33 | **0.00** | 0.08 | 0.75 | 0.46 |
| phaeo & $NO_3$ | 80 | 0.21 | 1.92 | 0.06 | 0.31 | 2.91 | **0.00** | 0.11 | 1.00 | 0.32 |
| phaeo & $SiO_3$ | 80 | 0.34 | 3.24 | **0.00** | 0.29 | 2.68 | **0.01** | 0.30 | 2.74 | **0.01** |
| phaeo & $PO_4$ | 80 | 0.21 | 1.86 | 0.07 | 0.37 | 3.52 | **0.00** | 0.06 | 0.55 | 0.58 |

The significant ($p$<0.05) relationships are marked in **bold** were done (Table 8.3). At at all three stations, PCC showed significant positive correlation with mesozooplankton and negative with bacterial abundance. However, it correlated positively with phosphate only at CB5.

Microzooplankton was observed to have significant positive correlation with chl *a*, at all stations. At some stations, it correlated positively with phaeopigments and mesozooplankton numbers, and negatively with bacterial numbers. Mesozooplankton correlated positively ($p<0.05$) with nitrate, phosphate and phaeopigments and, negatively with bacterial abundance. At some stations, bacterial abundance had a strong positive correlation with phaeopigments and nutrients, and negative with chl *a*.

Correlation between chlorophyll *a*, phaeopigment concentrations and the three nutrients was significantly positive at CB5 in particular.

### 8.2.5. Empirical growth rates

The derived growth rates ranged in the CB from 0.21 to 0.26 (0.24±0.01 $d^{-1}$) during SUM and FIM, 0.21 to 0.27 (0.26 ±0.01 $d^{-1}$) during WM and 0.25 to 0.29 (0.26 ±0.02 $d^{-1}$) during SpIM (Fig. 8.11). Similarly, in the WB, they ranged respectively from 0.25 to 0.26 (0.26 ±0.01 $d^{-1}$), 0.23 to 0.26 (0.25 ±0.01 $d^{-1}$), 0.21 to 0.26 (0.23 ±0.02 $d^{-1}$) and 0.22 to 0.29 (0.26 ±0.03 $d^{-1}$) during the seasons listed above. They did not show significant spatial variation during any season in the CB or WB. However, they varied significantly ($p<0.05$) with seasons in the CB. The lowest calculated growth rates were from WB during WM.

In terms of carbon, the biomass in the mixed layer varied from a minimum of 128 in SUM to a maximum of 2360 mg C $m^{-2}$ during SpIM in the CB (Fig. 8.11). In the WB, it varied from a low of 64 to the highest value of 2736 mg C $m^{-2}$ in the corresponding seasons. It can be noticed that the biomass was stable throughout, showing no or least spatio-temporal variability.

The mesozooplankton production calculated from the copepod growth rates did not show significant spatio-temporal variation either (Fig. 8.11). For the CB, it averaged 127±84, 133±104, 94±64, and 225±266 mg C $m^{-2}$ $d^{-1}$ during SUM, FIM, WM and SpIM respectively. In the WB, it was 76±78, 70±45, 113±43 and 247±303 mg C $m^{-2}$ $d^{-1}$ respectively. On an annual scale, the average daily production of mesozooplankton in the

