

**STUDIES ON MESOZOOPLANKTON WITH SPECIAL EMPHASIS  
ON CALANOID COPEPODS FROM THE COASTAL WATERS OF  
SOUTH ANDAMAN**



Thesis Submitted to the **Pondicherry University** in Partial Fulfilment of the  
Requirements for the Degree of **Doctor of Philosophy** in **Marine Biology**  
by

**I. ANANDAVELU, M.Sc.**

Under the guidance of

**Dr. G. Padmavati,**  
**Assistant Professor**



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**(A Central University), Brookshabad Campus, Port Blair-744 112,**  
**Andaman and Nicobar Islands, India**

**October 2016**

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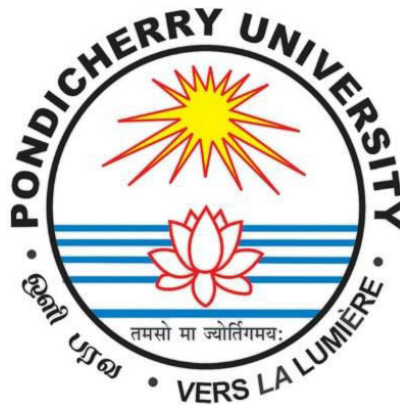
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**October 2016**



# PONDICHERRY UNIVERSITY

(A Central University established under the Pondicherry University Act 1985)

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### CERTIFICATE

I hereby certify that the thesis entitled, “**STUDIES ON MESOZOOPLANKTON WITH SPECIAL EMPHASIS ON CALANOID COPEPODS FROM THE COASTAL WATERS OF SOUTH ANDAMAN**” submitted by **Mr. I. Anandavelu**, for the award of the degree of **Doctor of Philosophy** to the Department of Ocean Studies and Marine Biology, **Pondicherry University**, is based on the work done by him under my guidance and supervision after fulfilling the basic requirements specified by the Pondicherry University. The thesis has been prepared in his original work and it has not previously formed the basis for the award to any candidate of any degree or diploma.

**Place: Port Blair**

**Date:**

**(Dr. G. Padmavati)**

**Research supervisor**

## **DECLARATION**

I, hereby declare that the thesis entitled “**STUDIES ON MESOZOOPLANKTON WITH SPECIAL EMPHASIS ON CALANOID COPEPODS FROM THE COASTAL WATERS OF SOUTH ANDAMAN**” has been carried out by me under the supervision of **Dr. G. Padmavati**, Assistant Professor for the award of **Doctor of Philosophy** in the Department of Ocean Studies and Marine Biology, Pondicherry University. This work has not been submitted earlier or published elsewhere for the award of any other degree or diploma.

**Place:** Port Blair

**Date:**

**(I. Anandavelu)**

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# CHAPTER 1

## GENERAL INTRODUCTION

### 1.1. Plankton

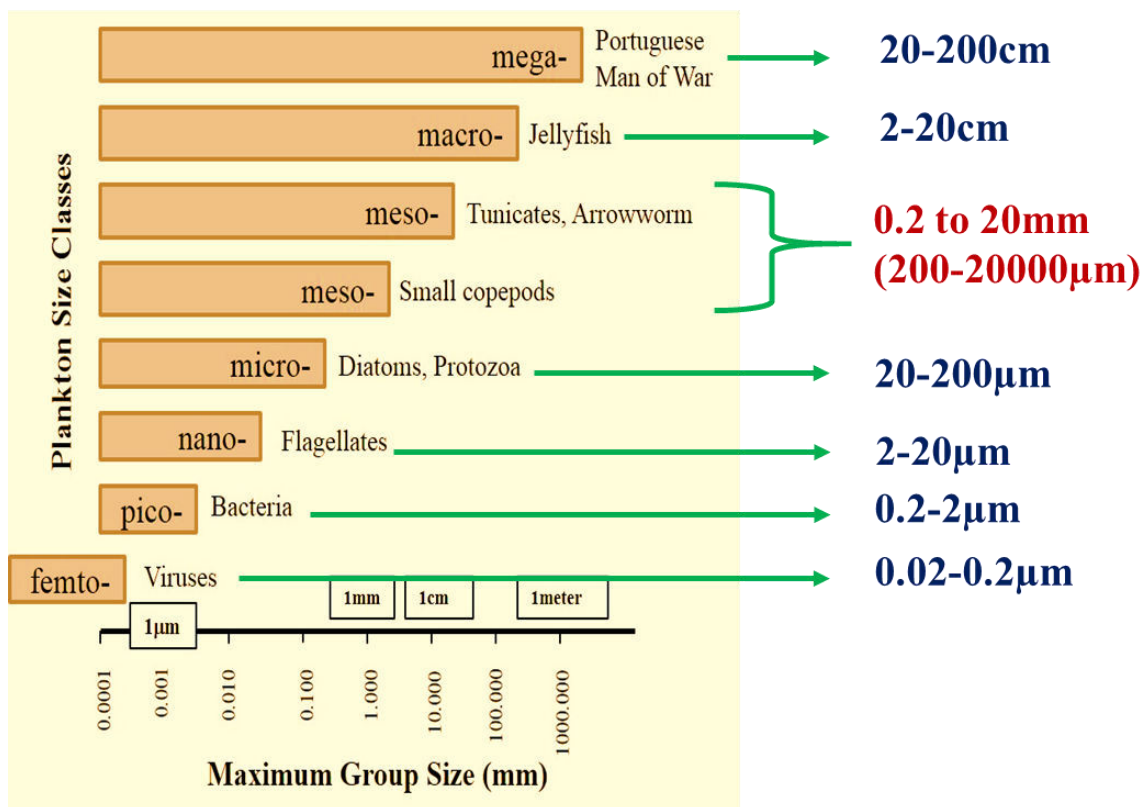
The term “*plankton*” derived from the Greek word “*planao*” meaning “*to wander*” refers to organisms that drift or swim weakly in the water, unable to move consistently against the current. Plankton are mainly classified based on the ability or not to perform photosynthesis as phytoplankton and zooplankton. Planktonic algae and other autotrophs are collectively called phytoplankton and are the most important primary producers in different marine ecosystems. The heterotrophic plankton are called the zooplankton. Generally, plankton size ranges from tiny flagellates (0.002mm) to giant jellyfish (2m diameter) (Dussart, 1965; Omori and Ikeda, 1984). Thus, the term plankton is a collective group that describes a basic ecological connection between the members of the plankton community. They can interact with one another by grazing, predation, parasitism, and competition among members of this dynamic group. The feature common to all plankton is their inability to move constantly horizontally through the ocean quickly enough to counter water currents. However, many can move vertically in the water column (Castro and Huber, 2003; Garrison, 2009).

### 1.2. Zooplankton

The zooplankton are heterotrophic plankton and secondary producers in marine pelagic waters and form an integral component of the ecosystem. The zooplankton community is characterized by varied groups of organisms of differing size and belongs to diverse phyla of the animal kingdom. There are 40 phyla in a new evolutionary classification of animal kingdom (Zhang, 2011), but only one, the Onychophora, lacks any marine representatives (Young *et al.*, 2002). Most of the phyla have indirect development as larva during their life cycle that may exist as planktonic life form. Those organisms with an entirely planktonic life history are referred to as *holoplankton* (e.g. copepods, ostracods, chaetognaths, siphonophores etc.) while vast number of temporary plankton or *meroplankton* includes larvae of benthic invertebrates, larvae of fishes and of other nektonic organisms. Other category named as *tychoplankton* that occur predominantly in shallow waters, especially in estuaries. This includes animals such as mysid and other crustaceans that spend part of the day or night as plankton. In

addition, some benthic species that swept into suspension from the bottom by strong currents or storms, such as some harpacticoid copepods, gammarid amphipods, cumaceans, isopods etc. are also included in the category of plankton (Raymont, 1983; Omori and Ikeda, 1992; Goswami, 2004).

In general, plankton size ranges over seven categories (Fig. 1.1), the femtoplankton and picoplankton constitute the smallest microscopic organisms having the size of 0.02-0.2 $\mu$ m and 0.2-2 $\mu$ m respectively. Heterotrophic nanoflagellates having 2-20 $\mu$ m size constitute nanoplankton. Other protozoans like ciliates belong to the next size class, the microzooplankton (20-200 $\mu$ m). Mesozooplankton size varies from 0.2 to 20mm. The next two size categories are macrozooplankton (2-20cm) and megazooplankton (20-200cm) which includes large jellyfishes, siphonophores, scyphozoans, pyrosoma etc. (Sieburth *et al.*, 1978).



**Fig. 1.1. Plankton size classes showed on a logarithmic scale from 0.1 $\mu$ m to 1m. Bars show the maximum size for each plankton group. Adopted from Sieburth *et al.* (1978).**

Mesozooplankton undertake a pivotal ecological role in marine ecosystems, including those in the food chain and trophic transfer, from the primary producers (phytoplankton) to higher trophic level (fishes and mammals). In the biological pump, carbon dioxide and inorganic nutrients are transformed by photosynthesis into particulate organic matter in the euphotic zone and various processes involve the transfer of energy to the deep ocean. Zooplankton play an important role in this transfer by feeding in surface waters and producing sinking fecal pellets (Fowler and Knauer, 1986; Small *et al.*, 1989; Altabet and Small, 1990; Banse, 1995). Diel migrating zooplankton and nekton are also important for vertical flux, by consuming organic particles at surface waters during night and metabolizing the ingested food down in the mixed layer at day time (Zhang and Dam, 1997; Longhurst and Harrison, 1988). The variability of zooplankton in any aquatic ecosystem is subjective to patchiness, diurnal vertical migration and seasons. The mesoplankton are represented with two bars (Fig. 1.1), reflecting a size range that extend two orders of magnitude, from 0.2 to 20mm and also reflecting the diverse assemblage of organisms within this size range. Mesozooplankton comprised of copepods, ostracods, decapod larvae, chaetognaths etc. and have been generally dominated by copepods, both in terms of density and diversity (Verity and Smetacek, 1996; Kiørboe, 1997).

### **1.3. Copepods**

Copepods (Crustacea: Arthropoda) are the most abundant metazoan animals in aquatic ecosystem and inhabit a variety of habitat such as marine and fresh water plankton, marine sediments, plant and animal associates, cryptic and subterranean habitat, deep-sea vents and anchialine caves (Huys and Boxshall, 1991; Kiørboe, 1998). The size range of marine planktonic form is usually between 0.5 to 5.0mm and are distributed in any pelagic habitats in the sea, from neritic to oceanic waters, and from the sea surface to the abyssal depths (Huys and Boxshall, 1991; Mauchline, 1998; Nishida and Nishikawa, 2011). The subclass Copepoda has been classified into two infraclasses, Progymnoplea and Neocopepoda. The former accommodating single order Platycopioida with a family Platycopiidae. The infraclass Neocopepoda has been further classified into two superorders namely Gymnoplea and Podoplea. The former with single order Calanoida accommodating 47 families while the superorder Podoplea divided into 7 orders namely Misophrioida (3 families), Cyclopoida (88 families), Gelyelloida (1 family), Mormonilloida (1 family), Harpacticoida (59 families),

Siphonostomatoida (43 families) and Monstrilloida (1 family) and the previously considered order Poecilostomatoida can no longer be considered as a group phylogenetically separated from Cyclopoida (Huys and Boxshall, 1991; Boxshall and Halsey, 2004; Mazzocchi and Capua, 2010; Zhang, 2011). The order Calanoida are the important marine planktonic copepods, feed exclusively on algal cells of phytoplankton and predators of animal prey. They are selective feeders and use a variety of methods to catch food particles. This broad similarity in feeding behavior is reflected in the basic uniformity of gross morphology in Calanoida compared to the other large orders. The morphology of typical calanoids are the cephalosome and five pedigerous somites encompasses a prosome, four to five segmented urosome in female and male respectively. Cephalosome consist of rostrum, antennule, antenna, labrum and paragnaths, mandible, maxillule, maxilla and maxilliped. The pedigerous somites comprising five pairs of swimming legs. The females with genital double somites, comprising fused genital and first abdominal somites and caudal ramus with seven setae.

The cyclopoids are generally abundant group and inhabit all kind of fresh water. They have considerable number of representatives in benthic, parasitic and free-living planktonic forms. The free-living cyclopoid, Oithonidae are planktonic and primarily marine in distribution. Cyclopoids possess digeniculate antennules bearing a sheath on segment XV in the male with the lack of a defined antennary exopod. The antennary exopod is represented by upto 3 setae but no exopodal segment remains. The cyclopoids are also characterized by the fusion of the first and second exopodal segments of the maxilla, and by a 4-segmented mandibular exopod derived by loss of the ancestral first exopodal segment.

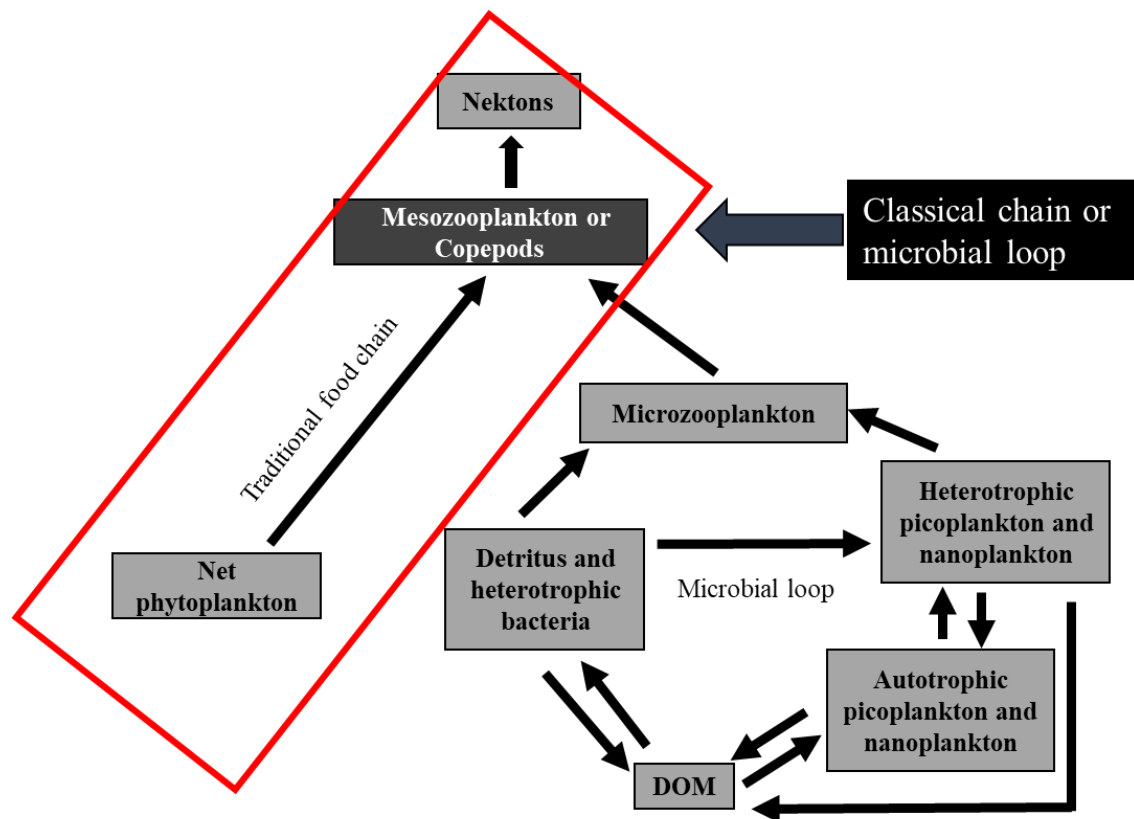
Harpacticoida are primarily benthic with few representative in planktonic form. They possess variety of structural features, such as elongate caudal rami or caudal setae or the internal oil droplets. They are distinctive with their short antennules and baseopod on the fifth leg in both sexes typically with 2 setae on it. The order Monstrilloida are endoparasitic in polychaetes and gastropod molluscs during their naupliar and postnaupliar stages and free-swimming, non-feeding adults. They are easily recognized by the absences of mouthparts, the form of anteriorly directed antennules in both the sexes, and the presence of ovigerous spines in the females (Huys and Boxshall, 1991).

### 1.3.1. Ecological importance of planktonic copepods

The abundance of copepods in marine plankton secures for them a vital role in the marine fishery. Copepods are considered as the major grazers of the phytoplankton and are important secondary producers in marine food webs (Wheeler, 1900; Shimode *et al.*, 2006; Gallienne and Robins, 2001) throughout the world ocean. They play a key role in the transfer of carbon from phytoplankton to higher trophic levels (Thompson *et al.*, 2000). In the productive ecosystem, supply of nutrients in the water determines the production, the primary production by the net phytoplankton could be utilized by the copepods and subsequently transferred to the top consumers (Riley, 1947; Smith, 1982; Schnack and Elbrächter, 1981; Turner, 1984; 1985). However, there is an alternative concept of microbial loop, where, the microbial community controls the biological production (Madhupratap and Parulekar, 1993; Madhupratap *et al.*, 2003). Copepod diets are diverse, composed of a variety of different kinds of food (Azam *et al.*, 1983; Kleppel, 1993) and reflecting the intricacy of the pelagic food web (Kleppel, 1993). In the oligotrophic tropical seas with low concentrations of phytoplankton prey, the copepods could feed on the alternate food available in that area (Sherr and Sherr, 1988; Cushing, 1989). The microbial food web consists of organisms, which transfers organic carbon from smaller autotrophs and heterotrophic bacteria to higher trophic levels. These smaller organisms involved in the microbial food web include both autotrophic and heterotrophic forms of picoplankton and nanoplankton. Most of this picoplankton and nanoplankton carbon biomass is channeled up in the food chain through the microzooplankton which are further consumed by mesozooplankton and in turn constitute the basic food for higher animals (Fig. 1.2). Copepods are so abundant that even their faecal pellets represent an ecologically important energy source for detritus feeders. The flux of faecal pellets to the ocean floor may have a significant impact on nutrient cycling and sedimentation rate (Huys and Boxshall, 1991).

The occurrence and distribution of copepods and other mesozooplankton influence pelagic fishery potential. Most fishes breed in areas where the planktonic biomass is high, so that their young ones could get sufficient food for survival and growth. Most of the commercially important pelagic fish and crustacean species depend on copepods at least during their larval development and some species even feed exclusively on copepods during their entire life cycle (Davis, 1955; Dewan *et al.*, 1977; Støttrup *et al.*, 1999) as they provide the necessary amount of protein for their rapid growth especially that of the gonad. Zooplankton determines the quantum of fish stock

and the decline in fishery resources is attributed to the diminished copepod population (Støttrup, 2000). Hence, zooplankton communities, based on their quality and species diversity, are used for assessing the productivity of fishery resource, fertility and health status of the ecosystem. Estimation of biochemical constituents of zooplankton is important in understanding their physiological functions, metabolism and nutritive value which are relevant to the marine ecosystem, in energy transfer and secondary production (Madhupratap *et al.*, 1979; Nageswara Rao and Krupanidhi, 2001; Nageswara Rao and Ratnakumari, 2002). They are considered to be nutritionally superior live feeds for commercially important cultivable species, as they are valuable source of protein, lipid, carbohydrate and enzymes etc. all of which enhance the metamorphosis of larvae (Nanton and Castell, 1999; Rajkumar *et al.*, 2008). Zooplanktons are considered as a potential indicator of different water mass and environmental change caused by pollution and climate change due to global warming (Russell, 1935; 1939). Hence, it is quite essential to estimate the mesozooplankton, particularly the copepod population, both quantitatively (density) and qualitatively (taxon composition and diversity) in marine pelagic ecosystem.



**Fig. 1.2. Pelagic food web.**

The ecology of zooplankton communities and copepod population has been studied in a wide range of habitats in temperate and subtropical seas which are characterized by strong seasonality in heat influx and water stratification, while fewer studies have been carried out in tropical waters, where the strong, permanent temperature stratification is the characteristic feature of the hydrographical conditions. Another characteristic of some tropical seas is the monsoon seasonality, which influence water circulation, and can lead to flow reversal and upward transport of nutrients (Longhurst and Pauly, 1987). Although, minor seasonal fluctuations in light and temperature observed in the tropics, are usually related to the variable pattern of rainfall and increased storm incidence during monsoon periods and associated upwelling events (Smith, 1982; Schalk, 1987; Baars *et al.*, 1990; Chisholm and Roff, 1990). The tropical ocean has been characterized by oligotrophic waters with low primary productivity and secondary productivity, however, zooplanktonic communities in the tropical region have their primary characteristic as high species richness, which in turn results in a large network of trophic interactions (Piontkovski and Landry, 2003).