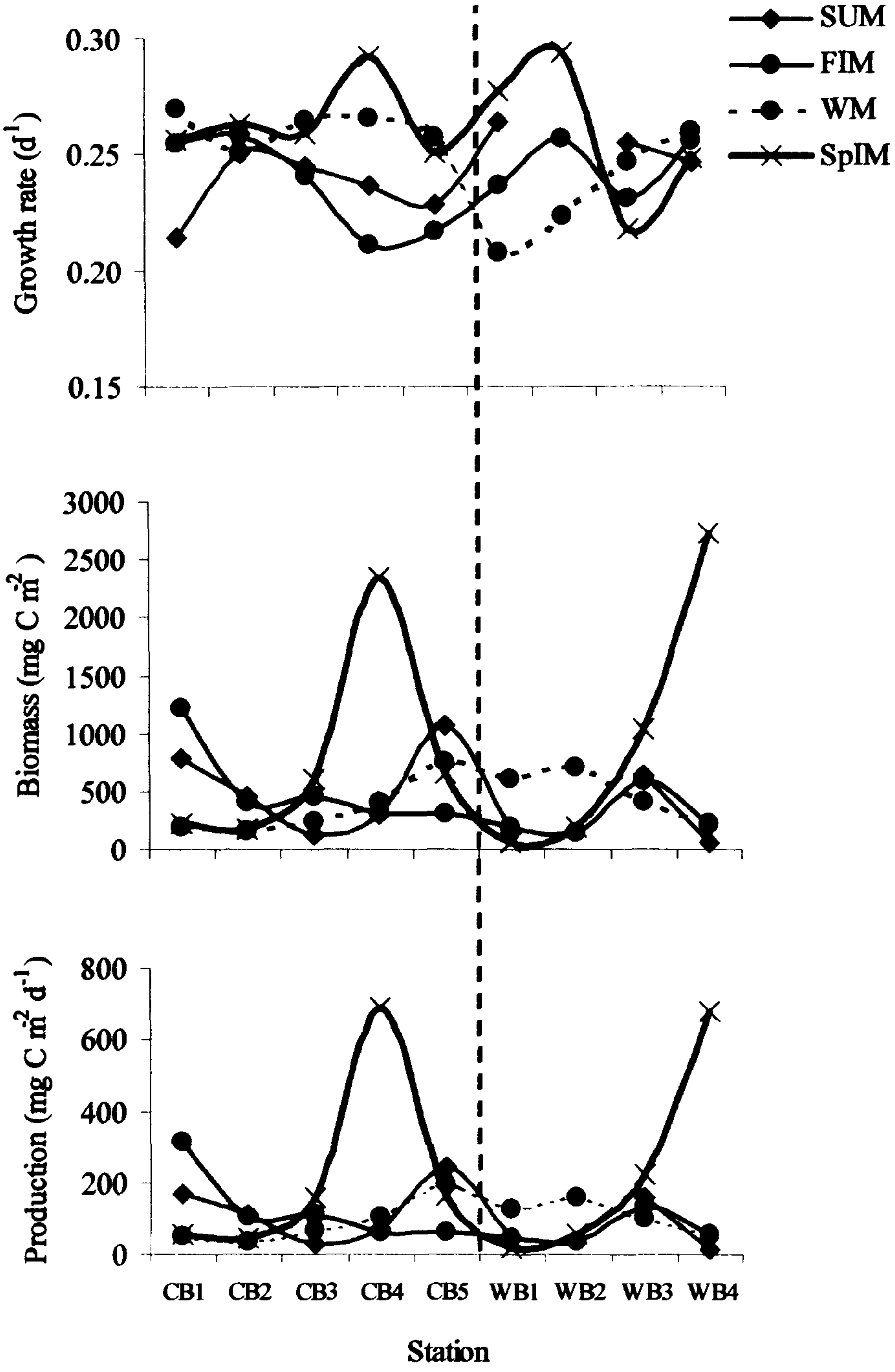


Figure. 8.11. Station-wise variation of mesozooplankton growth rates, biomass and production during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM) in the central and western Bay of Bengal

mixed layer for the CB and WB is 145±129 and 126±117 mg C $m^{-2}$ $d^{-1}$. Considering that the surface mesozooplankton production varies little with seasons, these values would correspond to an annual production rate of 53 g C $m^{-2}$ $yr^{-1}$ in the CB and 46 g C $m^{-2}$ $yr^{-1}$ in the WB. This production averaged 86 and 59% of primary production in both transects.

## 8.3. Discussion

### 8.3.1. Copepod composition

Zooplankton samples collected for experiments from the various stations, consisted mostly the warm water copepod species of *Corycaeus* and *Sapphirina* and coastally occurring herbivorous-omnivorous species such as *Undinula vulgaris, Temora stylifera, Acrocalanus* and *Oithona* spp. These species were also recorded from MLD during different seasons sampled.

### 8.3.2. Ingestion rate

The method of gut fluorescence adapted for this first study from BoB has certainly been useful to obtain a reasonable estimate of grazing rates and presents clear advantages over alternative incubation methods, minimizing potential sources of stress due to experimental handling and manipulation of animals discussed previously by Head and Harris (1996).

The gut fluorescence technique has been the most popular and widely used procedure to estimate *in situ* zooplankton grazing rates in the last decades. The principle behind measuring gut fluorescence is that the pigments from ingested algae can be quantitatively recovered from the animals by extracting them in an organic solvent. This gives the amount of gut contents, and knowing the turnover rate of gut contents or the gut evacuation rate, the rate of ingestion can be calculated. Uncertainty about the pigment destruction and its restriction to chl *a* bearing feed are the limitations of the method. This method assumes that the chlorophyll molecule does not degrade to undetectable products within the copepod gut (Penry and Frost 1991; Head and Harris 1996; McLeroy-Etheridge and McManus 1999). Dam and Peterson (1988) proposed an average destruction value of chl *a* in copepod guts as 33%. Penry and Frost (1991) suggested that pigment destruction is low (<20%) at low food concentrations, such as those found in the study area.