The Indo-Pacific region is a region of high zooplankton biodiversity, covering several high biological productivity areas and several important fishing grounds. Many developing countries along these region are facing the common issues: marine pollution, coastal destruction, overfishing, and marine aquaculture etc. (Ramanibai, 2015). These activities affect the coastal ecosystem in addition to climate change and other issues, in turn, the marine ecosystems in this area are being influenced both by climate change and human activities. As zooplankton play vital roles in the aquatic ecosystem, it can be used as an indicator of ecosystem change (Kathiresan and Bingham, 2001; Damotharan *et al.*, 2010). Although the coastal environment is only a small part of the epipelagic zone, but it is important to humans because it lies relatively close to shore and supports most of the world's marine fisheries production (Davis, 1955; Dewan *et al.*, 1977; Støttrup *et al.*, 1999). Coastal zone has high biological potential as it serves as feeding, nursery and spawning grounds with rich biodiversity and as an intermediary biotope between marine and freshwater environments. Eventually, the coastal water receives huge waste from human activities and contains the most used and abused marine biodiversity resources (Ramanibai, 2015).

Andaman Sea is a tropical sea, situated in the eastern part of the northeastern Indian Ocean, enclosed between Myanmar, Thailand and Malaysia in the north and east, Andaman and Nicobar Islands in the west and Sumatra in the south and occupies



$6.02 \times 10^3 \text{ Km}^2$  area with a volume of  $6.6 \times 10^3 \text{ Km}^3$  with an average depth of 1096 m (Lyman, 1966; Munk *et al.*, 2004; Pai *et al.*, 2010). The Andaman Sea is a part of the north eastern Indian Ocean, is almost a separate sea partitioned from the Bay of Bengal (BoB) by the Andaman and Nicobar Islands and Mentawai Islands west of Sumatra. Both the Andaman Sea and Bay of Bengal are connected to each other intensely in the Preparis Channel, Ten Degree Channel and the Great Channel and the exchange of water between the BoB and the Andaman Sea occur through these Channels. The Ten Degree Channel is about 1800 m deep while Preparis and great Degree Channel have 200m and 800m depth respectively (Varkey *et al.*, 1996).

The Andaman Sea is a median region which hosts and connects the waters of great oceans. There is a free interchange of water from the Pacific Ocean through South China Sea and the Straits of Malacca and the Andaman Sea into the Bay of Bengal and through the various openings in the Sumatra-Java-Borneo chain of islands in the Malay Archipelago into the southern part of Indian Ocean, especially during the period of north-east monsoon (Sewell, 1929b). In addition to that, the northeast Indian Ocean is very interesting for its low salinity surface water caused by large river runoff from three river systems, viz., Krishna-Godavari, Mahanadi-Ganges-Brahmaputra and Irrawady-Salween. This bay also plays a major role in determining the climatic conditions of India and other South East Asian countries. Thus, its ecology is of paramount interest. Apart from the above, the bay is also known for its oligotrophic nature as well as low productivity, thus resulting in high diversity of flora and fauna (Pai, 2007; 2010). The observations in the north Indian Ocean initiated with the historical expeditions, however, the documentation by Sewell (1925; 1928; 1929a, b; 1932; 1933) in various reports and memoirs had provided substantial knowledge from this region.

#### **1.4. Review of literature**

International Indian Ocean Expedition (IIOE, 1960-65) was the first intensive exertion that studied on zooplankton distribution and zoogeographic patterns from this region (Zeitzschel, 1973; Rao, 1979). In the recent times since IIOE, a considerable amount of scientific work has been carried out in Indian waters of the Bay of Bengal (Qazim, 1977; National Institute of Oceanography, 1977; Nair *et al.*, 1977; Peter and Nair, 1978; Bhattathiri *et al.*, 1980; Bhattathiri and Devassy, 1981; Devassy, 1983; Unger *et al.*, 2003; Madhupratap, 1983; Madhupratap *et al.*, 2003), Arabian Sea (Achuthankutty *et al.*, 1980; Nair *et al.*, 1981; Padmavati *et al.*, 1998; Achuthankutty *et*

*al.*, 2000; Rakhesh *et al.*, 2006) and Andaman Sea. The physical and hydrographical features of the Andaman Sea were reported by Sewell (1928, 1929a), Wyrki (1971, 1973), Maslennikov (1973), Osborne and Burch (1980), Rao *et al.* (1981) Murthy *et al.* (1981) Ramaraju *et al.* (1981) Bhattathiri *et al.* (1984) Varkey *et al.* (1996), Muduli *et al.* (2011) Jha *et al.* (2012) and Beegum *et al.* (2012). In contrast, little is known of the zooplankton inhabiting the coastal waters of Andaman Sea (Goswami and Rao, 1981; Madhupratap *et al.*, 1981a; b; Nair *et al.*, 1981; Marichamy, 1983; Antony *et al.*, 1997; Pai, 2007; Nair *et al.*, 2008; Santhanakumar *et al.*, 2010; Pillai *et al.*, 2011; 2014; Jha *et al.*, 2012), with most of the studies focused on taxonomy (Sewell, 1925; 1929b; 1932) and communities in the oceanic region (Goswami and Rao, 1981; Madhupratap *et al.*, 1981a; b; Nair *et al.*, 1981, Madhupratap and Haridas, 1986; Antony *et al.*, 1997; Nair *et al.*, 2002; Jyothibabu *et al.*, 2003; Madhu *et al.*, 2003; Pai, 2007; Padmavati *et al.*, 2008; Nair *et al.*, 2008; Nair and Gireesh, 2010; Karuppasamy *et al.*, 2011).

The coastal regions in South Andaman are characterized by the presence of highly diverse habitats such as coral reefs, mangrove forests, tidal creeks, seagrass patches, and sandy and rocky beaches. The coastal or neritic water are more highly dynamic habitats than the oceanic realm because they are subjected to fluctuations of salinity and nutrients due to the atmospheric precipitation. Nutrient enrichment caused by land run- off during the rainy period leads to proliferation of phytoplankton and swarming of filter feeders in the coastal waters (Goswami, 1985) that eventually benefits many larval forms of economically important groups in the coastal zooplankton community (Houde and Lovdal, 1982; Balbontin *et al.*, 1986; Anderson, 1994). Thus, in the context of biodiversity conservation, it is the coastal region that should have the top priority (Costello, 1998).

Andaman Sea is an oligotrophic sea with low production of planktonic biomass (Qazim and Anzari, 1981), a considerable production of zooplankton was observed in the coastal waters of Andaman Islands (Marichamy, 1983). Albeit, the coastal areas are more accessible, research has been scarcely focused on the border regions and particularly around the oceanic islands (Conway, 2005). However, most studies on zooplankton were carried out by the collection of offshore regions from various scientific cruises (Rao and Griffiths, 1998). The oceanic species of zooplankton and their distribution have been well described compared to that of the coastal species from the Indian Ocean (Conway, 2005). In addition, the continuous monitoring of zooplankton biomass in the neritic regime of the Andaman and Nicobar Islands have

been the neglected subject of Indian Ocean plankton research. Despite a growing interest on coastal research, there are few studies in zooplankton composition of Andaman and Nicobar Islands marine system (Goswami and Rao, 1981; Madhupratap *et al.*, 1981a; b; Nair *et al.*, 1981; Marichamy, 1983; Antony *et al.*, 1997; Pai, 2007; Nair *et al.*, 2008; Santhanakumar *et al.*, 2010; Pillai *et al.*, 2011; 2014; Jha *et al.*, 2012). Since, the information on the seasonal distribution of zooplankton from the coastal regions of these islands is scarce (Marichamy, 1983), studies were carried out to gain information on the dynamics of copepod community in the marine food web.

### **1.5. Objectives**

- To understand the variation in hydrography (physical and chemical) and their effect on zooplankton from the coastal waters of South Andaman.
- To study the composition of mesozooplankton with an emphasis on the abundance and species composition of copepods from the coastal waters of South Andaman.
- To study the spatial and temporal variation in zooplankton biomass, and species composition.
- To describe the systematics, taxonomy and morphology of the new and unreported calanoid copepod species from this area.
- To study the diversity and species associations of copepods in this area.

**MATERIALS AND METHODOLOGY****2.1. Study Area****2.1.1. Andaman and Nicobar Islands**

The Andaman and Nicobar (AN) Islands are located southeast of peninsular India and endowed with invaluable diversity of marine fauna. Geographically, the islands are the summits of a submarine range extending from the Arakan Yomas of Burma in the north to the Sumatra in the south (Tikadar and Das, 1985). The Andaman archipelago consist of a sequence of about 572 islands, islets, reefs and isolated rocks extending along a north-south direction covering an area of 8,249 km<sup>2</sup> with a coastline of 1962 km between 6°45' N to 14°N latitude and 92°E to 94°E longitude in the southeastern part of the Bay of Bengal (Fig. 2.1). AN Islands have been accounting for 0.6 million km<sup>2</sup> EEZ and 26.1% of the total Indian coastlines is an important biodiversity hotspot. These islands constitute with most number of protected areas that are boundaries of marine environment (Venkatraman and Wafar, 2005). Because of the large extent of its coast with a wide variety of habitats, AN Islands harbor immense diversity of flora and fauna.

The tropical ecosystem of the AN Islands is unique having diverse species with wide range of genetic diversity. High rainfall, extremely humid climate, undulating topography and backwater creeks are very conducive for faunal and floral diversity. Evergreen and littoral forests, mangroves and coral reefs are important components of the existing ecosystems prevailing in the islands. The Andaman Islands are well-known for their fringing reefs, the ecosystem is incredibly productive and supports diverse fauna. The waters around the Andaman Islands are one of the prominent biodiversity hotspots in the Indian Ocean (Nair et al., 2008). Lakshadweep Islands are well recognized for its biodiversity and endemism in marine fauna (Madhupratap et al., 1991; Casanova and Nair, 1999; 2002) however, the coastal water of AN Islands have a continuous interchange of water from the Pacific Ocean through Malacca Straits in to the Andaman Sea supporting a rich immigrant faunal assemblage. Moreover, the AN Islands formed as a barrier and/or filter that retain a rich immigrant faunal assemblage. In addition, the sheltered coral reef ecosystem of the Andaman Sea promotes speciation and endemism, as evidenced by the occurrence of the two new species of chaetognaths that are not found outside this area of the Bay of Bengal (Nair et al., 2008).

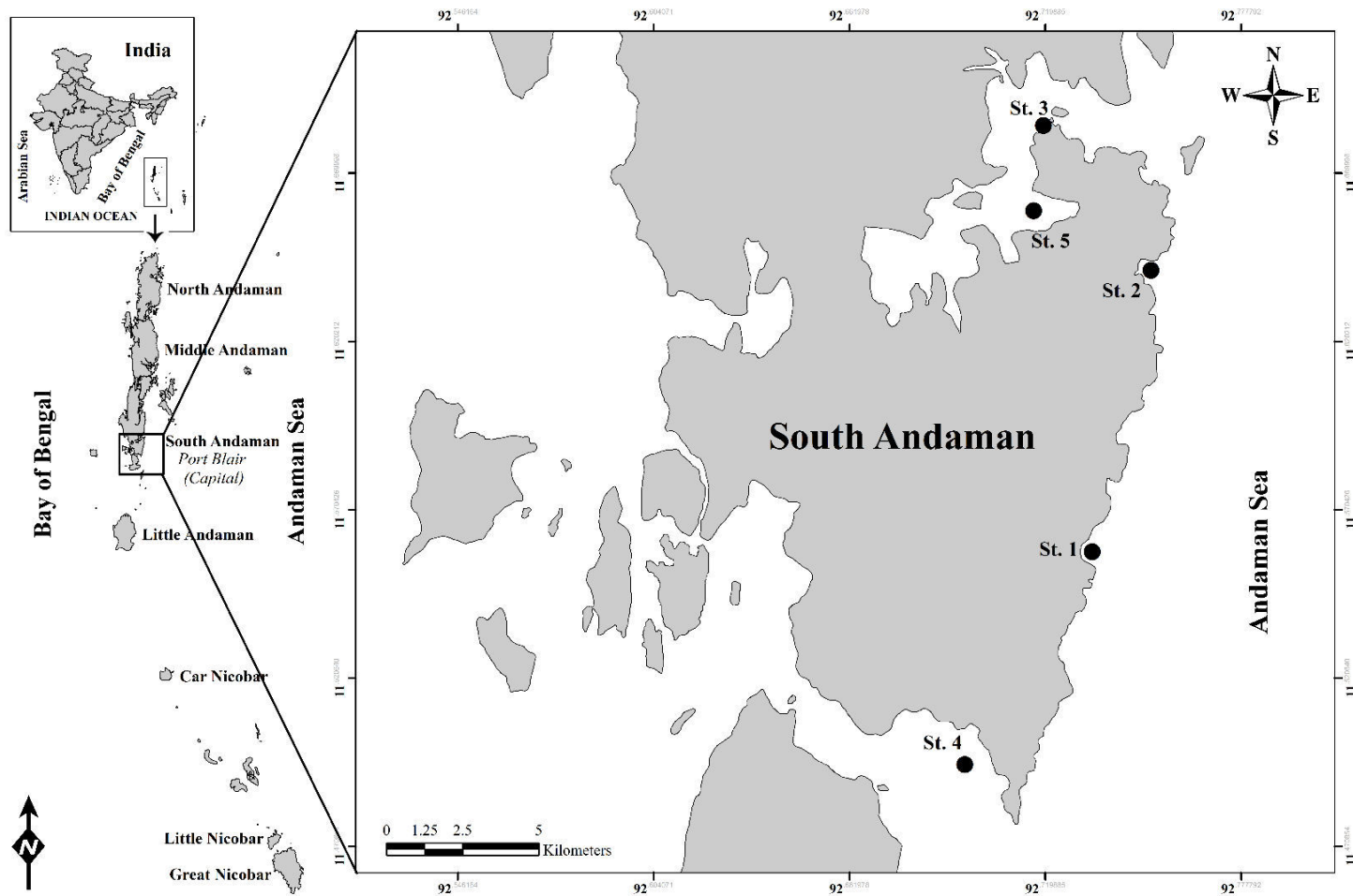


Fig. 2.1. Map showing the study area. St.1: Burmanallah; St.2: Carbyn's Cove; St.3: Chattam; St.4: Chidiyatapu; St.5: Junglighat.

Samplings of plankton were conducted on monthly basis from the coastal waters of South Andaman Island at five locations namely Burmanallah, Carbyn's Cove, Chattam, Junglight and Chidiyatapu (Fig. 2.1).

**Burmanallah** (11°33'20"N, 92°42'52"E) is a highly wave affected region found in the east coast of South Andaman about 17 km from Port Blair. The coastal region of Burmanallah is an open ocean extension that forms a long stretch of exposure during the low tide. The entire region is a bay shaped, with two freshwater influxes that are bordered by mangrove. In addition to that, it supports a wide diversity of coastal habitats such as coral reefs, mangroves, sea grasses and rocky shores. The anthropogenic influence is quite low compared to the other study areas of South Andaman, though there is a small settlement in the near shore area.

**Carbyn's Cove** (11°38'27"N, 92°44'59"E) is about 7 km from Port Blair, capital city of Andaman and Nicobar Islands. Carbyn's Cove is one of the important tourist places in the South Andaman. However, the presence of strong water current, influence of tidal mangrove creek and coral reefs located in close proximity makes this area unique. Carbyn's creek is a tidal estuary that receives input of fresh water mainly by atmospheric precipitation and serves as a major drainage channel by receiving domestic discharge from the local settlements making the creek relatively polluted. The creek peripheries are sheltered by different vegetation and dominated by mangrove species, namely *Rhizophora apiculata*, *R. mucronata*, *R. stylosa*, *Avicennia marina*, *A. officianalis* and *Ceriops decandra* and associated flora.

**Chattam** (11°41'11"N, 92°43'20"E) is the major port area that experiences heavy traffic movement of ships and fishing boats. The coastal water has been generally polluted with oil slicks, shipping waste, garbage and sewage waste.

**Chidiyatapu** is located in the southernmost tip of South Andaman (11°30'11"N, 92°42'01"E) 25 km away from Port Blair. This is a rocky coastal area with medium to coarse sand with detritus muddy area, with steep continental shelf and coastal environment. The coastal zone is endowed with extensive rocky outcrops and sandy beaches, corals, seaweeds, seagrass and mangroves.

**Junglight** (11°39'27"N, 92°43'22"E) bay is situated 6.0 km away from Port Blair and near to the Haddo harbor. It is one of the major fish-landing center in Port Blair. The area is enclosed by hills on all three sides and there is a marked freshwater influx in the intertidal region. This bay is highly influenced by anthropogenic activities,

## Materials and Methodology

oil spill from motorized boats, fishing trawlers, fish waste from fish landing centers and it receives a large amount of sewage discharge from the adjacent areas.

### 2.2. Sample collections

#### 2.2.1. Zooplankton and seawater collection

Samples were collected at 5 coastal stations such as Burmanallah, Carbyn's Cove, Chatham, Chidiyatappu and Junglighat from the South Andaman Island. Sub-surface samples were collected on monthly basis from January 2012 to April 2014 on board by using a fishing boat before dawn (04:00-04:30 hrs) from the coastal waters. A standard zooplankton net with 200 $\mu$ m mesh size and 0.2m<sup>2</sup> mouth area equipped with a flow meter (FLOWMETER MF315, OceanTest Equipment. Inc.) at the center of the mouth opening were the main gears used to collect mesozooplankton samples. The net was towed horizontally behind a boat at the speed of  $\leq 1$  knot for 15 to 20 minutes. The exact timing of all the tows and the flow meter readings were noted to measure the volume of water filtered for the collections.

In the laboratory, the filtered samples were made up to 1000 ml and the samples were homogenized for attaining sub-samples. The primary counting for number of zooplankton groups and copepod species were made by taking 10 ml of sub-samples by using a Stempel pipette from well mixed beaker containing 1/4<sup>th</sup> sub-sample (Omori and Ikeda, 1984) and were preserved in 4% formaldehyde/seawater solution and additional subsamples were inspected to search the rare species. Identification of the copepod community was made to species level. All species were identified based on keys and standard literatures of Cleve (1901), Scott (1909), Sewell (1929b; 1932; 1933), Kasturirangan (1963), Tanaka (1965), Bradford-Grieve *et al.* (1983), Bradford-Grieve (1994; 1999), Mulyadi (2002; 2004), Conway *et al.* (2003) and Razouls *et al.* (2005-2016). Other zooplankton taxa were identified to best possible taxa levels (Omori and Ikeda, 1984; Conway *et al.*, 2003) by using stereozoom-microscope and compound microscope. The remaining sample (3/4<sup>th</sup>) were utilized for biomass estimation (Omori and Ikeda, 1984).

Zooplankton have such significance in the productivity of the sea and the food chains therein, it is essential to know how to relate the number of organisms found to the volume of water filtered (Fraser, 1968). The zooplankton were expressed as numbers per cubic meter (Nos. m<sup>-3</sup>) by using the formula:

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$$\text{Individuals per cubic metre (Ind. m}^{-3}\text{)} = \frac{\text{Numbers of individuals in 10ml sample} \times 100}{\text{Volume of water filtered (V)}}$$

$$V = \alpha N_R A$$

$$A = \pi r^2$$

$$\alpha = d / N_{R(\text{average})}$$

V = Volume of water filtered

$\alpha$  = Flow meter calibration factor

$N_R$  = Number of revolutions (read from the flow meter dial)

A = Mouth area of the net

r = Radius of mouth of the net

d = Sample depth

$N_{R(\text{average})}$  = Number of revolutions averaged for 20 calibration tows

### 2.2.2. Hydrography

Environmental parameters like water temperature, salinity and pH were measured simultaneously with the plankton collection by using hand-held instruments such as mercury thermometer, refractometer (ATAGO, Japan) and pH meter (pH Testr 10) respectively at all stations. Seawater samples were collected in 300 ml BOD bottles for the estimation of Dissolved Oxygen (DO) by following Winkler's method (Strickland and Parsons, 1972).

### 2.3. Nutrients

All sampling bottles were cleaned with 10% hydrochloric acid prior to use, and then rinsed several times with distilled water as part of every sampling activity. Seawater samples (sub-surface) were collected in clean plastic bottles for the period of one year from May 2013 to April 2014. In laboratory, the water samples were filtered and analyzed for dissolved inorganic nitrate ( $\text{NO}_3\text{-N}$ ), nitrite ( $\text{NO}_2\text{-N}$ ), phosphate ( $\text{PO}_4\text{-P}$ ) and reactive silicate ( $\text{SiO}_4\text{-Si}$ ) adopting the standard procedures described by Strickland and Parsons (1972) and are expressed in  $\mu\text{M}^{-\text{L}}$ .

The nitrate in water sample was reduced to nitrite by using a column containing cadmium filings coated with copper. The nitrite thus produced was determined by diazotizing with sulphanilamide and coupling with N-(1-naphthyl)-ethylenediamine to form a highly coloured azo dye and the extinction of which was measured



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spectrophotometrically at 543 nm. The nitrite in the water sample was directly allowed to react with sulphanilamide in an acid solution, the resulting diazo compound reacted with N-(1-naphthyl)-ethylenediamine, and the resulted azo dye was measured spectrophotometrically at 543nm.

To estimate the phosphate, the water sample was reacted with a composite reagent containing molybdic acid, ascorbic acid, and potassium antimonyl-tartrate. The resulting complex was reduced *in-situ* to give a blue solution and the extinction of which was measured at 885 nm. The silicate was measured by the reaction of seawater with molybdate under conditions that result in the formation of the silicomolybdate, phosphomolybdate, and arsenomolybdate complexes. A reducing solution, containing metol and oxalic acid, was then added which reduces the silicomolybdate complex to give a blue reduction compound and the extinction of which was measured at 810 nm.

### 2.4. Chlorophyll-*a*

Chlorophyll-*a* was estimated by spectrophotometric method (Strickland and Parson, 1972). The pigment was extracted in 90% acetone and filtrates kept in refrigerator for 24 hrs under dark condition. The extract was centrifuged and supernatant was used to estimate the chlorophyll-*a* by using spectrophotometer. The optical density was measured at the wavelength of 630 nm, 645 nm and 665 nm.

$$\text{Chlorophyll-}a \text{ (C)} = 11.6 E_{665} - 1.31 E_{645} - 0.14 E_{630}$$

$$\text{Chlorophyll-}a \text{ in mg/m}^3 = \frac{C \times v}{V \times 1}$$

Where, E is the absorbance at different wavelength

C is the concentration of chlorophyll (in  $\mu\text{g/mL}$  when 1cm cuvette is used)

v is the volume of acetone in mL (12mL)

V is the volume of seawater in liters (1L)

### 2.5. Zooplankton Biomass

#### 2.5.1. Displacement volume method

The samples were filtered with plankton net with mesh size 50 $\mu\text{m}$ , which is smaller than the mesh size of the net used for towing. The samples were washed with distilled water and the remnant water was blotted with blotting paper. Then the material was put into a graduated measuring cylinder with known volume of water and the

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volume of plankton was measured. The displacement volume of zooplankton were expressed as ml. m<sup>-3</sup> (Omori and Ikeda, 1984; Goswami, 2004).

### 2.5.2. Estimation of wet weight

The samples was again filtered with same net and blotted with the blotting paper. The material was weighed to obtain the wet weight. The wet weight was expressed as mg. m<sup>-3</sup> (Omori and Ikeda, 1984; Goswami, 2004).

### 2.5.3. Estimation of dry weight

After the determination of the wet weight, the material was dried in an oven at 60°C for 24 hrs. The dry weight was expressed as mg. m<sup>-3</sup> (Omori and Ikeda, 1984; Båmstedt, 1985; Goswami, 2004).

### 2.5.4. Estimation of elemental composition

Carbon, Hydrogen and Nitrogen content of zooplankton subsample was determined by using CHN analyzer (Euro EA Elemental Analyzer, Euro Vector).

## 2.6. Data Analysis

Data were analyzed by using univariate and multivariate statistical techniques. The univariate descriptors used for the fauna were number of species and the abundance. The community structure was described for all zooplankton groups collectively and copepod species separately were calculated by using four indices for each of the different locations: Shannon diversity index ( $H'$ ) (Shannon and Weaver, 1963), Simpson dominance index ( $\lambda$ ) (Simpson, 1949), Margalef species richness index ( $d$ ) (Margalef, 1951; 1968) and Pielou's evenness index ( $J'$ ) (Pielou, 1975; 1977) were calculated. The equitability of the copepod fauna was further studied based on the species abundance distributions as k-dominance curves (Lamshead *et al.*, 1983).

### Shannon taxon diversity index

$$H' = \sum_{i=1}^R p_i \ln p_i = \sum_{i=1}^R \ln p_i^{p_i}$$

where,  $p_i$  is the abundance of the  $i^{\text{th}}$  taxon and R is the number of taxa encountered.

### Simpson dominance index

$$\lambda = \sum_{i=1}^R p_i^2$$

where, R is richness (total number of species/taxa in the dataset) and  $p_i$  is the abundance of the  $i^{\text{th}}$  species/taxon.

## Materials and Methodology

### Margalef diversity index

$$d_{Mg} = \frac{(S - 1)}{\ln N}$$

where,  $N$  is the total number of individuals in the sample and  $S$  is the number of species (or taxa) recorded.

**Pielou's evenness index ( $J'$ )** responds to the next expression:

$$J' = \frac{H'}{\text{Log}(S)}$$

Where,  $S$  is total species and  $N$  is total individuals

Data were analyzed by one-way analysis of variance (ANOVA), a  $p < 0.05$  level of significance, was applied to compare the means. When significant differences were found among treatments, Turkey's post hoc test was used to test specific differences among treatments by using Paleontological Statistics (PAST, Hammer *et al.*, 2001). Pearson correlation analysis was conducted in order to explain the variability in zooplankton distribution. Relationships were tested between hydrographical parameters (temperature, salinity, pH and dissolved oxygen), nutritional ( $\text{PO}_4$ ,  $\text{NO}_3$ ,  $\text{NO}_2$  and  $\text{SO}_4$ ) parameters and biological parameters (Chlorophyll-a, zooplankton and copepods). The statistical analysis of correlation was quantified by using IBM SPSS version 20.

To reveal similarities in mesozooplankton community among stations and seasons and to access the major trends in the zooplankton and copepod species composition of different stations, a multivariate cluster analysis was performed on a data matrix of species abundances (individuals/ $\text{m}^3$ ). The cluster analysis was performed on Bray Curtis similarity index calculated for square root transformed data and samples were grouped by using group-average linkage procedure (Clarke and Warwick, 1994). In order to explore the temporal (monthly) pattern of zooplankton and copepod population, non-metric Multidimensional Scaling (nMDS) was performed for the stations based on the Bray-Curtis similarity matrix between samples. Analysis of Similarity (ANOSIM) was subsequently used to test for significant differences in mesozooplankton community composition and copepod species between the stations and seasons. In addition, the similarity percentages analysis (SIMPER) was used to identify the species that accounted for most of the similarities within groups (Clarke and Warwick, 2001; Clarke and Gorley, 2006). All multivariate analysis and diversity indices were carried out by using the Plymouth Routines in Multivariate Ecological Research (PRIMER v6) programme (Clarke and Gorley, 2006).

## CHAPTER 3

### HYDROGRAPHY

#### 3.1. Introduction

The coastal waters are highly dynamic where the knowledge on environmental factors such as temperature, salinity, pH and dissolved oxygen (DO) is of great importance since they have pronounced impact on the qualitative and quantitative status of the biotic system. In addition to the environmental factors, an appropriate amount of nutrients determines the productivity of the marine ecosystem (Sarojini and Sarma, 2001). The climate of Andaman Islands is tropical with monsoon, cyclones, hot and humid conditions all through the year (Rao, 2010). These islands receives rainfall during both south-west and north-east monsoon with maximum precipitation during south-west monsoon period (Rangarajan and Marichamy, 1972; Ramaraju *et al.*, 1981; Santhanakumar *et al.*, 2010). The major rainfall receives through southwest monsoon from late May to September (Munk *et al.*, 2004; Satapoomin *et al.*, 2004; Nair and Gireesh, 2010), while weak stretch of northeast monsoon occurs during October-December and relatively meager during January to April are classified as inter monsoon period (Chakravarty *et al.*, 1987; Jayaraj and Andrew, 2005).

The physical and hydrographical features of the Andaman Sea is reported earlier (Sewell, 1928; Wyrcki, 1971; 1973; Maslennikov, 1973; Osborne and Burch, 1980; Rao *et al.*, 1981; Murthy *et al.*, 1981; Ramaraju *et al.*, 1981; Bhattathiri, 1984; Varkey *et al.*, 1996; Muduli *et al.*, 2011; Jha *et al.*, 2012; Beegum *et al.*, 2012). The distribution of phytoplankton coincide with the distribution of nutrients. Plankton abundance and high productivity at the coastal waters due to coastal upwelling and land runoff as the nutrient levels are high. Nutrient enrichments due to anthropogenic wastes and sewage due to urbanization, causes potential deterioration to marine ecosystems, which can also show adverse effects on human health through the food chain (Muduli *et al.*, 2011). Ocean current is also a very important parameter, which may affect the life and behavior of marine organisms. It also influences the variation of other hydrographic parameters, for instance the distribution of temperature, salinity and diffusion of nutrients and pollution introduced into the coastal water (Khokiattiwong, 1991). Moreover, sea current variation is one of the natural factors affect the movement and distribution of zooplankton.

## 3.2. Results

### 3.2.1. Environmental parameters

#### 3.2.1.1. Sea surface temperature (SST)

During the study period water temperature varied from 25-33°C. The highest SST of 33°C and 32°C was recorded from Junglighat (St.5) in April 2013 and 2014 respectively. While the lowest temperature 25°C was recorded at Burmanallah and Carbyn's Cove (St.1 and St.2) (Table 3.1). In general, the seasonal variation of temperature was recorded to be higher during the southwest monsoon period (May to September) with the average of 27.5°C and 28.2°C followed by northeast monsoon with the exception to Carbyn's Cove (St.2), where average SST was lowest (27.00±1.41°C) during northeast monsoon period compared to inter monsoon (27.4±1.5°C) (Table 3.2). SST was recorded to be lowest during the inter monsoon period in the rest of the stations that ranged from 27.3°C to 27.8°C. The monthly variation in the SST at different stations are depicted in Fig. 3.1.

#### 3.2.1.2. Sea surface salinity (SSS)

The monthly variation in the SSS at different stations are given in the Fig. 3.1. The lowest sea surface salinity recorded was 20 psu at Junglighat followed by 25 psu and 26 psu at Chattam (St.3) and Burmanallah (St.1) respectively, while highest SSS recorded was 34 psu (Table 3.1). The average surface salinity between the seasons were presented in the table 2 shows that the SSS invariably higher during inter monsoon period followed by southwest monsoon and ranged from 31.4±1.4 psu to 32.6±1.1 psu and 28.2±4.9 psu to 30.4±1.6 psu respectively. However, the average salinity at Carbyn's Cove and Junglighat was lower during southwest monsoon than northeast monsoon period (Table 3.2).

#### 3.2.1.3. pH

The average value of pH ranged between 7.6 and 7.8 in the study area however, the surface coastal waters showed slightly acidic during the months between August and October 2013 and ranged between 6.8 and 7.1 which in turn recovered in the succeeding periods (Table 3.1). The maximum value of pH recorded was 8.7 at Chidiyatapu (St.4). The average pH values were generally higher during the inter

monsoon (January to April) that ranged to  $7.7\pm 0.5$  and  $8.2\pm 0.5$  followed by northeast monsoon period (Table 3.2).

#### 3.2.1.4. Dissolved oxygen

The average value of dissolved oxygen (DO) ranged between  $6.1 \text{ mgL}^{-1}$  and  $6.7 \text{ mgL}^{-1}$  with the maximum of  $9.6 \text{ mgL}^{-1}$  at Burmanallah (St.1) during September 2013 and minimum of  $3.6 \text{ mgL}^{-1}$  during June 2012 at Junglighat (St.5). In general DO was higher during northeast monsoon that ranged between  $6.7\pm 0.6 \text{ mgL}^{-1}$  and  $8.6\pm 2.5 \text{ mgL}^{-1}$  at different locations. However DO was lowest during inter monsoon period with the range of  $6.0\pm 0.7 \text{ mgL}^{-1}$  and  $6.3\pm 0.6 \text{ mgL}^{-1}$ . The monthly variation in the pH and DO at different stations are depicted in Fig. 3.2.

#### 3.2.1.5. ANOVA and Correlation

The results of One-way ANOVA ( $p > 0.05$ ) revealed that none of the environmental parameters were significantly varied between the stations studied from South Andaman. In Burmanallah and Chattam (St.1 and St.3), the correlation between all the parameters are weak and there was no significant values observed. A significant moderate negative correlation ( $r = -0.523$ ;  $p < 0.01$ ,  $n = 28$ ) between the SST and DO was observed in Carbyn's Cove (St.2). A significant moderate positive correlation ( $r = 0.643$ ;  $p < 0.01$ ,  $n = 16$ ) was observed between pH and SSS at Chidiyatapu (St.4). While in Junglighat (St.5), a significant weak negative correlation was observed between SST with pH ( $r = -0.441$ ;  $p < 0.05$ ,  $n = 28$ ) and DO ( $r = -0.401$ ;  $p < 0.05$ ,  $n = 28$ ) and also between SSS and DO ( $r = -0.451$ ;  $p < 0.05$ ,  $n = 28$ ).

**Table 3.1. The average, maximum and minimum values of environmental parameters recorded from the study stations.**

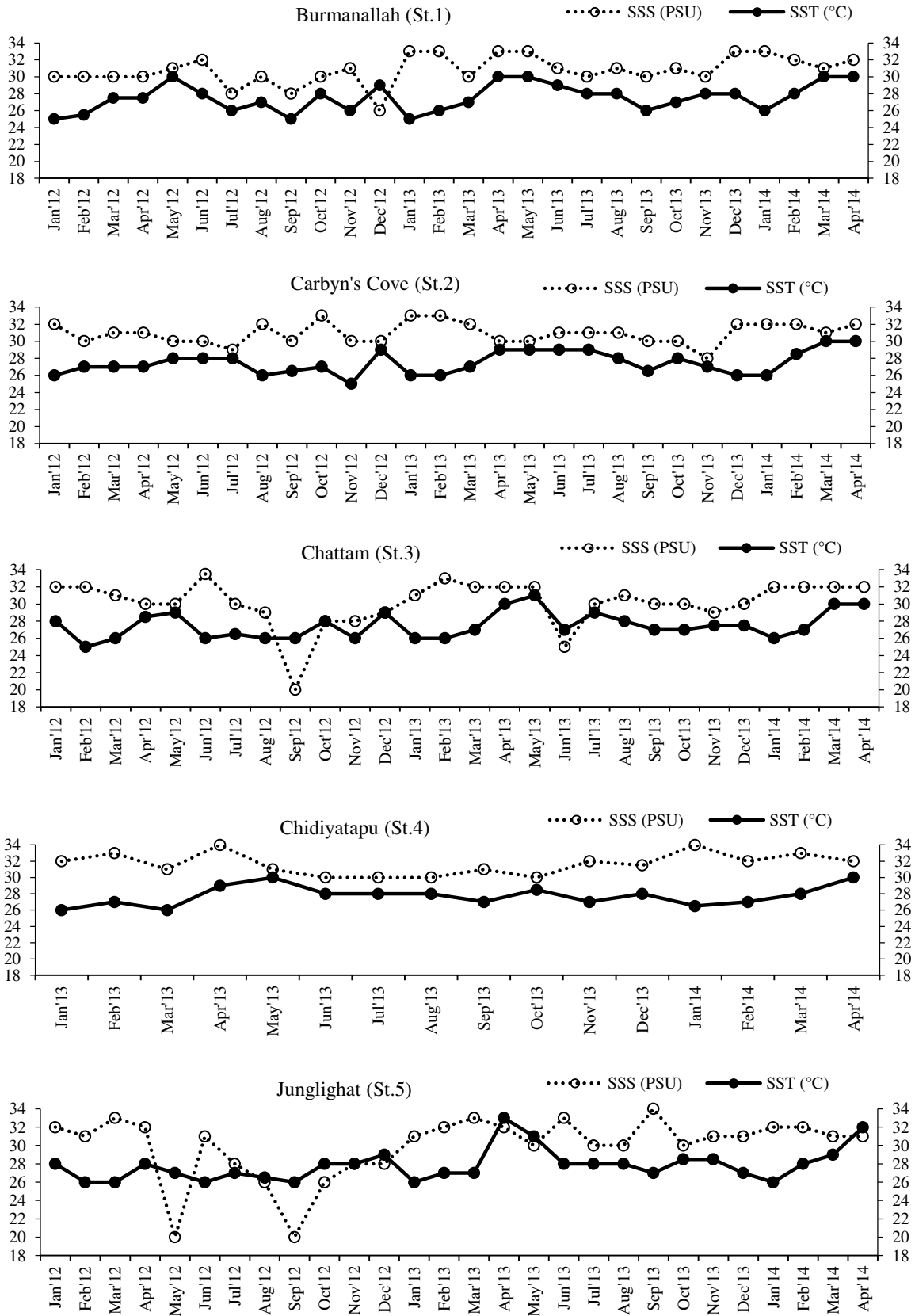
Station	SST ( $^{\circ}\text{C}$ )			SSS (PSU)			pH			DO ( $\text{mgL}^{-1}$ )		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Burmanallah	27.5	30.0	25.0	30.8	33.0	26.0	7.7	8.6	6.8	6.7	9.6	4.7
Carbyn's Cove	27.5	30.0	25.0	30.9	33.0	28.0	7.7	8.5	6.9	6.5	8.8	4.5
Chattam	27.5	31.0	25.0	30.2	34.0	25.0	7.7	8.4	6.9	6.5	8.1	4.4
Chidiyatapu	27.8	30.0	26.0	31.7	34.0	30.0	7.8	8.7	6.8	6.1	9.5	5.2
Junglighat	28.1	33.0	26.0	29.9	34.0	20.0	7.6	8.6	6.8	6.4	9.4	3.6

**Table 3.2. The average seasonal variation of environmental parameters from the study stations.**

Stations	Parameters	IM	SWM	NEM
		$\bar{X} \pm SD$	$\bar{X} \pm SD$	$\bar{X} \pm SD$
Burmanallah	SST (°C)	27.29±1.90	27.70±1.70	27.67±1.03
	SSS (PSU)	31.42±1.38	30.40±1.58	30.17±2.32
	pH	7.89±0.41	7.50±0.52	7.72±0.46
	DO (mgL <sup>-1</sup> )	6.11±0.68	6.76±1.26	7.69±1.11
Carbyn's Cove	SST (°C)	27.46±1.53	27.80±1.11	27.00±1.41
	SSS (PSU)	31.58±1.00	30.40±0.84	30.50±1.76
	pH	7.77±0.39	7.51±0.43	7.68±0.41
	DO (mgL <sup>-1</sup> )	6.34±0.63	6.48±1.50	7.05±0.38
Chattam	SST (°C)	27.46±1.80	27.55±1.67	27.50±1.00
	SSS (PSU)	31.75±0.75	29.05±3.86	29.00±0.89
	pH	7.76±0.44	7.50±0.44	7.77±0.49
	DO (mgL <sup>-1</sup> )	6.17±0.84	6.79±1.10	6.73±0.60
Chidiyatapu	SST (°C)	27.44±1.45	28.20±1.10	27.83±0.76
	SSS (PSU)	32.63±1.06	30.40±0.55	31.17±1.04
	pH	8.18±0.53	7.08±0.24	7.77±0.70
	DO (mgL <sup>-1</sup> )	6.00±0.67	5.80±0.31	8.64±2.49
Junglighthat	SST (°C)	27.83±2.41	28.25±1.62	28.17±0.68
	SSS (PSU)	31.83±0.72	28.20±4.87	29.00±2.00
	pH	7.73±0.50	7.41±0.36	7.83±0.56
	DO (mgL <sup>-1</sup> )	6.12±0.62	6.59±1.64	6.80±0.76