The chl *a* pigment concentrations ranging from 2 to 14 ng chl *a* $ind^{-1}$ in freshly caught animals in this study is similar to that obtained in the Black Sea by Besiktepe (2001). This experiment has shown that, when copepods are transferred to seawater devoid of available phytoplankton, there was drastic and/or very steady decline in their gut pigments especially of chl *a* indicating rapid metabolic activity in these animals. Intermittent increases in the pigment concentrations, especially of the phaeophytin, implied that the animals were re-ingesting some of the egested matter (Goes et al. 1999). This suggests that the animals in the surface layers of the Bay of Bengal not only feed on the phytoplankton that is available but also resort to coprophagy especially in times of low chl *a* concentrations. Such a behaviour has also been reported for the tropical planktonic herbivores (Frankenberg and Smith 1967). Since sinking fecal pellets rapidly acquire bacterial flora (Lampitt 1985), it would increase the calorific value of the pellets when ingested (Goes et al. 1999). Ingestion of such pellets would be an important means of survival for the copepods in the warm, moderately to highly oligotrophic surface layers of the Bay.

The gut evacuation rate constants obtained during this study (4.02-4.08 $h^{-1}$) are high. Dam and Peterson (1988) have shown that the rate increases exponentially with increasing temperature. They also demonstrated that the rate doubles with every 10°C increase in temperature. For instance, they found a gut evacuation rate constant of 3.6 $h^{-1}$ at a temperature of 20°C. The k-values obtained in this study account for gut clearance times ranging from 14.7 to 14.9 mins. Comparatively, much slower gut evacuation rates were found in many previous studies in the temperate oceans (Dagg and Grill 1980; Dagg and Wyman 1983; Kleppel et al. 1985; Simard et al.1985; Tsuda and Nemoto 1987). These rates are strongly linked to temperature (Kiorboe et al. 1982; Dagg and Wyman 1983) especially in coastal regions, where food availability may be adequate.

In oceanic regions however, where temperature does not fluctuate rapidly, Kiorboe et al. (1982) showed that it varied with food concentration. Shorter gut clearance time with increasing food concentration was shown in cladocerans (Murtaugh 1985), and in copepods (Baars and Oosterhuis 1984). It is predicted that gut passage time should be longer at lower food concentrations (Penry and Jumars 1986, 1987). The higher gut evacuation rate constants and shorter gut transit times obtained in this study appear to be related to higher metabolic rates that are a manifestation of warmer temperatures in the Bay. Further, in starvation experiments, coprophagy may bias the results and, under such conditions, k would be underestimated (Baars and Helling 1985). Gut evacuation rate constants, showing no particular trend either with temperature or body size, have also been shown to range from 1.044 to 0.966 $h^{-1}$ in spring and autumn in the Bohai Sea (Li et al. 2003).

One of the most remarkable characteristics of the open-ocean oligotrophic regions is the steady-state of phytoplankton biomass through out the year (Venrick 1990). Zooplankton grazing has been suggested as the main reasons for this steady state (Cullen et al. 1992). As already mentioned in Chapter 2, the grazing impact of copepods is reported to account for 8-14% of PP in the Atlantic (Huskin et al. 2001 a), 26% in the Gironde Estuary (Sautour et al. 2000) and 21.4–91.4% in the Pacific Ocean (Li et al. 2003). The average daily grazing by the medium size fraction was 16.7% of primary production in the Black Sea (Besiktepe 2001) and 40% in the Arabian Sea (Roman et al. 2000). The large range of grazing impact of 39->100% of daily PP in the Bay appears to imply that copepods in this warm pool evacuate their food rather rapidly. It is also probable that there are other sources of food (bacteria/microbes-laden aggregates of suspended particulate matter from allochthonous, riverine inputs and, coprophagy) to meet up the grazing rate exceeding the daily PP.

### 8.3.3. Respiration rates

The respiration rates obtained in this study are comparable closely to those obtained by Gauld (1951). However, these rates ranging from 0.15 to 0.38 μl $O_2$ $ind^{-1}$ $h^{-1}$ are far more than those reported by Thor et al. (2003) for the copepod, *Acartia tonsa* in temperate waters. They found that its respiratory oxygen consumption (RO) decreased from 0.057±0.01 μl $O_2$ $ind^{-1}$ $h^{-1}$ in well-fed animals to 0.023±0.003 μl $O_2$ $ind^{-1}$ $h^{-1}$ in animals starved for 12 h. The elevated respiration rates typical of animals inhabiting in the tropics impose a higher demand in terms of energy resources to be allocated to the maintenance of basal metabolism. Higher oxygen consumption rates of *Calanus sinicus* (0.21-0.84 μl

$O_2$ ind.$^{-1}$ h$^{-1}$) in the Yellow Sea were often associated with high temperature (Li et al. 2004).

Environmental temperature, body size and locomotion play an enormous role in deciding the respiration rates (Ikeda 1985; Mazzocchi and Paffenhofer 1999). Lampert (1984) suggested that at $Q_{10}$ coefficient, the metabolic rate doubles for every 10°C. The respiration rate is shown to increase from 0.84 to 7.4 nl $O_2$ individual$^{-1}$ h$^{-1}$ with increasing weight (2.0 to 32 μg) even when the temperatures are as low as 3°C. Andrew et al. (1989) suggested that respiration activity can greatly increase at night time due to increased swimming activity of the animals to reach the surface layers. Greater specific respiration rates of tropical zooplankton as Hernandez-Leon and Ikeda (2005) highlight, are due to the combined effects of warm water temperature and smaller body size of individuals, both of which are associated with increased rates.

Dam et al. (1995) found mesozooplankton respiration averaging 55 mg C m$^{-2}$ day$^{-1}$, equivalent to 20% of the daily PP at the JGOFS Bermuda Atlantic time-series station (BATS). As Valiela (1984) suggest, if it is assumed that respiration roughly accounts for 33% of total carbon ingestion, the estimates of copepod respiration in this study exceed those of ingestion rate. Though, the daily loss by zooplankton respiration (0.3-5.2 mg C m$^{-3}$ d$^{-1}$; 6-142% of PP) exceeded that of daily PP at some stations, it was ~3-41% of the zooplankton grazing on PP. Akin to the RO observed during this study, Li et al. (2004) also estimated the daily loss of copepod respiratory carbon to be exceeding the estimates of their carbon ingestion rates for reasons of high temperature.

Rates of respiration in the surface layer of the ocean are typically high, averaging ~1.2 g C m$^{-2}$ d$^{-1}$ (Duarte and Agusti 1998; Williams 1998). They represent a global respiration of about 143 Gt C yr$^{-1}$ in the open oceans. This estimate is about three to four times the accepted estimates of primary production (35–65 Gt C yr$^{-1}$; Field et al. 1998). Epipelagic respiration was found to be 144±21 mg C m$^{-2}$ d$^{-1}$ between 10°N and S (Hernandez-Leon and Ikeda 2005). They also found that specific respiration rates were the highest in equatorial waters and decreased rapidly, pole-ward. With seasonally varying abundance of zooplankton, the carbon loss due to their respiration also varied seasonally in the mixed layer depths in the Bay. It was the highest during SpIM (1.26 to 349.45 mg C m$^{-2}$ d$^{-1}$) and lowest during SUM (0.08 to 96.14 mg C m$^{-2}$ d$^{-1}$).

### 8.3.4. Evaluation of grazing through microcosm experiments

Microcosm experiments have a long tradition in ecological studies and are still a powerful research tool, which can increase our understanding of trophic interactions (Fraser and Keddy 1997). Size fractionation as done during this study led to a significant reduction of phytoplankton cell counts in the size fraction of 20 µm passed seawater. For instance, in the 20 µm fractionated sample, the cells were mostly negligible to <10% of those in the whole seawater. However, a comparison of chl *a* values showed upto 30-60 % reduction in the <20 µm fraction. This indicates that nano- or picophytoplankton contributed up to 60% of the total phytoplankton biomass. Bacteria were higher in the microcosms with added zooplankton. As Kirchman and Rich (1997) pointed out, bacteria responded quickly to the substrate additions that would have been as particulate and, dissolved organic matter from zooplankton.

Chlorophyll *a* concentration as well as phytoplankton numbers greatly increased with nutrient addition, especially in the whole seawater at CB5, where micro- and meso-zooplankton communities were in moderate quantities. Diatoms and dinoflagellates are the most abundant classes of marine phytoplankton (Lalli and Parsons 1993). Diatoms that are generally known to have rapid growth rates (Furnas 1990), even under nutrient-depleted conditions, were abundant in the surface waters of the BoB (Paul et al. 2007). Many chains of diatoms such as *Chaetoceros* and *Thalassiosira* that were found in the northern region of the Bay are known to prevent grazing without sacrificing nutrient uptake ability (Munk and Riley 1952).

When extra zooplankton were added to nutrient amended whole seawater, the microzooplankton numbers as well as chl *a* levels were low throughout the experiment, indicating that mesozooplankton grazed on a significant amount of phytoplankton as well as microzooplankton. High positive correlation between microzooplankton and mesozooplankton at CB5 also explains the dependance of mesozooplankton on microzooplankton for food.

The moderate increase in chl *a* in the nutrient amended 200 µm and 100 µm passed seawater is suggestive of microzooplankton being important grazers of the microphytoplankton (McManus and Ederington-Cantrell 1992; Ruiz et al. 1998). As

Calbet and Landry (2004) propose, these microherbivores in oceanic regions consume up to 70% of the phytoplankton produced. This view is also supported from the highly positive correlation between their numbers and those of phytoplankton as well as chl *a* concentration.