IM: inter monsoon; SWM: southwest monsoon; NEM: northeast monsoon

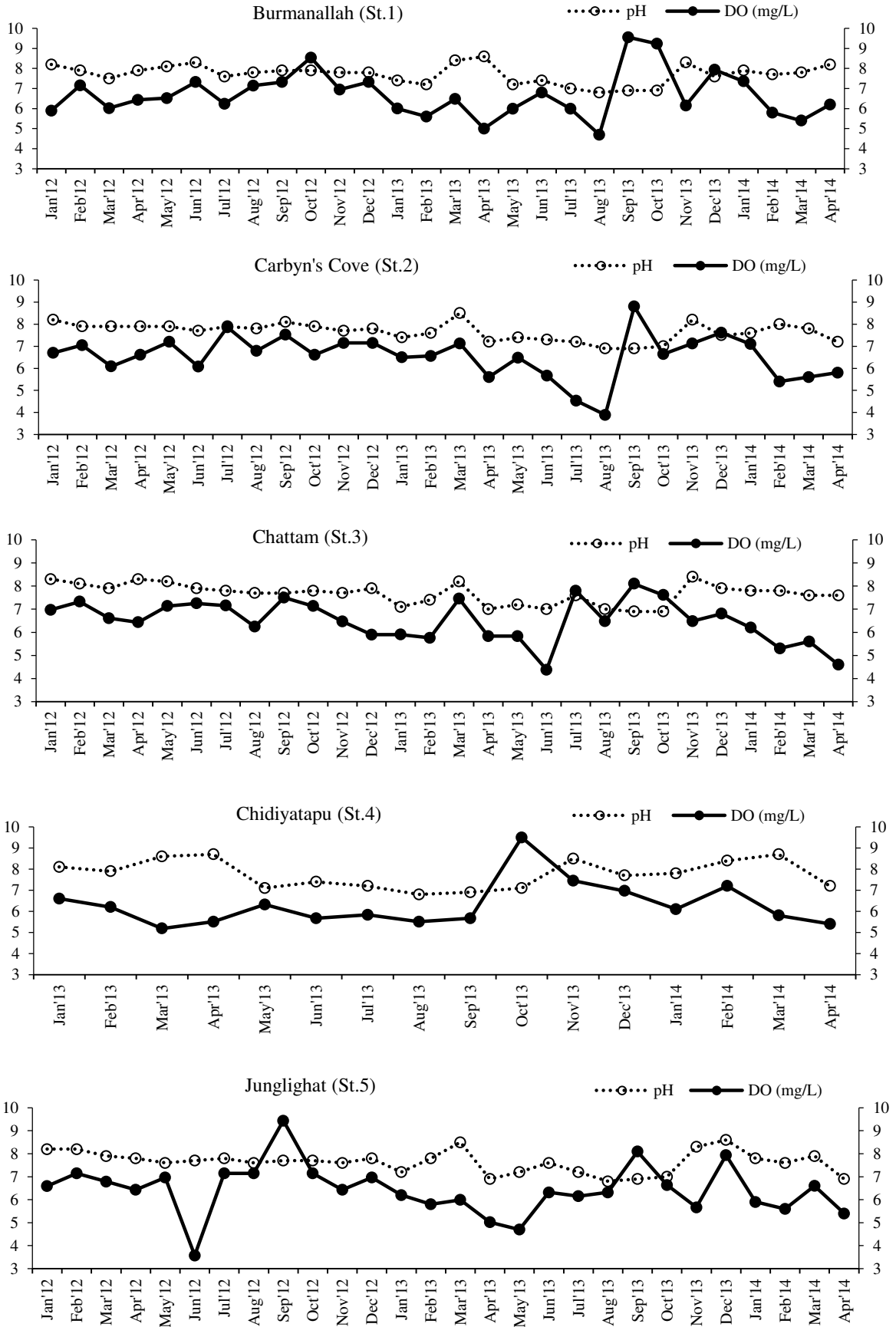
## Hydrography



**Fig. 3.1. Monthly variations in the temperature and salinity in the study area.**



## Hydrography



**Fig. 3.2. Monthly variations in the pH and dissolved oxygen in the study area.**

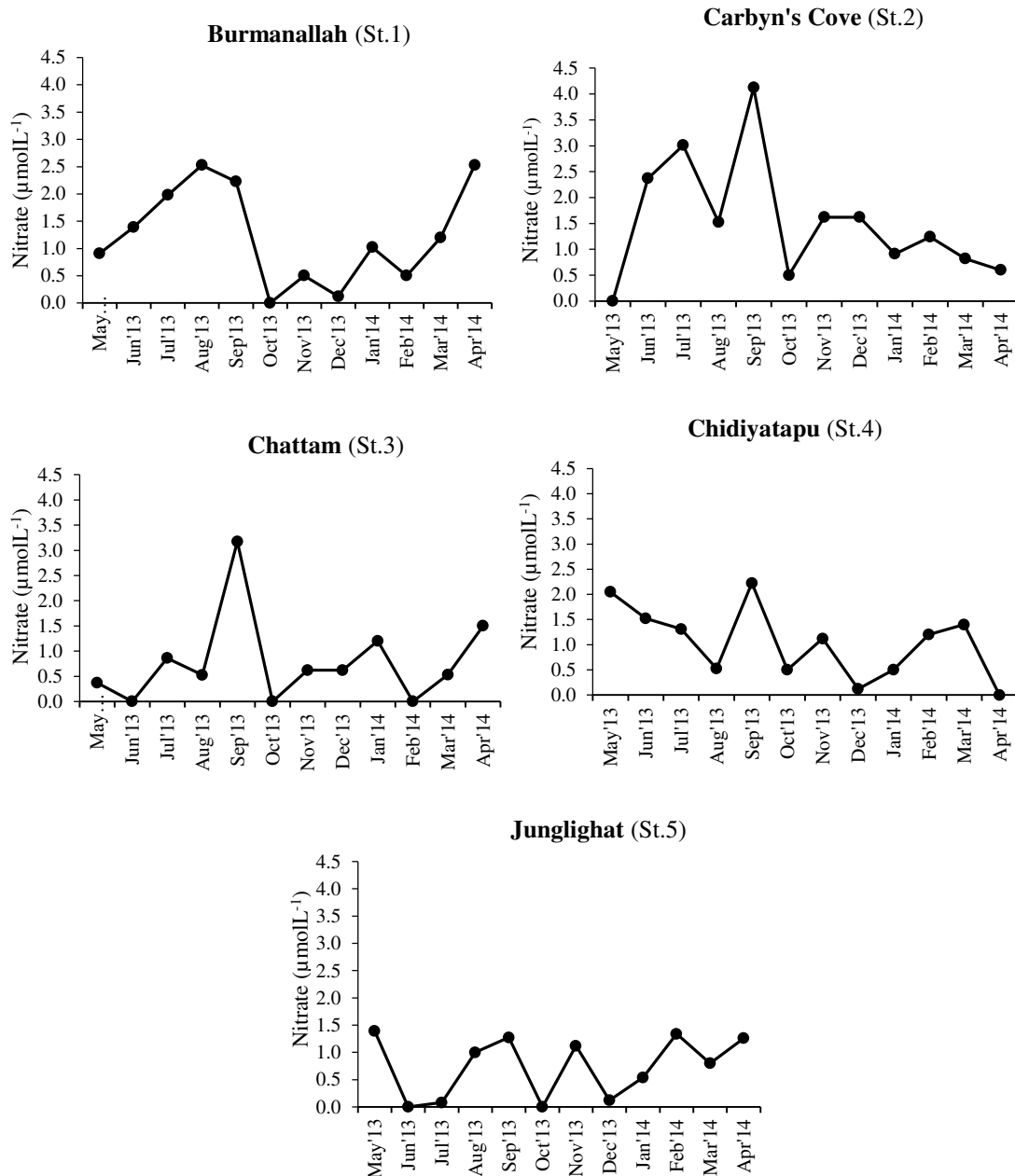
### 3.2.2. Seawater nutrients and Chlorophyll *a*

#### 3.2.2.1. Nitrate

The nitrate concentrations ranged from 0.08 to 4.12  $\mu\text{mol.L}^{-1}$  with higher average concentration in Carbyn's Cove (St.2) ( $1.53 \pm 1.16 \mu\text{mol.L}^{-1}$ ) followed by Burmanallah (St.1) ( $1.24 \pm 0.89 \mu\text{mol.L}^{-1}$ ) while the lowest nitrate was detected in Junglighat (St.5) ( $0.74 \pm 0.56 \mu\text{mol.L}^{-1}$ ). At Burmanallah (St.1), the nitrate concentration was recorded in the range between 0.12  $\mu\text{mol.L}^{-1}$  and 2.53  $\mu\text{mol.L}^{-1}$ . The maximum concentration (2.53  $\mu\text{mol.L}^{-1}$ ) was recorded during April 2014 and August 2013 followed by September'13 (2.22  $\mu\text{mol.L}^{-1}$ ) and the minimum (0.12  $\mu\text{mol.L}^{-1}$ ) during December'13 in Burmanallah (St.1). In Carbyn's Cove (St.2), the concentration varied from 0.50 to 4.12  $\mu\text{mol.L}^{-1}$ . Higher concentration (4.12  $\mu\text{mol.L}^{-1}$ ) was recorded in September'13 followed by 3.01  $\mu\text{mol.L}^{-1}$  and 2.37  $\mu\text{mol.L}^{-1}$  in July and June 2013 respectively. At Chattam (St.3), the concentration of nitrate ranged between 0.37  $\mu\text{mol.L}^{-1}$  and 3.17  $\mu\text{mol.L}^{-1}$  with maximum during southwest monsoon season (September 2013) and minimum during early monsoon period. The nitrogen content varied from 0.12 to 2.22  $\mu\text{mol.L}^{-1}$  in Chidiyatapu (St.4) with maximum during September'13 and minimum in the December'13. At Junglighat (St.5), the nitrate concentration varied from 0.12 to 1.39  $\mu\text{mol.L}^{-1}$ . Maximum (1.39  $\mu\text{mol.L}^{-1}$ ) was recorded during early monsoon period (May 2013) and minimum (0.12  $\mu\text{mol.L}^{-1}$ ) during December'13 (Fig. 3.3).

#### 3.2.2.2. Nitrite

The nitrite content in the study area ranged from 0.4 to 1.21  $\mu\text{mol.L}^{-1}$  during the study period. The concentration of nitrite varied from 0.4 to 0.8  $\mu\text{mol.L}^{-1}$ , 0.4 to 0.67  $\mu\text{mol.L}^{-1}$ , 0.4 to 1.21  $\mu\text{mol.L}^{-1}$ , 0.4 to 1.0  $\mu\text{mol.L}^{-1}$  and 0.4 to 0.96  $\mu\text{mol.L}^{-1}$  at Burmanallah (St.1), Carbyn's Cove (St.2), Chattam (St.3), Chidiyatapu (St.4) and Junglighat (St.5) respectively with higher concentration during monsoon period while below detectable level in October and December in Burmanallah (St.1). A strong positive correlation was observed between Nitrate and Nitrite content among all stations except Junglighat (St.5), where the correlations was very weak. Whereas in Chattam (St.3), they were moderately correlated. The correlation was significant in all the stations, Burmanallah (St.1) ( $r= 0.748, p<0.01; n=12$ ), Carbyn's Cove (St.2) ( $r= 0.745, p<0.01; n=12$ ) and Chidiyatapu (St.4) ( $r= 0.792, p<0.01; n=12$ ) except Chattam (St.3) ( $r= 0.488, p=0.108; n=12$ ) and Junglighat (St.5) ( $r= 0.069, p=0.830; n=12$ ; Fig. 3.4).

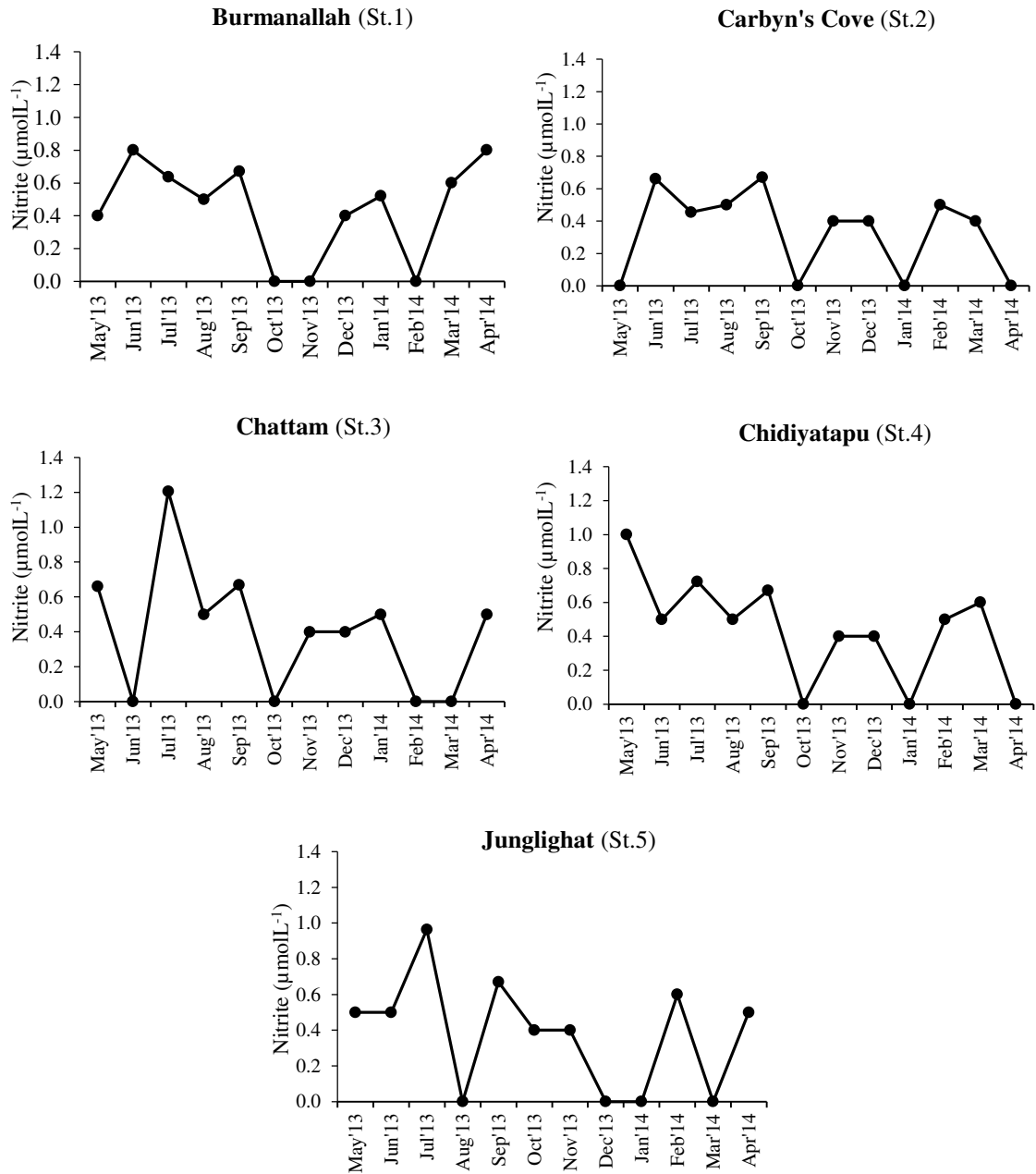


**Fig. 3.3. Spatial and temporal variation of nitrate in the study area.**

### 3.2.2.3. Phosphate

The concentration of phosphate varied from 0.60 to 2.25 µmol.L<sup>-1</sup> with maximum average of 1.029±0.714 µmol.L<sup>-1</sup> at Carbyn’s Cove (St.2) followed by Burmanallah (St.1) (0.875±0.615 µmol.L<sup>-1</sup>) and the concentration was minimum at Chattam (St.3) (0.683±0.728 µmol.L<sup>-1</sup>). In Burmanallah (St.1) and Carbyn’s cove (St.2), the concentration ranged from 0.6 to 1.8 µmol.L<sup>-1</sup> and 0.9 to 2.25 µmol.L<sup>-1</sup> respectively with maximum concentration during July 2013 and no phosphate was detected between November and December 2013 at Burmanallah (St.1). At stations Chattam (St.3),

Chidiyatapu (St.4) and Junglightat (St.5), the phosphate concentration ranged from 1.0 to 1.5  $\mu\text{mol.L}^{-1}$ , 1.0 to 1.8  $\mu\text{mol.L}^{-1}$  and 0.9 to 1.5  $\mu\text{mol.L}^{-1}$  respectively with higher concentration in August and October'13 at all stations, however, the concentration remains high till November.

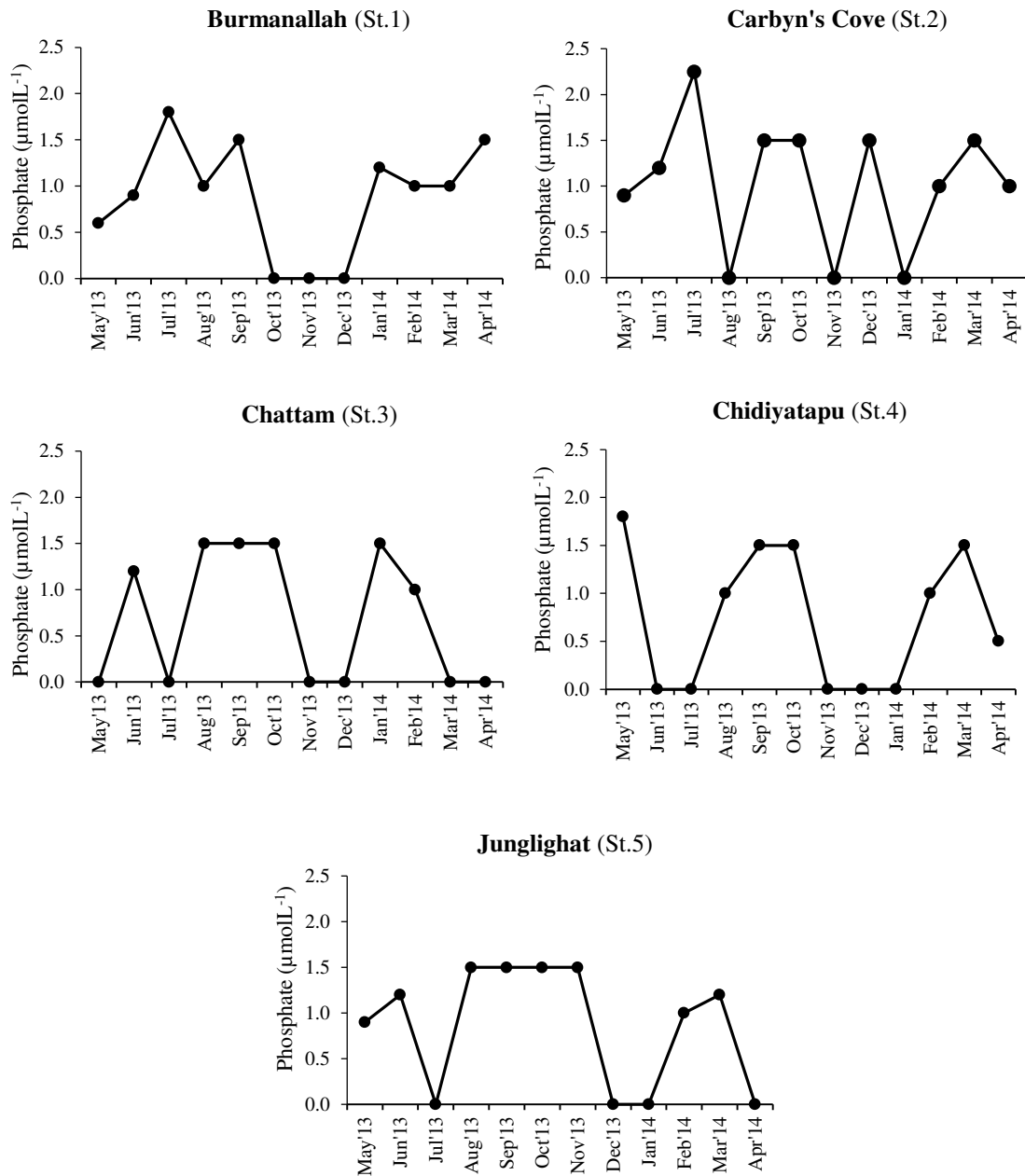


**Fig. 3.4. Spatial and temporal variation of nitrite in the study area.**

The phosphate positively correlated with nitrate ( $r=0.806$ ;  $p<0.01$ ;  $n=12$ ) and nitrite ( $r=0.684$ ;  $p<0.05$ ;  $n=12$ ), also it is statistically significant in Burmanallah, while a weak correlation was found in Chattam, Carbyn's Cove and Junglightat, whereas nitrate was moderate in Chidiyatapu ( $r=0.429$ ;  $n=12$ ). Phosphate and silicate content

## Hydrography

were moderately correlated in Burmanallah ( $r = -0.444$ ), Chidiyatapu ( $r = 0.501$ ) and Junglight ( $r = 0.564$ ) while weakly correlated in rest of the stations. The phosphate and silicate were correlated negatively in Burmanallah and Carbyn's Cove, whereas positive in the rest of the stations (Fig. 3.5).