It is apparent that size is an important characteristic in determining both nutrient uptake and efficiency in phytoplankton. The chl *a* in the nutrient amended 20 μm fraction did not respond much to nutrient increment. The smaller sized phytoplankton offers increased nutrient uptake efficiency at very low ambient nutrient concentrations, through a greater surface area to volume ratio (Malone 1980). However, the fact that nutrients were present in concentrations well above detection limits ($NO_3$: 0-2.2, $SiO_3$: 2.0-4.8, $PO_4$: 0.3-1.6 μM) during this season, there was negligible effect of additional nutrients here. Even though ~30-60% of chl *a* and abundant bacteria were present in the 20 μm passed FSW, most mesozooplankton added died after the 2$^{nd}$ day of the experiment. One reason might be that of size constraint in feeding on these smaller-sized feed organisms.

Diatom growth in marine waters is likely to be limited by dissolved silica (DSi) when DSi/DIN (Dissolved inorganic nitrogen) ratios are less than 1 (Redfield et al. 1963 and Brzezinski 1985). The DSi concentrations >2 μM already found in the ambient seawater during this season was enough to support diatom growth without any more addition as Dortch and Whitledge (1992) proposed. Nitrogen can also stimulate chlorophyll production without necessarily influencing growth (Meeks 1974). However, the significantly positive relation of phytoplankton cell counts with chlorophyll *a* suggests that the contribution of microphytoplankton growth to the chlorophyll is substantial.

Phytoplankton responses to nutrients may depend in part on bacteria. Bacteria are effective competitors for phosphorus (P; Currie and Kalff 1984), and may sequester P or, delay its availability to phytoplankton. However, the high concentrations (>1 μM) of phosphate in these experiments appear to be sufficient for phytoplankton growth.

Microzooplankton numbers reportedly very low in the Bay (Gauns et al. 2005), were found to be few and also highly variable between samples analyzed on each day. They showed a negative relationship with bacteria. This is probably because bacteria make up a large proportion of their diet (Richard et al. 2005). Higher bacterial abundance during the lag phase of phytoplankton and its significant positive relationship with nutrients suggests that bacteria play active role in remineralization of organic matter

### 8.3.5. Empirical growth rates

During this study high growth rates ranging from 0.23 ±0.02 to 0.26±0.01 $d^{-1}$ were obtained in the Bay of Bengal. These are higher than those obtained in the Arabian Sea, at HOTS and at BATS, but lower than those from the equatorial Indian Ocean as detailed below.

The growth rate for the Arabian Sea zooplankton community comprising all size-fractions estimated with the Hirst and Sheader (1997) model ranged from 0.08 to 0.18 $d^{-1}$, with a mean of 0.12 $d^{-1}$ (Roman et al. 2000). Sazhina (1985) reported higher growth rates (0.33-0.45 $d^{-1}$) for smaller copepod species in the equatorial countercurrent of the Indian Ocean. The growth rates for the 200-500 μm mesozooplankton fraction averaged 0.17 $d^{-1}$ at HOTS and 0.15 $d^{-1}$ at BATS respectively (Roman et al. 2002 a). As Huntley and Lopez (1992) argue, temperature is a major factor determining the high growth rates in the Bay. For instance, *g*, as high as 1.2 $d^{-1}$was found in the near shore waters off Jamaica, at temperatures of 28°C (Hopcroft et al. 1998 a).

The zooplankton production estimates made using zooplankton biomass and calculated growth rates in this study (CB: 145±129 and WB: 126±117 mg C $m^{-2}$ $d^{-1}$) match the estimates in the Arabian Sea (156 mg C $m^{-2}$ $d^{-1}$; Roman et al. 2000). However, the annual production rates (53 g C $m^{-2}$ $yr^{-1}$ in the CB and 46 g C $m^{-2}$ $yr^{-1}$) are much higher than those observed at HOTS (9.5 g C $m^{-2}$ $yr^{-1}$) and BATS (4 g C $m^{-2}$ $yr^{-1}$; Roman et al 2002 a).

The average zooplankton: primary production ratios estimated for the Arabian Sea (0.12; Roman et al. 2000), HOTS (0.05; Roman et al., 2002) and BATS (0.03; Roman et al. 2002) are lower than those obtained during this study (0.55 and 0.33). Smith et al. (1998) demonstrated that over 200 mg C $m^{-2}$ $d^{-1}$ of zooplankton was consumed by myctophid fishes in the western Arabian Sea. Such zooplanktivore fishes in the surface waters of the Bay (Dalpadado and Gjosaeter 1988) may be responsible for removing a considerable amount of zooplankton.

Presuming that phytoplankton production and grazing are in balance or, in steady state, the mesozooplankton grazing should equal primary production. During this study, the copepod grazing:PP ratio (carbon ingested by zooplankton : primary production) was 39->100% in the Bay. Since the ingestion rates measured in this study are based on phytoplankton consumption alone, it means that non-fluorescent organic matter including protozoans (Kleppel 1992; Dam et al. 1995; Verity and Paffenhoffer 1996; Roman and Gauzens 1997) constitutes an important part of the copepod diet in the Bay of Bengal. In many oceanic waters, >90% of total chlorophyll is due to <2 μm phytoplankton cells and therefore, too small to be efficiently grazed by copepods. Thus, it may be concluded that a significant proportion of the primary production in the CB is rooted through the microzooplankton. More studies need to be done to understand the effect of episodic occurrences of chl *a* levels as in bloom conditions. Nevertheless, the direct estimates of copepod grazing rates obtained in this study are the first reports from the Bay of Bengal.

With the low numbers of microzooplankton, the mesozooplankton appear to sustain mostly on the low to moderate chl *a* production in this warm pool region. As Berggreen et al. (1988) propose, a wide size spectrum and diversity of copepods occur in the tropics where food resources are typically low. My estimates of mesozooplankton growth and production would then be overestimates if the actual *in situ* mesozooplankton growth rates were food-limited.

## 8.4. Conclusions

It can be summarized that higher growth rates of zooplankton in the Bay of Bengal are associated with the warmer temperature. The reason being: Bay is a warm pool region during most months of the year. Thus, seasonal variations in growth rates were not marked. In tropical ecosystems, thermal variation is of little consequence. Microcosm experiments have been useful to suggest that the mesozooplankton in the Bay are perpetually dependant on phytoplankton as their major diet. Similar to reports from the Arabian Sea their high biomass in the surface waters is invariable during different seasons. Further, their production rates also appear to be invariable in the surface layers of the Bay. In the Bay, the mesozooplankton represents a major component, contributing significantly to the carbon cycle. These first ever mesozooplankton respiration rates derived under non-feeding conditions during winter of 2005 from the Bay of Bengal might be underestimates. Estimation of such rates over a seasonal cycle and range of feeding conditions would be greatly helpful in understanding carbon cycle in the Bay of Bengal. While this study is providing newer understanding on mesozooplankton biology in terms of vital rates, more such studies are essential for deriving far reaching insights.

# *Chapter 9*

# Chapter 9

## *Summary*

Bay of Bengal, sprawling on the east of Indian peninsula is important for the Indian subcontinent. For, it is a region analogous to the Arabian Sea on the west that has shaped our cultures from time immemorial. The instantaneous thoughts that come to mind when we think of the Bay are: its fishery resources, navigable waters, the world's vast Sundarban mangroves (and all the remaining Royal Bengal Tigers therein), the Indian horse-shoe crab, the Bengali-relishing Hilsa and, occasional super cyclones. Above all, thoughts will also be of the rains that irrigate, vitalize, sustain and govern the life and, livelihoods of all flora and fauna on the terrain falling under the Bay's monsoonal swath. For science and research, the Bay is still a virgin domain to explore.

In its geographical setting, the Bay of Bengal (BoB) is quite akin to the Arabian Sea (AS). Both of these regions are landlocked in the north and, experience seasonally reversing monsoon winds as well as surface currents. However, they differ vastly in their hydrographic and hydro-chemical characteristics, and thereby in their biological processes. Bay receives much larger freshwater discharges ($1.6 \times 10^{12}$ $m^{-3}$ $yr^{-1}$) than the AS ($0.3 \times 10^{12}$ $m^{-3}$ $yr^{-1}$). Also the precipitation in the Bay is in excess of evaporation; making its surface waters at least 3-7 psu less saline. The low-salinity, and warmer surface temperatures (>28°C) make the surface layers of the Bay strongly stratified. With mild/sporadic coastal upwelling and absence of any open ocean upwelling, the entrainment of nutrients into the mixed layer is restricted. All these physico-chemical settings make it to remain moderately oligotrophic.

A comparative analysis of mesozooplankton collected from five pre-decided locations in the open-ocean (central Bay; CB) and four in western Bay (WB) has been made for this study. To obtain information on spatio-temporal variability in the mesozooplankton biomass, abundance, taxonomic groups and species of copepods, sampling was carried out during summer monsoon (SUM), fall intermonsoon (FIM), winter monsoon (WM) and spring intermonsoon (SpIM) from the CB and WB. To decipher the mesozooplankton in response to physico-chemical parameters, various hydrographic parameters collected during the cruises were correlated.