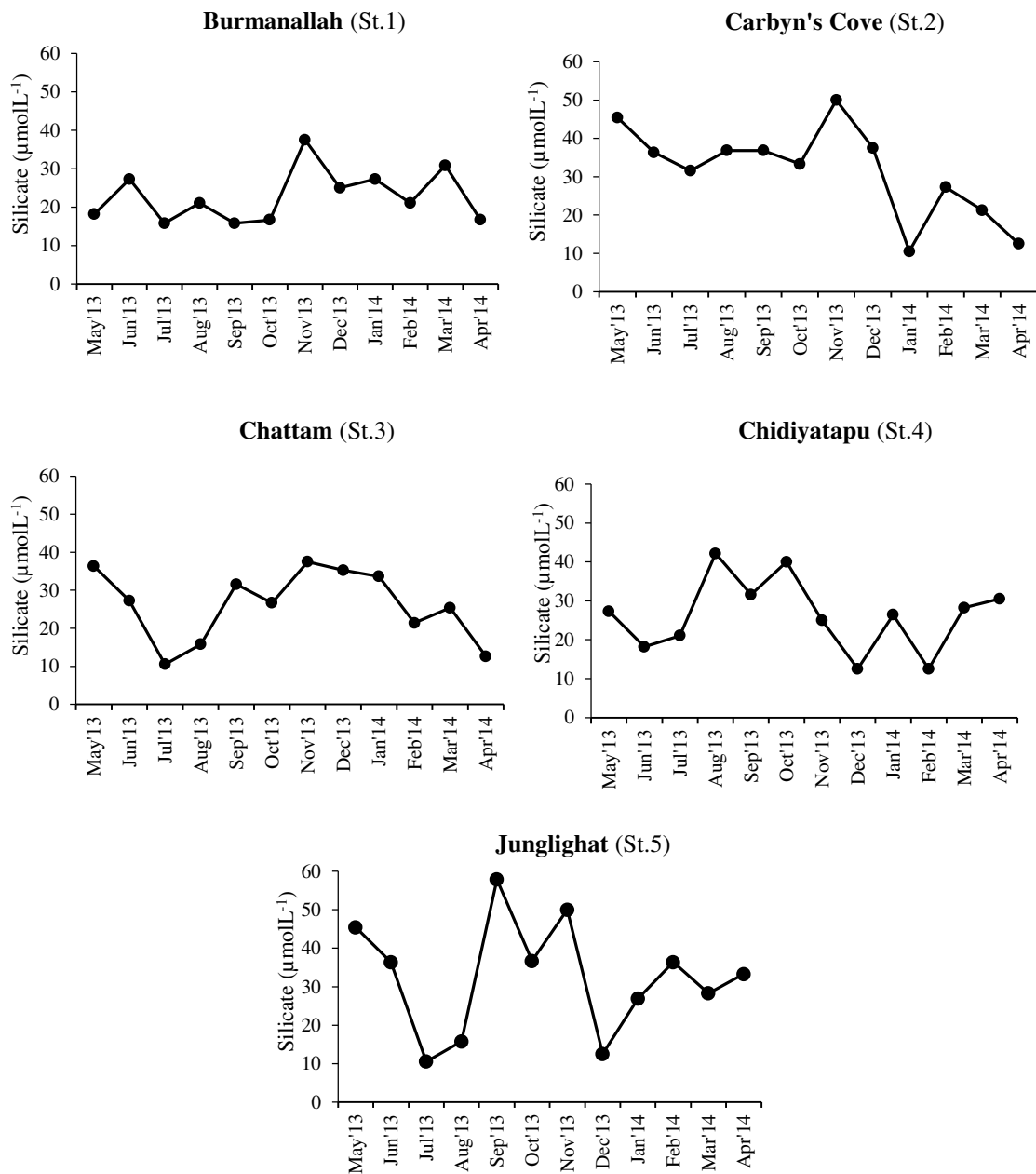
**Fig. 3.5. Spatial and temporal variation of phosphate in the study area.**

### 3.2.2.4. Silicate

The average concentration of silicate were higher during the northeast monsoon season (October-December) and varied from  $23.74 \pm 10.07 \mu\text{mol.L}^{-1}$ ,  $39.42 \pm 7.28 \mu\text{mol.L}^{-1}$ ,  $32.75 \pm 4.73 \mu\text{mol.L}^{-1}$ ,  $27.27 \pm 11.60 \mu\text{mol.L}^{-1}$  and  $39.27 \pm 19.88 \mu\text{mol.L}^{-1}$  at

## Hydrography

Burmanallah (St.1), Carbyn's Cove (St.2), Chattam (St.3), Chidiyatapu (St.4) and Junglighat (St.5) respectively. The maximum concentration ( $37.5 \mu\text{mol.L}^{-1}$ ) was recorded in November 2013 and minimum ( $15.78 \mu\text{mol.L}^{-1}$ ) during July and September 2013 at Burmanallah (St.1). In Carbyn's Cove (St.2) and Chattam (St.3) the concentration was recorded to be highest during November with  $50.0 \mu\text{mol.L}^{-1}$  and  $37.5 \mu\text{mol.L}^{-1}$  followed by May with  $45.45 \mu\text{mol.L}^{-1}$  and  $36.67 \mu\text{mol.L}^{-1}$  respectively while the concentration was lower ( $10.52 \mu\text{mol.L}^{-1}$ ) during January 2014 at Carbyn's Cove (St.2) and lower ( $10.5 \mu\text{mol.L}^{-1}$ ) during July at Chattam (St.3) (Fig 3.6).



**Fig. 3.6. Spatial and temporal variation of silicate in the study area.**

The silicate concentration ranged between  $12.5 \mu\text{mol.L}^{-1}$  and  $42.12 \mu\text{mol.L}^{-1}$  at Chidiyatapu (St.4) with maximum during August 2013 and minimum during February 2014. At Junglighat, the concentration of silicate ranged from  $10.53$  to  $57.89 \mu\text{mol.L}^{-1}$  with maximum concentration during September 2013 followed by November ( $50.0 \mu\text{mol.L}^{-1}$ ) and May ( $45.45 \mu\text{mol.L}^{-1}$ ) months. In all the stations, weak correlation was found between silicate with nitrate and nitrite however nitrate was correlated moderately in Junglighat with  $r$  values of  $0.535$ . The correlation between silicate and phosphate content was also moderate except in Carbyn's Cove (St.2) and Chattam (St.3) where the correlation was very weak.

### 3.2.2.5. Chlorophyll *a*

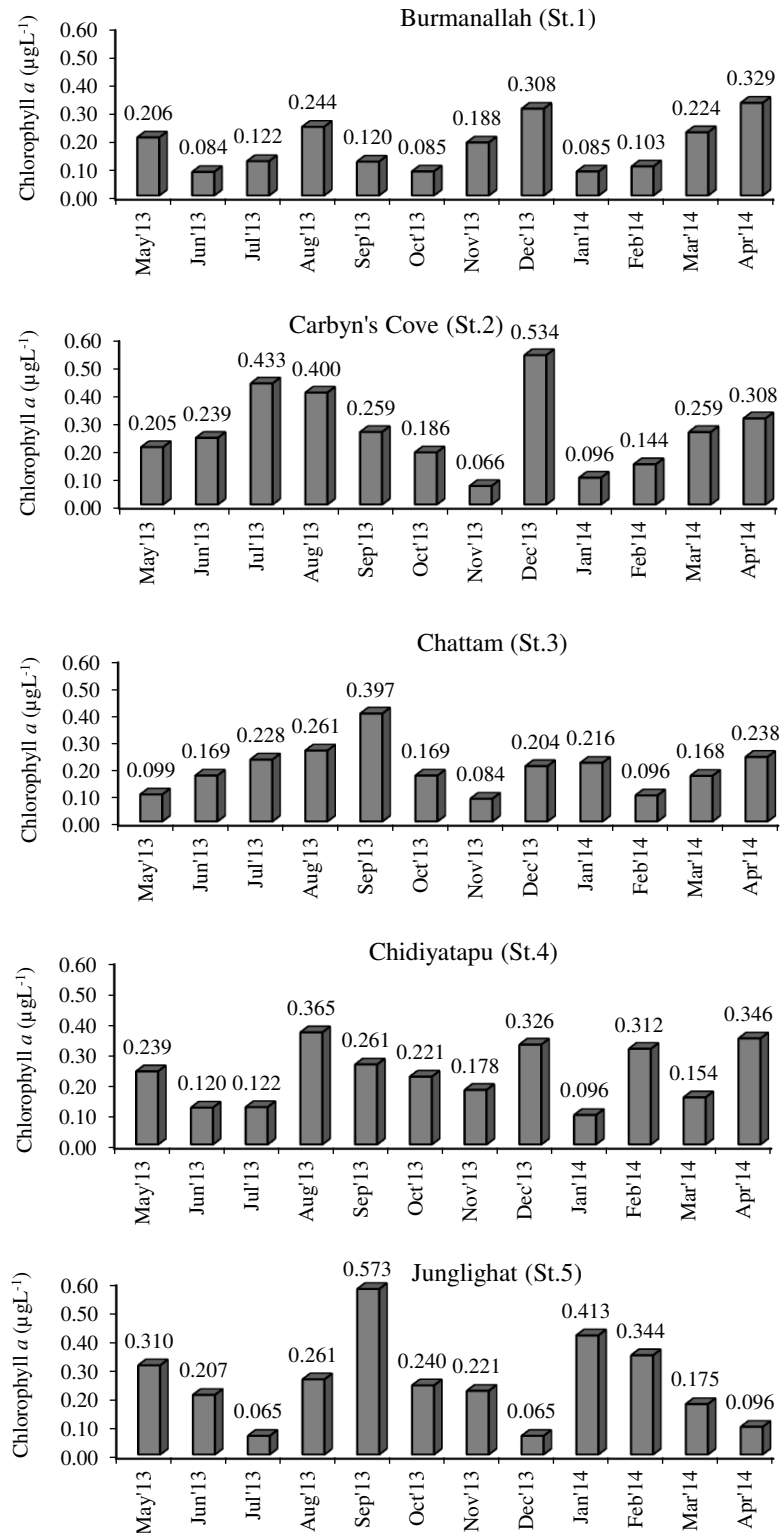
Overall, the concentration of Chlorophyll *a* ranged from  $0.048 \mu\text{g.L}^{-1}$  and  $0.477 \mu\text{g.L}^{-1}$  in the study area. The monthly variation in the concentration of the Chlorophyll *a* pigment estimated at different stations are presented in Fig. 3.7. The chlorophyll *a* concentration was maximum during northeast monsoon season at Chattam (St.3) (avg.  $0.213 \pm 0.132 \mu\text{g.L}^{-1}$ ), Chidiyatapu (St.4) (avg.  $0.246 \pm 0.063 \mu\text{g.L}^{-1}$ ) and Junglighat (St.5) (avg.  $0.275 \pm 0.214 \mu\text{g.L}^{-1}$ ) while in Carbyn's Cove (St.2), maximum (avg.  $0.319 \pm 0.114 \mu\text{g.L}^{-1}$ ) was recorded during summer monsoon season, whereas at Burmanallah (St.1) (avg.  $0.185 \pm 0.098 \mu\text{g.L}^{-1}$ ), it was during inter monsoon period. In Burmanallah, the maximum concentration was  $0.329 \mu\text{g.L}^{-1}$  followed by  $0.308 \mu\text{g.L}^{-1}$  during April'14 and December'13 respectively, whereas minimum ( $0.084 \mu\text{g.L}^{-1}$ ) was recorded during June'13. At Carbyn's Cove, the pigment estimated was higher ( $0.534 \mu\text{g.L}^{-1}$ ) during December'13 followed by July and August'13 with  $0.433 \mu\text{g.L}^{-1}$  and  $0.40 \mu\text{g.L}^{-1}$  respectively. At Chattam and Junglighat, the maximum concentration of  $0.397 \mu\text{g.L}^{-1}$  and  $0.573 \mu\text{g.L}^{-1}$  was estimated during September'13 and lower concentration during November and December'13 respectively. At Chidiyatapu, the pigment estimated was maximum ( $0.365 \mu\text{g.L}^{-1}$ ) during August'13 followed by April'14 and December'13. The minimum ( $0.096 \mu\text{g.L}^{-1}$ ) concentration was recorded during January'14.

### 3.2.2.6. Correlation between physico-chemical and biological factors

The chlorophyll *a* was moderately correlated with SST ( $r= 0.558$ ;  $n=12$ ) at Burmanallah (Table 3.3), but, it exhibited weaker correlation at remainder of the locations. Salinity and chl *a* showed a moderate positive correlation at Carbyn's Cove ( $r= 0.413$ ;  $n=12$ ; Table 3.4) and Junglighat ( $r= 0.603$ ,  $p<0.05$ ;  $n=12$ ; Table 3.7). A

## Hydrography

moderate negative correlation was found between chl *a* and pH at Carbyn's Cove ( $r = -0.416$ ) and Chattam ( $r = -0.471$ ;  $n = 12$ ), whereas, positively correlated with DO ( $r = 0.453$ ;  $n = 12$ ; Table 3.5). In terms of relationship with nutrients, chlorophyll *a* was strongly correlated with nitrate ( $r = 0.821$ ;  $p < 0.01$ ;  $n = 12$ ) and silicate ( $r = 0.643$ ;  $p < 0.05$ ;



**Fig. 3.7. Monthly variation in the Chlorophyll *a* concentration in the study area.**



## Hydrography

n=12) at Chattam and Junglightat, respectively. While, the correlation of chl *a* with other nutrients such as nitrite, phosphate and silicate were moderate to weak at Chattam (St.3). Similarly at Junglightat (St.5), chl *a* was correlated moderately with nitrate and phosphate, and weakly with nitrite. In all other stations, the correlation of water nutrients with Chlorophyll *a* was very weak except in Carbyn's Cove (St.2) where moderately correlated with phosphate (r= 0.488). In Burmanallah (St.1) and Chidiyatapu (St.4), the pigment values were not significantly correlated with any nutrients. Moreover, the analysis of variance (One-way ANOVA) also suggests that the water nutrients and Chl *a* values were not significantly varied between the stations.

**Table 3.3. Correlation between physicochemical parameters and Chlorophyll *a* in Burmanallah (St.1).**

Burmanallah	SST	SSS	pH	DO	Chl <i>a</i>	NO <sub>3</sub> -N	NO <sub>2</sub> -N	PO <sub>4</sub> -P	SiO <sub>4</sub> -Si
SST									
SSS	0.176	1							
pH	0.292	0.259	1						
DO	-.639*	-0.054	-0.256	1					
Chl <i>a</i>	0.558	0.289	0.32	-0.347	1				
NO <sub>3</sub> -N	0.122	-0.328	-0.21	-0.281	0.221	1			
NO <sub>2</sub> -N	0.247	-0.022	-0.088	-0.081	0.22	.748**	1		
PO <sub>4</sub> -P	-0.005	-0.2	-0.136	-0.203	-0.119	.806**	.684*	1	
SiO <sub>4</sub> -Si	0.099	-0.063	.637*	-0.268	0.054	-0.375	-0.222	-0.444	1

\*. Correlation is significant at the 0.05 level.

\*\*.. Correlation is significant at the 0.01 level.

**Table 3.4. Correlation between physicochemical parameters and Chlorophyll *a* in Carbyn's Cove (St.2).**

Carbyn's Cove	SST	SSS	pH	DO	Chl <i>a</i>	NO <sub>3</sub> -N	NO <sub>2</sub> -N	PO <sub>4</sub> -P	SiO <sub>4</sub> -Si
SST	1								
SSS	.116	1							
pH	-.103	-.060	1						
DO	-.645*	-.274	.050	1					
Chl <i>a</i>	.050	.413	-.416	-.250	1				
NO <sub>3</sub> -N	-.326	-.152	-.150	.235	.295	1			
NO <sub>2</sub> -N	-.091	-.089	.138	-.077	.262	.745**	1		
PO <sub>4</sub> -P	.319	.177	-.259	.013	.487	.349	.205	1	
SiO <sub>4</sub> -Si	-.204	-.728**	-.087	.153	.045	.211	.366	-.019	1

\*. Correlation is significant at the 0.05 level.

\*\*.. Correlation is significant at the 0.01 level.

**Table 3.5. Correlation between physicochemical parameters and Chlorophyll *a* in Chattam (St.3).**

Chattam	SST	SSS	pH	DO	Chl <i>a</i>	NO <sub>3</sub> -N	NO <sub>2</sub> -N	PO <sub>4</sub> -P	SiO <sub>4</sub> -Si
SST	1								
SSS	.380	1							
pH	-.028	.211	1						
DO	-.251	.063	-.146	1					
Chl <i>a</i>	-.179	-.003	-.471	.453	1				
NO <sub>3</sub> -N	-.063	.162	-.127	.398	.820**	1			
NO <sub>2</sub> -N	.276	.174	.059	.485	.406	.488	1		
PO <sub>4</sub> -P	-.715**	-.180	-.577*	.187	.394	.131	-.274	1	
SiO <sub>4</sub> -Si	-.258	-.144	.199	.098	-.251	.032	-.229	.014	1

\*. Correlation is significant at the 0.05 level.

\*\* . Correlation is significant at the 0.01 level.

**Table 3.6. Correlation between physicochemical parameters and Chlorophyll *a* in Chidiyatapu (St.4).**

Chidiyatapu	SST	SSS	pH	DO	Chl <i>a</i>	NO <sub>3</sub> -N	NO <sub>2</sub> -N	PO <sub>4</sub> -P	SiO <sub>4</sub> -Si
SST	1								
SSS	-.316	1							
pH	-.428	.660*	1						
DO	-.019	-.200	.037	1					
Chl <i>a</i>	.333	-.194	-.270	-.005	1				
NO <sub>3</sub> -N	-.108	-.181	-.019	-.231	-.340	1			
NO <sub>2</sub> -N	.113	-.316	-.053	-.394	-.042	.792**	1		
PO <sub>4</sub> -P	.322	-.125	-.181	.219	.298	.429	.331	1	
SiO <sub>4</sub> -Si	.236	-.222	-.477	.199	.163	-.095	-.222	.501	1

\*. Correlation is significant at the 0.05 level.

\*\* . Correlation is significant at the 0.01 level.

**Table 3.7. Correlation between physicochemical parameters and Chlorophyll *a* in Junglighat (St.5).**

Junglighat	SST	SSS	pH	DO	Chl <i>a</i>	NO <sub>3</sub> -N	NO <sub>2</sub> -N	PO <sub>4</sub> -P	SiO <sub>4</sub> -Si
SST	1								
SSS	-.414	1							
pH	-.352	.079	1						
DO	-.604*	.420	.164	1					
Chl <i>a</i>	-.361	.603*	-.282	.130	1				
NO <sub>3</sub> -N	.424	.125	-.239	-.372	.452	1			
NO <sub>2</sub> -N	.232	.137	-.412	-.168	.041	.069	1		
PO <sub>4</sub> -P	-.032	.151	-.210	.103	.437	.238	-.016	1	
SiO <sub>4</sub> -Si	.203	.498	-.148	-.105	.642*	.535	.306	.564	1

\*. Correlation is significant at the 0.05 level.

\*\* . Correlation is significant at the 0.01 level.

### 3.3. Discussion

The climate of these islands is tropical and experiences monsoon, cyclones, with hot and humid conditions throughout the year (Rao, 2010). The neritic waters are highly dynamic habitat than the oceanic realm and subjected to fluctuations of environmental condition. The information on environmental factors, mainly temperature, salinity, pH and dissolved oxygen (DO) is of great importance since they have pronounced impact on the biotic system, also an appropriate concentration of nutrients determines the phytoplankton productivity (Sarojini and Sarma, 2001). Hydrographical studies are essential as the periodic control of primary and secondary production changed in response to recent climate changes that are related to monsoon-induced upwelling/downwelling processes (Schalk, 1987; Baars *et al.*, 1990; Rashiba, 2010). Primary producers form the base of the marine food web. Their growth is influenced by multiple factors, which in turn influence the concentration of dissolved oxygen and light penetration in the marine environment (Al-Kandari *et al.*, 2009). Understanding the role of factors that influence the production in marine environment is highly essential in learning how to manage the environment for sustainable healthy ecosystem.

The present investigation was conducted primarily to study the distribution and diversity of mesozooplankton and species composition of copepods from the coastal waters of South Andaman. Physico-chemical parameters such as temperature, salinity, pH and dissolved oxygen (DO) were recorded for all the collection and, whereas the seawater nutrients and biological parameter (chlorophyll *a*) was estimated for the period of one year from May 2013 to April 2014. The results showed that the lower values of sea surface salinity (SSS) invariably recorded during January and February (inter monsoon period) months, however, the peak in the SST was consistently observed during the months of April and May. Rangarajan and Marichamy (1972) was observed a similar trend with temperature studiedly increased from January to April during the years 1964 to 1970 and also observed a clear double oscillation in a year, the maxima occurred in April and November. Also in the present study, the peak in the temperature was observed during May and December and decline in June (Fig. 3.1) may be due to the onset of the southwest monsoon (Rangarajan and Marichamy, 1972). However, the variation in temperature did not indicate a consistent pattern in the coastal waters of South Andaman. Highest SST was during inter monsoon (Nair and Gireesh, 2010) with 33°C and 32°C recorded in April 2013 and 2014 respectively in the study area. The seasonal variation of temperature showed higher temperature during the southwest

monsoon period (May to September) with an average of 27.5°C and 28.2°C followed by northeast monsoon. In contrast, the maximum average surface temperature in the Andaman Sea was recorded during inter monsoon ( $29.7 \pm 0.5^\circ\text{C}$ ) by Biju *et al.* (2013) was due to sampling only during the month of March and April months and minimum during northeast monsoon ( $28.2 \pm 0.3^\circ\text{C}$ ) (Biju *et al.*, 2013). The subsurface temperature of the seawater in the earlier studies varied from 26°C to 29°C (Madhu *et al.*, 2003; Rao, 2010) however, in the present study, maximum temperature recorded (30 to 33°C) was quite higher comparable to that of 22-34°C recorded by Rashiba (2010) from this area. In a recent study from this area, the SST and SSS during the inter monsoon period (April) was recorded as 29.9°C to 29.6°C and 32 to 32.4 psu (Pillai *et al.*, 2011) showed similar results as found in this study.

The salinity acts as a limiting factor in the distribution of living organisms, and its variation caused due to dilution and evaporation is most likely to influence the fauna (Gibson, 1982). Generally, changes in the salinity in the brackish water habitats such as estuaries, backwaters and mangrove are due to the influx of freshwater from land run off, caused by monsoon or by tidal variations. This is further evinced by decrease in salinity content during southwest monsoon and northeast monsoon (Table 3.2). In the present study, salinity at all the stations was high during inter monsoon (non-rainy) and low during the monsoon seasons. The SSS invariably higher during inter monsoon period that ranged from  $31.42 \pm 1.38$  psu to  $32.63 \pm 1.06$  psu similar to the results of Biju *et al.* (2013) from this area. The higher values during inter monsoon could be attributed to the low amount of rainfall, higher rate of evaporation (Sampathkumar and Kannan, 1998; Govindasamy *et al.*, 2000; Gowda *et al.*, 2001; Rajasegar, 2003). In addition, the hydrography particularly temperature and salinity is comparable to other studies from Andaman Sea (Antony *et al.*, 1997; Madhu *et al.*, 2003; Satapoomin *et al.*, 2004; Nair *et al.*, 2008; Jha *et al.*, 2012; Sachithanandam *et al.*, 2013; Biju *et al.*, 2013; Pillai *et al.*, 2014). The salinity in the coastal waters of Andaman Sea is comparatively lower is due to the freshwater discharged from rivers and rainfall is very important, especially during the southwest monsoon and northeast monsoon periods and higher during inter monsoon where the pH values was also higher with range of 7.76 to 8.18 in the study area. The pH of surface water was quite lower and DO was higher compared to Jha *et al.* (2012), reported the environmental quality of Treis Island, Nicobar. The surface waters of Andaman Sea were well oxygenated during all the seasons (Nair and Gireesh, 2010). The average value of DO recorded was comparable to  $5.1 \pm 6.0$  ml L<sup>-1</sup> from

Andaman Sea (Pai, 2007) and  $6.34 \pm 0.68 \text{ mg L}^{-1}$  to  $8.12 \pm 1.32 \text{ mg L}^{-1}$  from Bay of Bengal (Jagadeesan *et al.*, 2013). Moreover, the dissolved oxygen was higher in coastal areas than offshore regions of southern part of Andaman Sea (Limpsaichol *et al.*, 1987; Jithlang, 2011).

Generally, fluctuations in pH values during different seasons of the year is attributed to factors like removal of  $\text{CO}_2$  by photosynthesis through bicarbonate degradation, dilution of seawater by freshwater influx, low primary productivity, reduction of salinity and temperature and decomposition of organic materials as stated by Karuppasamy and Perumal (2000) and Rajasegar (2003). High pH was recorded during summer seasons, which might be due to the influence of light penetration (Das *et al.*, 1997) and high photosynthetic activity (Subramanian and Mahadevan, 1999). The surface coastal waters showed slightly acidic during the months between August and October 2013 that ranged between 6.8 and 7.1 that in turn recovered in the succeeding periods. The average pH values were generally higher during the inter monsoon (January to April) may be due to the non-rainy and depleted source of fresh water input (Das *et al.*, 1997). The acidic pH recorded during the present study were owing to the local acidification caused by heavy atmospheric precipitation and runoff that might have resulted in the over load of organic and inorganic nutrients in the coastal waters during monsoon. The degradation of materials coupled with other chemical process may have gradually decreased the pH during the monsoon period (August to October). Usually the mixing of fresh water with seawater involves a marked change in pH and increases the level of dissolved salts, which promote the coagulation of fine particulate matter (Phillips, 1972). Eashwar *et al.* (2001) also noticed regions of low pH and high temperature in some shallow water columns in the immediate vicinity of the land mass during intense volcanic activity near Barren Island (Pillai *et al.*, 2011). An attempt has been made to evaluate the ecological status of Bay of Bengal (Pai, 2010). The information on the physicochemical parameters were comparable to the present study. The pH of the Bay of Bengal ranged from 6.5 to 7.5 however, the most number of samples remain with pH of 7.0. In general pH in the coastal waters of Andaman Islands ranged between 8.50 - 8.68 (Jha *et al.*, 2012; Sachithanandam *et al.*, 2013).

The DO content of natural waters varies with temperature, salinity, turbulence, the photosynthetic activity of algae and plants, and atmospheric pressure (Vijayakumar *et al.*, 2000). A strong oxygen reduction was observed in the depth layers around Barren Islands with surface to mixed layer water varied from 4.36 to 4.32  $\text{ml L}^{-1}$  (Pillai *et al.*,

2011). In the present investigation, a higher value of dissolved oxygen was recorded during monsoon months at all the stations. Higher dissolved oxygen concentration observed during the monsoon season might be due to the cumulative effect of higher wind velocity joined with heavy rainfall and the resultant freshwater mixing (Das *et al.*, 1997). Dissolved oxygen was observed low during inter monsoon, which could be attributed to high temperature and salinity of the water and the oxygen holding capacity of water decrease with increasing temperature and salinity. In the present study, the correlation between temperature and DO were negative in all the stations and also, statistical significance was found in Burmanallah, Carbyn's Cove and Junglighat (Tables 3.3, 3.4 and 3.7). In the present investigation none of the measured parameters were significantly varied between the coastal stations from South Andaman. However the correlation between some parameters showed significance for instance a moderate negative correlation between the SST and DO was observed in Carbyn's Cove and moderate positive correlation was observed between pH and SSS at Chidiyatapu. In Junglighat, a significant weak negative correlation was observed between SST with pH and DO and also between SSS and DO consistent with the negative relationship between oxygen solubility and temperature.

Nutrient enrichment has been caused by rainfall and storm incidence during monsoon periods and associated upwelling events in tropical coastal waters (Smith, 1982; Schalk, 1987; Baars *et al.*, 1990; Chisholm and Roff, 1990). The seawater nutrients such as nitrate, nitrite, phosphate and silicate invariably attain a peak during the southwest monsoon (September) from all the stations. The monsoon periods influence water circulation, and can lead to flow reversal and upward transport of nutrients (Longhurst and Pauly, 1987). However, seasonality in the availability of nutrients was not clear due to the coastal waters that is more dynamic and influenced by numerous factors. Sarojini and Sarma (2001) studied the vertical distribution of seawater nutrients and environmental parameters from the offshore regions of Andaman and Nicobar. Kabanova (1964) reports very low surface phosphates in the Bay of Bengal while the phosphate is almost absent in the Andaman Sea because of high production. The nitrate and nitrite values were also low in the surface waters of the Bay of Bengal and increases sharply to 15 to 20  $\mu\text{g at/l}$  at thermocline depths and 22 to 26  $\mu\text{g at/l}$ , in deeper parts. Concentrations of 1.5 to 2.0  $\mu\text{g at/l}$  are reported in the euphotic zone in the central part of the Andaman Sea (Kabanova, 1964).

During the northeast monsoon, under favorable wind conditions weak upwelling occurs along the eastern shore of the Andaman Sea (Wyrski, 1973). The upwelling over the shelf also affects the distribution of temperature, salinity and vertical stability in the northern part of the Andaman Sea (Varkey *et al.*, 1996). Moreover, Andaman Sea coast is marked by mangrove forest and seagrass meadows distributed along the coastal belt. Large mangrove forests are the main habitat structure along the coast (Satapoomin and Sombat, 1997; Ramachandran *et al.*, 2005; Dam Roy and Krishnan, 2005). The waters from this brackish water mangrove area bring lot of nutrients to the coastal regions (Santhanakumar *et al.*, 2010). Muduli *et al.* (2011) studied the hydrochemical characteristics in and around Port Blair bay, almost covered all the seasons in the year 2007. A weak correlation between salinity and DO indicates higher photosynthetic activity in the lower saline water, which is supported by negative correlation between salinity and Chl *a* (Muduli *et al.*, 2011). A similar trend was found in Chattam and Chidiyatapu (Table 5 and 6). In contrary, at Junglighat a moderate positive correlation of salinity with DO and significant positive correlation of salinity with Chl *a* indicates higher photosynthetic activity in the higher saline water (Table 7). A strong negative correlation between salinity and the nutrients indicates that the fresh water through terrestrial runoff is the source of nutrients (Muduli *et al.*, 2011). A negative correlation of DO with NO<sub>3</sub> be due to the higher consumption rate of NO<sub>3</sub> by autotrophs that produce huge amount of oxygen in the system. Nutrient enrichment in the Port Blair is mainly by anthropogenic wastes and sewage due to urbanization, causes potential deterioration of marine ecosystems, which can also show an effect on human health through the food chain (Muduli *et al.*, 2011). Surface Chl *a* was observed as 0.32 and 0.38 mg. m<sup>-3</sup> and 0.12 and 0.24 mg. m<sup>-3</sup> in the surface waters by Pillai *et al.* (2011) and Jha *et al.* (2012) respectively in comparison to 0.048 and 0.477 µg L<sup>-1</sup> in the present study.

Andaman Sea are very complex basins, with frequent cyclonic depressions, high precipitation and sea surface temperature, low surface salinity (Ramaraju *et al.*, 1981; Murthy *et al.*, 2000; Shenoi *et al.*, 2002; Pankajakshan *et al.*, 2002; Vinayachandran *et al.*, 2002; Jayu and Prasannakumar, 2006). These analyses require long-term observations, which are scarce, and the regime shifts in question are often not recognized until years or decades after the event. A better understanding of the mechanisms linking climate to the ecosystem response will facilitate identification of

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regime shifts and may improve management responses to climate-induced changes in the ecosystem.



**COMMUNITY STRUCTURE OF MESOZOOPLANKTON****4.1. Introduction**

The mesozooplankton are heterotrophic plankton with size range of 0.2 to 20mm, represented by diverse assemblage of organisms of both holoplankton and meroplankton that are important secondary producers in marine pelagic ecosystem. Mesozooplankton assumes a pivotal ecological role in structuring the marine ecosystem (Verity and Smetacek, 1996; Kiørboe, 1997), including those in the food chain and the matter transfer, from the primary producers to higher trophic level. They transfer organic matter by feeding in surface and producing sinking faecal pellets (Fowler and Knauer, 1986; Small *et al.*, 1989; Altabet and Small, 1990; Banse, 1995). The normal vertical migration of zooplankton also has a significant role in vertical flux by consuming organic particles in the surface waters at night and metabolizing the ingested food below the mixed layer during the day (Zhang and Dam, 1997; Longhurst and Harrison, 1988) because of upward vertical migration (VM) around dusk and downward VM around dawn.

The Andaman and Nicobar Islands are endowed with invaluable diversity of marine fauna. Andaman Sea is considered as oligotrophic sea (Qazim and Anzari, 1981), although it has been found to have substantial production of zooplankton in the coastal waters (Marichamy, 1983). Although, coastal areas are more accessible, research has been scarcely focused on these regions and around the oceanic islands (Conway, 2005). Most studies on zooplankton were carried out at offshore regions from various scientific cruises (Rao and Griffiths, 1998). The oceanic species of zooplankton and their distribution have been well described compared to that of the coastal species from Indian Ocean (Conway, 2005). In addition, the continuous monitoring of zooplankton biomass in the neritic regime of the Andaman and Nicobar Islands have been the neglected subject of Indian Ocean plankton research. Studies on biological features especially zooplankton of Andaman Sea, northeast Indian Ocean are mainly limited to oceanic regions. The knowledge on spatio-temporal distribution and variation of major component of mesozooplankton, i.e. copepods has been meager and less informative due to the remoteness of these islands from mainland part of the Indian subcontinent.

Generally, in the productive waters, the primary productions by net phytoplankton are transferred to higher trophic levels through mesozooplankton.

Whereas, in oligotrophic waters, the primary productions are channeled up by microbial food web are in turn transferred to nektons by mesozooplankton. The quantity and quality of zooplankton has a profound impact on the larval development of fishes and thus affects the fishery production and economy of marine system. So it is essential to estimate the quality and quantity of mesozooplankton in any pelagic waters. The major aim of the present study is to evaluate the status of mesozooplankton and copepod community in the coastal waters of South Andaman. Additionally, distribution patterns of different taxa in the neritic waters of Andaman Sea are discussed in relation to hydrographic regime in this highly dynamic coastal region, also a transition zone that receives huge water from the Pacific Ocean.

## **4.2. Results**

### **4.2.1. Biodiversity and composition of zooplankton**

The mesozooplankton samples collected by using a plankton net of 200 $\mu$ m mesh size and analyzed from the coastal stations of South Andaman Islands during month January 2012 and April 2014. A total of 29 taxa recorded which one unidentified group. The mesozooplankton taxa comprised of copepods, chaetognaths, appendicularians, ascidian tadpole larvae, thaliaceans, hydrozoans, narcomedusas, siphonophores, foraminiferans, amphipods, isopods, mysids, cumaceans, cirripedes, stomatopods, lucifers, ostracods, decapod larvae, gastropod veliger, bivalve veliger, polychaete larvae, pluteus larvae, bipinnaria larvae, bryozoan larvae, fish eggs and larvae, crustacean nauplii, flatworm and unidentified groups (Table 4.1) belonged to 10 phyla namely Cnidaria, Chordata, Echinodermata, Chaetognatha, Arthropoda, Bryozoa, Annelida, Mollusca, Platyhelminthes and Retaria (Appendix I).

### **4.2.2. Mesozooplankton density and percentage composition**

Overall, a total average of  $4155.1 \pm 1196.0$  ( $\bar{x} \pm SD$ ,  $n = 128$ ) individuals per cubic meter of zooplanktons were found in the present study. A large proportion of mesozooplankton abundance was contributed by copepods (66.0%) with total average of  $2744.3 \pm 474.1$  ind. $m^{-3}$  followed by crustacean nauplii (7.7%), gastropod veliger larvae (6.0%), bivalve veliger larvae (4.6%), appendicularians (4.3%), other decapod larvae (2.9%) and chaetognaths (1.6%) with an average density of  $65.9 \pm 29.9$  ind. $m^{-3}$  to  $320.8 \pm 143.3$  ind. $m^{-3}$ . Other zooplankton groups contributed less than 1% to the total abundance with an average density between  $1.0 \pm 0.7$  ind. $m^{-3}$  and  $35.8 \pm 40.1$  ind. $m^{-3}$ .

**Appendix I List of mesozooplankton taxa collected in the study area.**

Kingdom Animalia Linnaeus, 1758

Phylum Cnidaria Hatschek, 1888

Class Hydrozoa Owen, 1843

Order Narcomedusae Haeckel, 1879

Order Siphonophorae Eschscholtz, 1829

Phylum Chordata Haeckel, 1874

Fish eggs

Fish larvae

Subphylum Tunicata Lamarck, 1816

Class Appendicularia Lahille, 1980

Family Fritillariidae Seeliger, 1895

*Fritillaria* sp.

Family Oikopleuridae Lahille, 1987

*Oikopleura* sp.

Class Ascidiacea Blainville, 1824

Ascidian tadpole larvae

Class Thaliacea Nielsen, 1995

Order Doliolida Delage and Hérouard, 1898

*Doliolum* sp.

Order Salpida Forbes, 1853

*Salpa* sp.

Phylum Echinodermata (Klein, 1734)

Pluteus larvae

Bipinnaria larvae

Phylum Chaetognatha Leuckart 1854

Family Krohnittidae Tokioka 1965

Genus *Krohnitta* Ritter-Zahony 1910

*Krohnitta* sp.

Family Sagittidae Claus and Groben 1905

Genus *Sagitta* Quoy and Gaimard 1827

*Sagitta* sp.

Genus *Aidanosagitta* Tokioka and Pathansali 1965

*Aidanosagitta* sp.

Community structure of mesozooplankton

Genus *Ferosagitta* Kassatkina 1971

*Ferosagitta* sp.

Genus *Flaccisagitta* Tokioka 1965

*Flaccisagitta* sp.

Genus *Pseudosagitta* Germain and Joubin 1912

*Pseudosagitta* sp.

Genus *Zonosagitta* Tokioka 1965

*Zonosagitta* sp.

Family Pterosagittidae Tokioka 1965

Genus *Pterosagitta* Costa 1969

*Pterosagitta* sp.

Phylum Arthropoda von Siebold, 1848

Subphylum Crustacea Brünnich, 1772

Crustacean nauplius

Class Maxillopoda Dahl, 1956

Subclass Copepoda Milne-Edwards, 1840

Class Maxillopoda Dahl, 1956

Subclass Thecostraca Gruvel, 1905

Infraclass Cirripedia Burmeister, 1834

Class Ostracoda Latreille, 1802

Class Malacostraca Latreille, 1802

Subclass Hoplocarida Calman, 1904

Order Stomatopoda Latreille, 1817

Subclass Eumalacostraca Grobben, 1892

Superorder Peracarida Calman, 1904

Order Mysida Haworth, 1825

Order Amphipoda Latreille, 1816

Order Isopoda Latreille, 1817

Order Cumacea Kroyer, 1846

Superorder Eucarida Calman, 1904

Order Decapoda Latreille, 1802

Family Luciferidae de Haan, 1849

*Lucifer* sp.