Stratified sampling was carried out using multiple plankton net in the upper 1000 m. Vertical hauls from discrete depths (1000-500m; 500-300m; 300m-base of thermocline (BT); BT to top of thermocline (TT) and, TT to surface) were made. Mesozooplankton biovolume and biomass was measured and samples sorted to various taxonomic groups. The copepod species taxonomic identification was carried out to understand the variation in species composition and diversity spatio-temporally. Rates of copepod ingestion and respiration were estimated experimentally onboard during the winter monsoon cruise. Onboard microcosm experiments were also set up at three different salinity regimes in the Bay for understanding the plankton dynamics in size fractionated and nutrient altered conditions. Parameters such as chlorophyll *a*, phytoplankton abundance and type, micro- and mesozooplankton abundance and bacterial total counts were measured on all days in the experimental duration of 7 days.

**Salient observations:**

- Except during WM, the SST usually persisting at ≥28°C, kept the Bay a warm pool. The lower surface salinity (~24-29 psu) at most northern stations, varying only slightly between the seasons signified stratification.
- Prominent oxygen minimum zone (OMZ) was observed during all seasons along both transects between depths of 150 and 600 m. The dissolved oxygen (DO) in this zone was quite low in the northern locations in CB during all the seasons. A thick band of suboxic water (5µM) was observed between 150 and 300 m throughout the WB during SUM. The intensity of OMZ was variable between seasons.
- Chlorophyll *a* (chl *a*) concentrations were <0.9 mg $m^{-3}$ throughout the study period and varied significantly with seasons in CB, not in WB. Prominent deep chl *a* maxima were observed in all seasons, signifying lack of nutrients in upper 30 m. There was no difference in chl *a* concentration between transects. Higher nutrients and chl *a* in mixed layer depth (MLD) at stations CB1, CB5 and WB3 were associated with cold-core eddies.
- Highest mesozooplankton biovolume was observed during SUM and SpIM in the CB. In the WB, the biovolume was lowest during SUM and the greatest during SpIM. In general, maximum biovolume occurred in the MLD, during SUM and SpIM in particular, and decreased with increasing depth. From the

negligible differences in biovolume and numerical abundance between the day and the night, diel vertical migration among mesozooplankton in the Bay was not evident.

- Among the notable observations, mesozooplankton standing stocks in terms of their carbon biomass are comparable to those in the high primary productivity regions of central and eastern Arabian Sea. Their carbon biomass in mixed layer depth (MLD) is stable throughout the year in both transects, as was also notified from the Arabian Sea.
- Total numbers of mesozooplankton groups recoded during the study are 33 in WB, 37 in CB. While the highest number of groups was observed during SpIM the least were during SUM. Their number decreased with increasing depth along both transects. Predominance of groups changed with seasons and showed variable vertical and latitudinal gradients.
- Major groups such as copepods, chaetognaths, ostracods, appendicularians, polychaetes, invertebrate eggs and foraminifera were common in both transects during different seasons.
- Large *Pyrosoma* swarms occurred along both transects during SUM. Scyphomedusae were abundant during SpIM. Both these warm water groups contributed significantly to the overall biovolume in these two seasons.
- The Bay is essentially copepod dominated. They contribute 67-88 % to the total mesozooplankton abundance. Copepod individuals belonging to five Orders (Calanoida, Cyclopoida, Harpacticoida, Mormonilloida and Poecilostomatoida) were identified from the CB and one additional Order (Siphonostomatoida) from the WB. Calanoida was the most dominant in both transects.
- A total of 38 copepod families were recorded (CB: 37; WB: 38) in the Bay. With eight of them *viz.* Clausocalanidae, Eucalanidae, Metridinidae, Paracalanidae, Oithonidae, Mormonillidae, Corycaeidae and Oncaeidae being preponderant. Vertical partitioning of copepod families was quite distinct.
- The numerical abundance of copepods was in general similar along both transects during all the seasons; implying that CB is similar in terms of copepod populations. Their diversity was mostly higher in the mixed layer depth (MLD) and, in some deeper strata. The numbers of copepod species

were less in WB (in 82 genera, 201species) compared to that in the CB (83, 251).