Phylum Bryozoa Ehrenberg, 1831

## Community structure of mesozooplankton

### Cyphonautes larvae

Phylum Annelida Lamarck, 1809

Class Polychaeta Grube, 1850

Polychaete larvae

Phylum Mollusca Linnaeus, 1758

Class Gastropoda Cuvier, 1795

Gastropod veliger larvae

Class Bivalvia Linnaeus, 1758

Bivalve veliger larvae

Phylum Platyhelminthes Claus, 1887

Flatworms

Unranked Rhizaria Cavalier-Smith, 2002

Phylum Retaria Cavalier-Smith, 1999

Subphylum Foraminifera

### 4.2.3. Spatial variation of mesozooplankton

In almost all stations (except Junglighat (St.5)) the mesozooplankton comprised of 29 taxa and copepods dominated among other mesozooplankton with high relative abundance of 74.4% of copepods in Carbyn's Cove (St.2) followed by 67.9% at Chidiyatapu (St.4). Other zooplanktons include, crustacean nauplius dominated with 9.4% (Carbyn's Cove and Chattam (St.2 and St.3)), gastropods and bivalves with higher relative abundance of 8.3% (Burmanallah (St.1)) and 7.0% (Chattam (St.3)) respectively and lower in Carbyn's Cove (St.2) (3.6% and 2.7% respectively), appendicularians contributed with 6.0% in Junglighat (St.5) and 5.3% in Chattam (St.4) followed by decapod larva with 4.0% and 3.9% in Chidiyatapu (St.4) and Junglighat (St.5) respectively, chaetognaths in Junglighat (St.5) (2.6%) and cirripedes with 2.1% in Burmanallah (St.1) (Fig. 4.1 and Table 4.1).

#### 4.2.3.1. Burmanallah (St.1)

Mesozooplankton comprised of 29 taxa, dominated by copepods (66%) with mean abundance of  $2259.5 \pm 1220.9$  (n=28) followed by gastropod veliger larva (8.3%) with  $280.5 \pm 522.8$  (n=28), bivalve veliger larva (5.9%) with  $199.0 \pm 284.9$  (n=28), crustacean nauplius (4.0%) with  $136.1 \pm 122.1$  (n=28), decapod larva (2.1%), Cirripedes (2.1%), appendicularians (1.8%), chaetognaths (1.5%) and foraminifera (1.3%) and other groups such as polychaete larva and fish eggs were about 0.8% trailed by ostracods

(0.7%), Isopods (0.6%), amphipods (0.5%), siphonophores and lucifers (0.4%). The remaining groups such as thaliaceans, pluteus larva, bipinnaria larva, fish larva, ascidacean tadpole larva, hydromedusa, narcomedusa, mysids, cumaceans, stomatopods, bryozoan larva and flat worms were least encountered with 0.2 to 0.1%.

#### **4.2.3.2. Carbyn's cove (St.2)**

In Carbyn's Cove all 29 taxa were found and dominated by copepods with mean abundance of  $3245.7 \pm 1708.6$  (n=28) contributed 74% to total zooplankton population followed by crustacean nauplius (9.4%) with  $409.8 \pm 444.0$  (n=28), gastropod veliger larva (3.6%) with  $156.4 \pm 253.7$  (n=28), appendicularians (2.8%) with  $121.9 \pm 116.3$  (n=28), bivalve veliger larva (2.7%) with  $116.1 \pm 320.4$  (n=28), decapod larva (2.1%), chaetognaths (0.9%), pluteus larva (0.7%) and foraminifera (0.5%) and other groups such as isopods, ostracods and fish eggs contributed 0.3% to total zooplankton. The remaining groups such as thaliaceans, bipinnaria larva, siphonophores, lucifers, fish larva, ascidacean tadpole larva, hydromedusa, narcomedusa, amphipods, mysids, Cumaceans, Stomatopods, cirripedes, bryozoan larva and flat worms were least with relative abundance up to 0.2%.

#### **4.2.3.3. Chattam (St.3)**

Mesozooplankton in Chattam were dominated by copepods (60.7%) with mean abundance of  $3198.5 \pm 2595.2$  (n=28) followed by crustacean nauplius (9.4%) with  $496.0 \pm 262.0$  (n=28), gastropod veliger larva (7.0%) with  $366.1 \pm 331.3$  (n=28), bivalve veliger larva (6.9%) with  $362.4 \pm 466.8$  (n=28), appendicularians (5.3%) with  $281.0 \pm 250.1$  (n=28), decapod larva (2.3%), ostracods (2.0%), chaetognaths (1.4%) and siphonophores (1.0%). Other groups were polychaete larva (0.7%), isopods (0.6%), fish larva (0.5%), cirripedes (0.4%), lucifers (0.3%) and pluteus larva (0.3%) whereas the remaining groups namely, foraminifera, fish eggs, amphipods, thaliaceans, bipinnaria larva, ascidacean tadpole larva, hydromedusa, narcomedusa, mysids, cumaceans, stomatopods, bryozoan larva and flat worms were least encountered up to 0.2%.

#### **4.2.3.4. Chidiyatapu (St.4)**

Copepods were dominant (67.9%) with mean abundance of  $2290.3 \pm 722.3$  (n=16) followed by crustacean naupli (6.7%) with  $225.2 \pm 253.2$  (n=16), appendicularians (5.1%) with  $173.0 \pm 186.0$  (n=16), gastropod veliger larva (4.6%) with  $155.5 \pm 106.3$  (n=16), decapod larva (4.0%) with  $134.6 \pm 58.2$  (n=16), bivalve veliger larva (2.4%) with

#### Community structure of mesozooplankton

82.2±96.9 (n=16), chaetognaths (1.6%), foraminifera (1.5%), thaliaceans (1.1%), cirripedes (0.8%), and other groups such as fish eggs (0.6%), polychaete larva, siphonophores and Lucifer with 0.5% tailed by ostracods, isopods and amphipods with 0.4% and ascidacean tadpole larva (0.3%) to the total abundance. The remaining groups such as pluteus larva, bipinnaria larva, fish larva, hydromedusa, narcomedusa, mysids, cumaceans, stomatopods, bryozoan larva and flat worms were least encountered (0.2%).

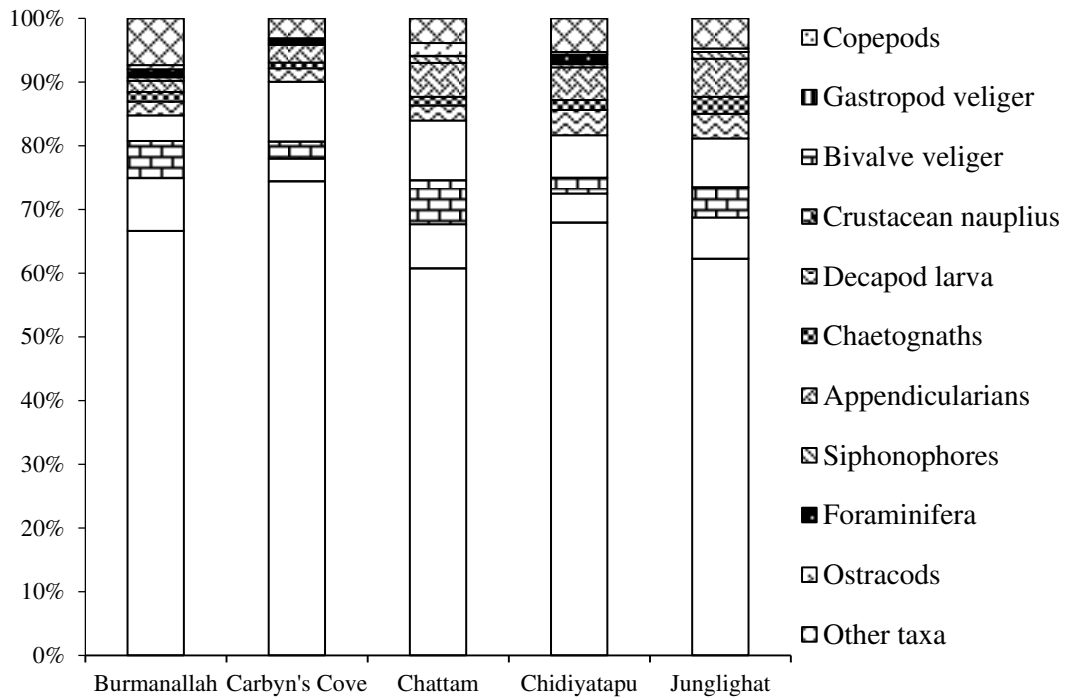
#### 4.2.3.5. Junglighat (St.5)

Mesozooplankton comprised of 26 taxa in Junglighat, dominated by copepods (62.2%) with mean abundance of 2727.4±1295 (n=28) followed by crustacean nauplius (7.7%) with 337.0±433.0 (n=28), gastropod veliger larva (6.5%) with 284.9±224.9 (n=28), appendicularians (6.0%) with 262.9±164.5 (n=28), bivalve veliger larva (4.7%) with 205.8±228.2 (n=28), decapod larva (3.9%) with 171.4±305.7 (n=28), chaetognaths (2.6%) with 115.2±117.6 (n=28), siphonophores (1.0%), fish eggs (0.9%) and polychaete larva (0.7%), ostracods, isopods and lucifers with 0.6%, cirripedes (0.4%), and fish larva (0.3%). Other groups such as foraminifera, amphipods, thaliaceans, pluteus larva, bipinnaria larva, ascidacean tadpole larva, hydromedusa, narcomedusa, mysids, stomatopods, bryozoan larva and were least encountered up to 0.2% whereas cumaceans and flat worms were absent in this region. The mesozooplankton community show significant difference among the stations in terms of assemblage structure (ANOSIM, Global R=0.205;  $p=0.001$ ). The pairwise tests indicates that all stations differed significantly in the assemblage of zooplankton except Burmanallah (St.1) and Chidiyatapu (St.4) (R=0.015;  $p=0.36$ ) (Table4.2).

**Table 4.1. Comparison of mean density, standard deviation and percentage composition of mesozooplankton for the entire study.**

Zooplankton	Burmanallah (St.1)		Carbyn's Cove (St.2)		Chattam (St.3)		Chidiyatapu (St.4)		Junglighat (St.5)	
	$\bar{X}\pm SD$ (n=28)	%	$\bar{X}\pm SD$ (n=28)	%	$\bar{X}\pm SD$ (n=28)	%	$\bar{X}\pm SD$ (n=16)	%	$\bar{X}\pm SD$ (n=28)	%
Copepods	2259.5±122.9	66.6	3245.7±1708.6	74.4	3198.5±2595.2	60.7	2290.3±722.3	67.9	2727.4±1295.3	62.2
Chaetognaths	51.7±54.4	1.5	38.8±41.5	0.9	71.2±55.7	1.4	52.7±42.3	1.6	115.2±117.6	2.6
Appendicularians	59.9±41.6	1.8	121.9±116.3	2.8	281.0±250.1	5.3	173.0±186.0	5.1	262.9±164.5	6.0
Ascidians	4.4±4.8	0.1	1.1±2.1	0.0	8.7±9.7	0.2	9.4±9.6	0.3	2.2±5.1	0.0
Thaliaceans	8.5±8.7	0.2	3.4±6.3	0.1	9.2±12.2	0.2	37.3±104.3	1.1	4.3±11.8	0.1
Hydrozoans	2.7±4.6	0.1	3.5±7.7	0.1	10.1±15.6	0.2	2.1±4.7	0.1	31.8±68.1	0.7
Narcomedusae	1.7±3.4	0.1	9.5±32.8	0.2	2.1±3.9	0.0	0.6±1.7	0.0	0.6±1.3	0.0
Siphonophores	18.2±15.4	0.5	10.5±18.0	0.2	55.1±74.2	1.0	16.3±16.2	0.5	45.3±57.3	1.0
Foraminiferans	42.6±93.8	1.3	21.8±33.6	0.5	3.8±5.7	0.1	51.2±50.5	1.5	1.1±2.8	0.0
Amphipods	18.6±32.8	0.5	3.2±5.1	0.1	9.1±11.4	0.2	14.8±13.5	0.4	4.3±8.7	0.1
Isopods	20.8±29.9	0.6	11.1±9.9	0.3	29.3±31.1	0.6	12.3±14.4	0.4	28.4±39.2	0.6
Mysids	2.2±2.0	0.1	1.5±1.7	0.0	1.7±2.2	0.0	1.7±1.7	0.1	1.1±1.4	0.0
Cumaceans	2.4±4.6	0.1	3.8±6.4	0.1	1.4±2.6	0.0	2.6±6.5	0.1	0.0±0.0	0.0
Cirripedes	71.6±123.9	2.1	10.7±14.7	0.2	20.7±24.5	0.4	25.8±25.4	0.8	18.5±46.1	0.4
Stomatopods	2.9±8.6	0.1	0.4±2.3	0.0	1.3±3.2	0.0	2.6±3.4	0.1	0.5±1.3	0.0
Lucifers	12.5±18.1	0.4	5.9±7.5	0.1	15.9±20.2	0.3	17.0±17.7	0.5	26.6±69.2	0.6
Ostracods	22.4±28.0	0.7	12.5±20.1	0.3	106.8±254.1	2.0	12.8±16.7	0.4	24.6±49.2	0.6
Decapod larvae	72.2±45.7	2.1	91.1±84.9	2.1	123.0±161.1	2.3	134.6±58.2	4.0	171.4±305.7	3.9
Gastropod veliger	280.5±522.8	8.3	156.4±253.7	3.6	366.1±331.3	7.0	155.5±106.3	4.6	284.9±224.9	6.5
Bivalve veliger	199.0±284.9	5.9	116.1±320.4	2.7	362.4±466.8	6.9	82.2±96.9	2.4	205.8±228.2	4.7
Polychaete larvae	28.1±29.7	0.8	19.3±15.2	0.4	38.0±47.2	0.7	15.8±14.2	0.5	32.8±34.5	0.7
Pluteus larvae	6.8±9.2	0.2	29.5±100.8	0.7	13.8±32.5	0.3	2.3±3.3	0.1	1.1±5.9	0.0
Bipinnaria larvae	5.4±10.4	0.2	1.1±2.8	0.0	1.4±3.2	0.0	6.6±13.0	0.2	0.8±1.9	0.0
Bryozoan larvae	4.6±5.6	0.1	8.1±27.3	0.2	2.1±3.4	0.0	2.7±2.9	0.1	1.5±2.6	0.0
Fish eggs	26.6±20.3	0.8	12.3±17.0	0.3	26.6±32.0	0.5	19.3±14.9	0.6	39.8±49.4	0.9
Fish larvae	5.7±9.3	0.2	3.4±4.5	0.1	8.5±11.4	0.2	3.3±4.1	0.1	12.7±24.2	0.3
Crustacean nauplii	136.1±122.1	4.0	409.8±444.0	9.4	496.0±262.0	9.4	225.2±253.2	6.7	337.0±433.0	7.7
Flatworm	1.3±3.0	0.0	1.0±2.2	0.0	1.8±2.8	0.0	0.9±2.0	0.0	0.0±0.0	0.0
Unidentified	22.6±31.6	0.7	8.0±8.8	0.2	2.1±3.3	0.0	1.8±2.3	0.1	0.0±0.0	0.0





**Fig. 4.1. Relative abundance of mesozooplankton at different stations in the study area.**

**Table 4.2. Pairwise test of ANOSIM based on mesozooplankton data from different stations. Values of the R-statistic and corresponding *p* levels are indicated.**

Stations	Burmanallah (St.1)	Carbyn's Cove (St.2)	Chattam (St.3)	Chidiyatapu (St.4)	Junglighat (St.5)
Burmanallah (St.1)		**	**	NS	**
Carbyn's Cove (St.2)	0.196		**	*	**
Chattam (St.3)	0.258	0.253		**	**
Chidiyatapu (St.4)	0.015	0.107	0.206		**
Junglighat(St.5)	0.32	0.224	0.13	0.284	

\*\**p*=0.001; \**p*=0.05; NS: not significant

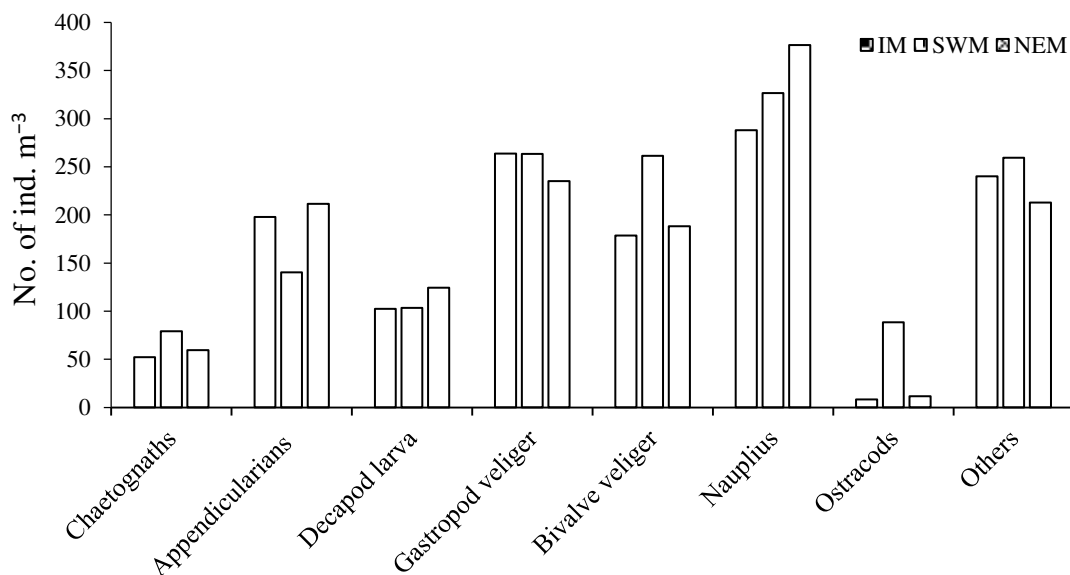
#### 4.2.4. Seasonal variation of mesozooplankton

Among the mesozooplankton, different groups were found to be dominating at different seasons, chaetognaths, bivalve veliger and ostracods were dominant during southwest monsoon (May-September) while appendicularians, decapod larvae and crustacean nauplii were dominated during northeast monsoon (October-December) season (Fig. 4.2). Seasonally the copepods were higher during inter monsoon (January-

### Community structure of mesozooplankton

April) period with  $3022.11 \pm 2156.24 \text{ ind. m}^{-3}$  followed by southwest monsoon with  $2643.96 \pm 1213.42 \text{ ind. m}^{-3}$  (Table 4.3). Monthly variation of copepod and mesozooplankton density are depicted in the figures 4.3 and 4.4 respectively. Although, the density varied between monthly collection, statistically no significance or clear pattern of seasonal variation was found neither with copepods nor mesozooplankton groups (one-way ANOVA,  $p > 0.05$ ). However from the Fig. 4.3, a peak in the copepod density was found during the month of April 2013 at Chattam (St.3) ( $14003.8 \text{ ind. m}^{-3}$ ) and Junglighat (St.5) ( $6520.2 \text{ ind. m}^{-3}$ ). In Burmanallah (St.1) and Carbyn's Cove (St.2), the average copepod density was found to be  $2259.5 \pm 1220.9 \text{ ind. m}^{-3}$  and  $3245.7 \pm 1708.6 \text{ ind. m}^{-3}$  respectively, with peak density during January'12 ( $6934.8 \text{ ind. m}^{-3}$ ) and April ( $6177.3 \text{ ind. m}^{-3}$ ) and August'13 ( $6813.0 \text{ ind. m}^{-3}$ ) in Carbyn's Cove while in Burmanallah, density was higher during January ( $4391.4$ ), June ( $3880.7 \text{ ind. m}^{-3}$ ) and October ( $4052.2 \text{ ind. m}^{-3}$ ) 2012 and in October'13 ( $5235.5 \text{ ind. m}^{-3}$ ).

Overall, the zooplankton groups namely chaetognaths, ostracods, isopods and fish eggs and larvae were relatively abundant during southwest monsoon whereas, foraminifera, amphipods, cumaceans, polychaete larva, bipinnaria larva and flat worm were higher during inter monsoon period. While, some groups such as narcomedusae, stomatopods, bryozoan larva, pluteus larva, gastropod veliger and bivalve veliger were dominant during inter monsoon and southwest monsoon and decapod larvae, appendicularians and nauplius were dominant during northeast monsoon period.