- Copepod species diversity showed spatio-temporal variability. Along both transects, the species rich ness generally decreased northwards. This study brings out the fact that both warmer temperature and oligotrophic regimes of the Bay are responsible for the high copepod diversity.
- Forty copepod species in WB, and, 69 in CB occurred during all the seasons. The dominant epipelagic species in various seasons in CB are: *Macrosetella gracilis, Paracalanus aculeatus, P. crassirostris, Corycaeus speciosus* and *Clausocalanus furcatus;* in WB are: *Paracalanus parvus, Acrocalanus gibber, A. longicornis, Oithona plumifera* and *Centropages furcatus.* The poecilostomatoid copepod *Oncaea venusta* is the key species in the Bay.
- Estimates of copepod ingestion, egestion, gut transit time and respiration rates were measured onboard using on live copepods collected from the surface waters. Due to warmer water temperatures,high gut evacuation rate constants (4.05 h$^{-1}$) and faster gut transit times (15 min) were found in the surface living copepods. Their ingestion rates (9.5-68.5ng chl eq. ind$^{-1}$ h$^{-1}$) corresponded to 1.3-87 mg C m$^{-3}$ d$^{-1}$ (*i.e.* 39->100% of daily primary production: PP).
- It appears that the carbon demands of zooplankton are not met by PP alone. Their egestion through fecal pellets in the range of 2.9-20.6 ng chl eq. ind$^{-1}$ h$^{-1}$ corresponds to 0.4-26.1 mg C m$^{-3}$ d$^{-1}$.
- From the microcosm experiments, it was found that the large phytoplankton especially in the northern stations of the Bay respond faster to increased nutrient pulses within a span of 2-3 days. Mesozooplankton were found to be mostly omnivorous, feeding on microzoo- as well as large phyto-plankton. Increased microzooplankton in abundance under reduced predation pressure of mesozooplankton appears to suggest that the microzooplankton grazing on microphytoplankton is considerable.
- Mesozooplankton respiration accounted for 79-205 ng C ind$^{-1}$ h$^{-1}$; their respiratory carbon loss from MLD varied seasonally and ranged from 0.008 to 350 mg C m$^{-2}$ d$^{-1}$ *i.e.* 15-63 % of daily PP in MLD. The highest rates were during SpIM and the lowest during SUM.

- High growth rates (0.21-0.29 $d^{-1}$) of mixed layer mesozooplankton in the Bay are linked to the warmer temperatures in the surface layers. Zooplankton annual production amounts to 53 g C $m^{-2}$ $yr^{-1}$ in CB and 46 g C $m^{-2}$ $yr^{-1}$ in WB, which is ~86% and 59% of PP.
- In the overall, seasonal changes in mesozooplankton biovolume, abundance and groups are clearly evident. Temporal shifts in the occurrence of major groups including copepod species are also imminent.
- From the total of 278 copepod species recorded in this study; 172 species were common for both transects. As many as, 20 species are the first records from the Indian Ocean. Since only 75 species were reported previously from the Bay; >200 copepod species recorded during this study are first reports from the Bay.

This study is the first detailed investigation on zooplankton that systematically covered the same locations during four seasons from the hither-to poorly studied Bay of Bengal. Further, the measurements of ingestion, egestion, respiration rates and derivation of growth rates have been carried for the first time from the Bay. This rater exhaustive study has brought to the fore many details of mesozooplankton ecology, diversity and their vital rates from this part of the world oceans.

### A few suggestions for future studies

1. The classical taxonomy must give way to advanced methods of biodiversity analyses. One of the ways is the use of molecular techniques to decipher the level(s) of genetic dissimilarity needed to differentiate species described through morphological analyses. It would be ideal to recognize the genetic trait(s) responsible for speciation of copepods that are most diverse and, inhabit a wide array of habitats.
2. As the grazing rates derived in this study are based on phytoplankton alone, development of a quantitative method estimating the feeding patterns simultaneously on phytoplankton, microzooplankton, mesozooplankton would be greatly helpful. Direct measurements of growth, fecundity and survival rates also need to be understood.

3. Searches for newer, bioactive, biotechnologically potent and industrially useful molecules are sure to benefit by including deepwater forms of zooplankton.
4. Techniques of culturing some truly marine copepods are also necessary.
5. There is a strong need for continuous monitoring of zooplankton abundance and preponderant copepod species from a select set of locations on weekly, monthly, seasonal, annual and decadal basis to understand their biological variability and the impact of climate change they experience. Their shifts in abundance or, group/species dominance would be indicative of possible changes in fisheries both in terms of composition and harvestable yields from the Bay of Bengal.

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## Publications

**Veronica Fernandes,** Spatial distribution of mesozooplankton in eddy- extant regions in central Bay of Bengal. ***Journal of Marine Research*** (accepted)

**Veronica Fernandes** and Ramaiah N, Spatial variability in mesozooplankton community during the 2001 summer monsoon in the central and western Bay of Bengal. ***Aquatic Ecology*** (revision requested)

Mangesh Gauns, Madhupratap M, Ramaiah N, Jyothibabu R, **Veronica Fernandes**, Jane T Paul, Prasannakumar S, Comparative accounts of biological productivity characteristics and estimates of carbon fluxes in the Arabian Sea and the Bay of Bengal. *Deep-Sea Research* II 52 (2005): 2003-2017