**Fig. 4.2. Seasonal variation of major zooplankton groups in the study area. IM: Inter monsoon; SWM: Southwest monsoon; NEM: Northeast monsoon.**

Community structure of mesozooplankton

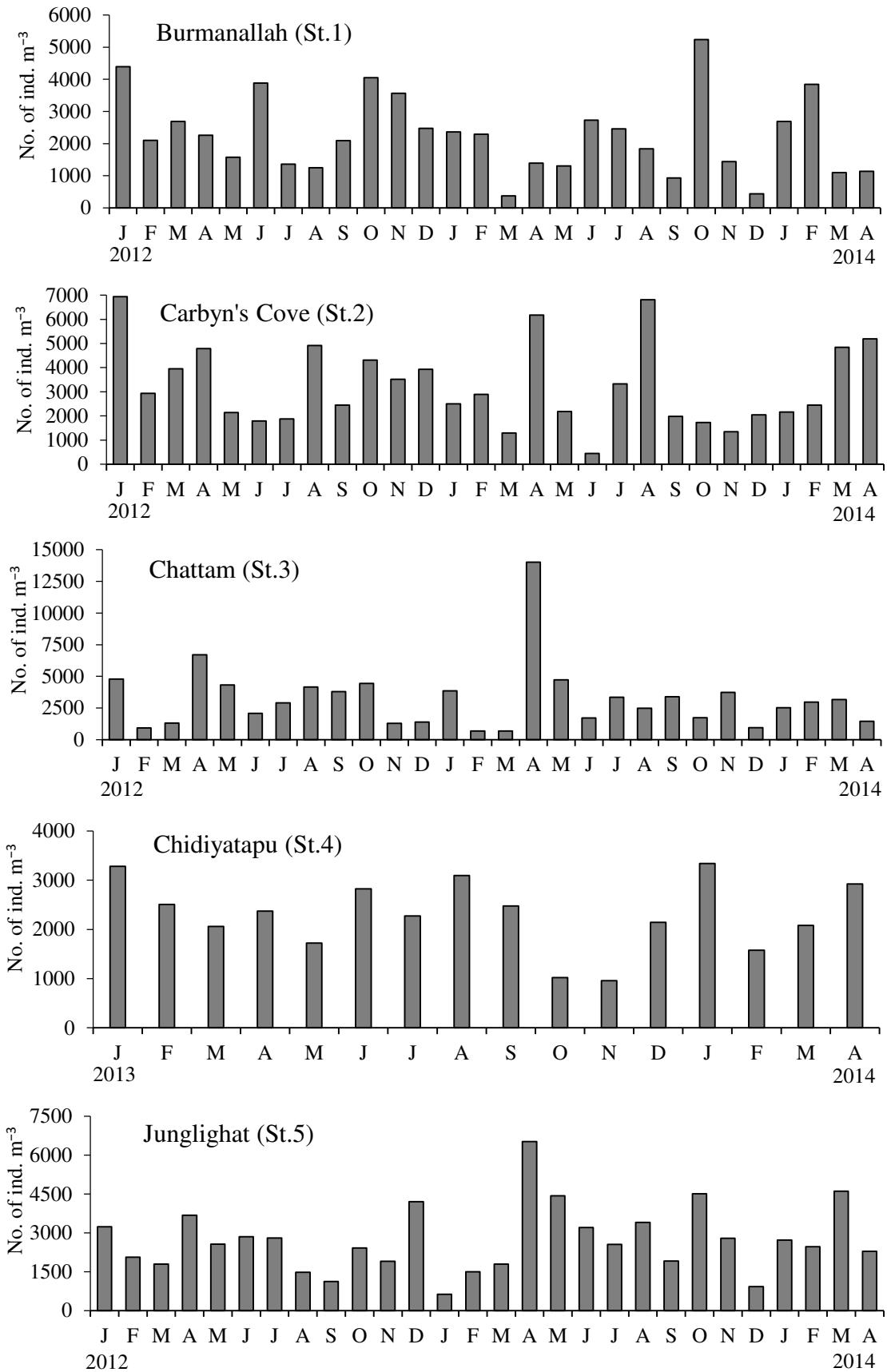
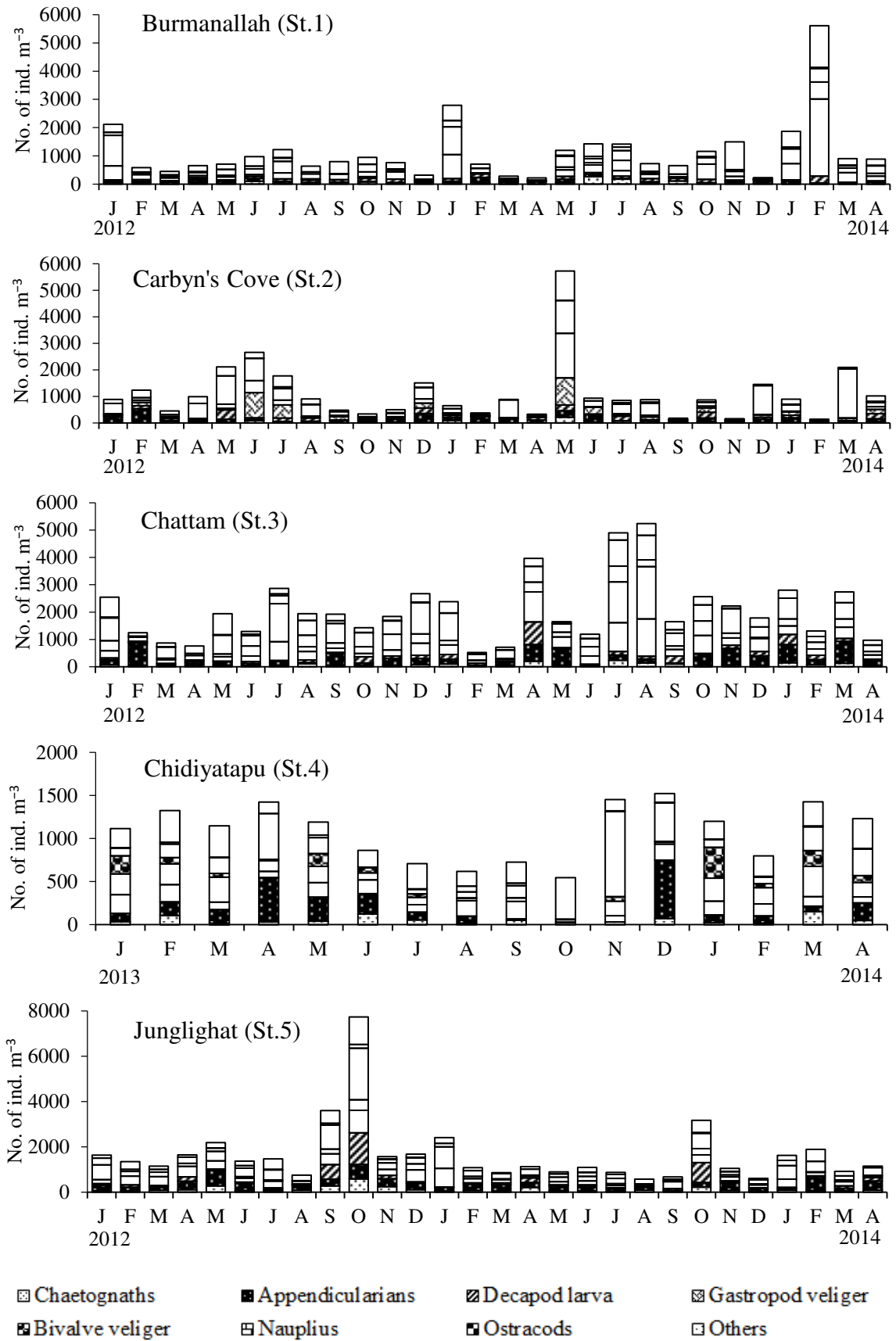


Fig. 4.3. Monthly variation of copepod density in the study area.

Community structure of mesozooplankton



**Fig. 4.4. Monthly variation of major zooplankton groups, except for copepods, in the study area.**

**Table 4.3. Seasonal variation of mesozooplankton groups in the study area.**

<b>Mesozooplankton</b>	<b>IM</b>	<b>SWM</b>	<b>NEM</b>
Copepods	3022.11±2156.24	2643.96±1213.42	2536.89±1390.99
Chaetognaths	52.14±47.04	79.17±70.98	59.40±55.52
Appendicularians	197.70±194.73	140.19±152.33	211.56±206.14
Ascidacean tadpole	5.18±7.41	4.57±7.81	4.07±6.09
Thaliaceans	10.18±12.25	5.06±7.78	18.85±81.86
Hydromedusae	14.28±46.32	8.22±23.98	8.77±16.45
Narcomedusae	2.39±8.30	5.43±24.79	0.90±2.01
Siphonophores	29.46±32.57	28.94±59.76	25.72±29.22
Foraminiferans	31.43±71.23	15.74±30.09	11.52±31.14
Amphipods	11.65±24.88	8.97±10.11	4.66±9.55
Isopods	14.22±23.22	28.61±36.22	20.54±16.90
Mysids	1.74±1.80	1.44±1.81	1.80±1.98
Cumaceans	2.52±5.49	1.88±4.44	1.07±2.22
Cirripedes	27.84±69.86	26.45±33.46	31.30±90.51
Stomatopods	1.29±2.89	2.22±7.09	0.49±1.46
Lucifers	8.38±11.79	19.21±22.94	17.93±63.79
Ostracods	8.21±14.40	88.22±202.55	11.41±11.48
Decapod larvae	102.49±120.96	103.37±108.71	124.18±165.43
Gastropod veliger	263.58±401.78	263.16±303.40	235.01±239.26
Bivalve veliger	178.37±257.09	261.25±450.64	188.22±262.39
Polychaete larvae	32.28±40.83	24.18±24.37	25.14±24.09
Pluteus larvae	5.83±16.93	20.11±79.07	8.88±30.55
Bipinnaria larvae	4.06±8.83	2.59±7.05	0.21±0.79
Bryozoan larvae	2.81±3.92	6.36±21.63	1.65±4.22
Fish eggs	19.03±18.37	33.00±32.72	17.97±16.59
Fish larvae	6.17±8.91	8.74±16.09	2.87±4.45
Crustacean nauplii	287.85±302.80	326.48±288.26	376.44±373.27
Flat worm	1.49±2.86	0.52±1.58	0.84±1.98
Unidentified	7.68±14.77	6.90±13.60	7.56±26.66

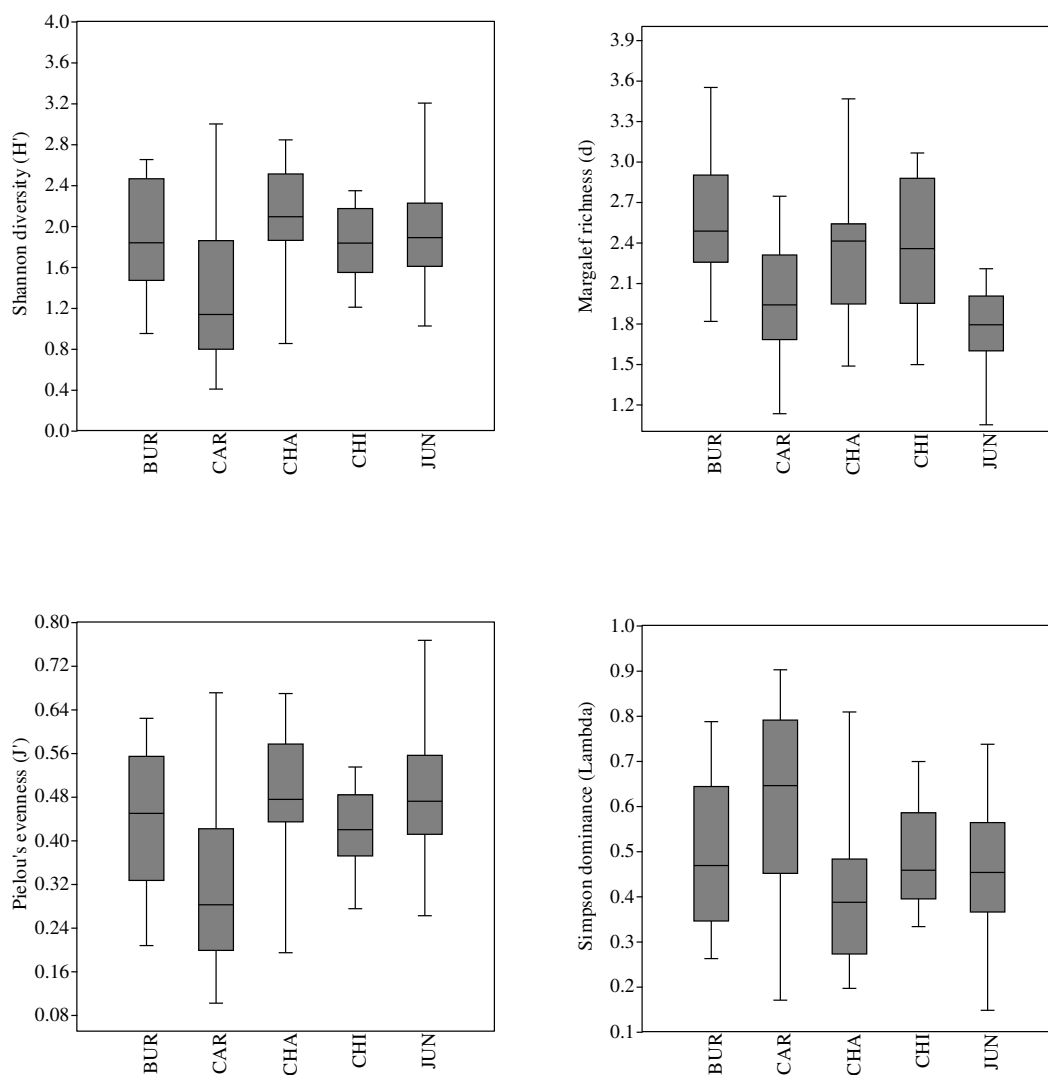
IM: Inter monsoon; SWM: Southwest monsoon; NEM: Northeast monsoon

#### 4.2.5. Mesozooplankton diversity

The average values of Shannon diversity ( $H'$ ) and number of individuals ( $N$ ) were found to be higher in the Chattam (St.3) followed by Junglighat (St.5) (Table 4.4). While, the average richness value ( $2.571 \pm 0.410$ ;  $n=28$ ) and number of taxa ( $21.43 \pm 3.13$ ;  $n=28$ ) was maximum in Burmanallah (St.1) followed by Chidiyatapu (St.4) and Chattam (St.3) respectively. The lowest number of taxa was found in Junglighat (St.5) followed by Carbyn's Cove (St.2) with  $15.82 \pm 2.31$  ( $n=28$ ) and  $17.21 \pm 3.82$  ( $n=28$ ) respectively (Table 4.4). Shannon diversity index showed that the

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occurrence of mesozooplankton was maximum in the Chattam ( $2.095 \pm 0.453$ ,  $n=28$ ) and ranged from 0.851 to 2.842, followed by Junglighat ( $1.922 \pm 0.535$ ,  $n=28$ ) and Burmanallah ( $1.900 \pm 0.546$ ,  $n=28$ ; Fig. 4.5). The Pielou's evenness ( $J'$ ) index was maximum in the station Junglighat ( $0.848 \pm 0.129$ ,  $n=28$ ) followed by the Chattam ( $0.482 \pm 0.103$ ,  $n=28$ ). In Carbyn's Cove, all diversity indices were found to be least, except the Simpson dominance (Lambda) index (Fig. 4.5). The average dominance index was maximum in Carbyn's Cove ( $0.610 \pm 0.217$ ,  $n=28$ ) followed by Burmanallah ( $0.494 \pm 0.160$ ,  $n=28$ ).



**Fig. 4.5. Variation in zooplankton groups (a) diversity, (b) richness, (c) evenness, (d) dominance in the study area. BUR: Burmanallah; CAR: Carbyn's Cove; CHA: Chattam; CHI: Chidiyatapu; JUN: Junglighat.**

**Table 4.4. Variation in the zooplankton diversity (Mean  $\pm$  SD) in the study stations.**

Stations	Diversity indices					
	S	N	H'(log <sub>2</sub> )	d	J'	Lambda
Burmanallah (St.1)	21.43 $\pm$ 3.13	3391.5 $\pm$ 1914.6	1.900 $\pm$ 0.546	2.571 $\pm$ 0.410	0.431 $\pm$ 0.123	0.494 $\pm$ 0.160
Carbyn's Cove (St.2)	17.21 $\pm$ 3.82	4361.4 $\pm$ 1890.9	1.371 $\pm$ 0.702	1.953 $\pm$ 0.427	0.333 $\pm$ 0.159	0.610 $\pm$ 0.217
Chattam (St.3)	20.71 $\pm$ 3.45	5267.5 $\pm$ 3181.5	2.095 $\pm$ 0.453	2.354 $\pm$ 0.441	0.482 $\pm$ 0.103	0.397 $\pm$ 0.142
Chidiyatapu (St.4)	20.44 $\pm$ 4.11	3372.8 $\pm$ 788.1	1.833 $\pm$ 0.326	2.395 $\pm$ 0.473	0.424 $\pm$ 0.071	0.490 $\pm$ 0.103
Junglighat (St.5)	15.82 $\pm$ 2.31	4382.4 $\pm$ 1833.8	1.922 $\pm$ 0.535	1.785 $\pm$ 0.270	0.848 $\pm$ 0.129	0.456 $\pm$ 0.153

S: number of species; N: number of individuals; d: Margalef richness; J': Peilou's evenness; H'(log<sub>2</sub>): Shannon diversity; Lambda: Shannon dominance.

#### 4.2.6. Zooplankton biomass

The zooplankton biomass in terms of displacement volume and wet weight was found to be higher at Chattam (St.3) (0.381 $\pm$ 0.252 ml. m<sup>-3</sup> and 295.4 $\pm$ 174.4 mg. m<sup>-3</sup>) followed by Junglighat (St.5) (0.318 $\pm$ 0.263 ml. m<sup>-3</sup> and 233.3 $\pm$ 189.8 mg. m<sup>-3</sup>) while the dry weight biomass was recorded maximum at Carbyn's Cove (St.2) (22.7 $\pm$ 36.4 mg. m<sup>-3</sup>) followed by Chattam (St.3) (20.6 $\pm$ 9.9 mg. m<sup>-3</sup>) (Table 4.5).

##### 4.2.6.1. Displacement volume biomass

The displacement volume of mixed zooplankton ranged from 0.059 ml/m<sup>3</sup> to 0.655 ml/m<sup>3</sup> at Burmanallah (St.1), 0.086 ml/m<sup>3</sup> to 0.611 ml/m<sup>3</sup> at Carbyn's Cove (St.2), 0.102 ml/m<sup>3</sup> to 0.869 ml/m<sup>3</sup> at Chattam (St.3), 0.088 ml/m<sup>3</sup> to 0.484 ml/m<sup>3</sup> at Chidiyatapu (St.4) and 0.073 ml/m<sup>3</sup> to 1.164 ml/m<sup>3</sup> at Junglighat (St.5) (Table 4.5). The average biomass was found to be maximum during the inter monsoon season at Burmanallah (0.275 $\pm$ 0.202 ml/m<sup>3</sup>) and Junglighat (0.386 $\pm$ 0.349 ml/m<sup>3</sup>). In Carbyn's Cove and Chidiyatapu, the higher biomass was recorded during southwest monsoon season with 0.276 $\pm$ 0.226 ml/m<sup>3</sup> and 0.331 $\pm$ 0.111 ml/m<sup>3</sup> respectively while at Chattam (0.517 $\pm$ 0.325 ml/m<sup>3</sup>) during northeast monsoon season.

##### 4.2.6.2. Wet weight biomass

The wet weight biomass of mixed zooplankton ranged from 55.3 to 583.1 mg/m<sup>3</sup> at Burmanallah (St.1), 43.3 mg/m<sup>3</sup> to 669.8 mg/m<sup>3</sup> at Carbyn's Cove (St.2), 85.4 mg/m<sup>3</sup> to 597.3 mg/m<sup>3</sup> at Chattam (St.3), 75.0 mg/m<sup>3</sup> to 347.7 mg/m<sup>3</sup> at Chidiyatapu

(St.4) and 79.9 to 850.8 mg/m<sup>3</sup> at Junglighat (St.5) (Table 4.5). In similar to displacement volume, the average maximum in wet weight was found during inter monsoon season at Burmanallah and Junglighat with 236.5±185.2 mg/m<sup>3</sup> and 264.9±260.3 mg/m<sup>3</sup> respectively. In Carbyn's Cove and Chidiyatapu, the higher biomass was recorded during southwest monsoon season with 271.4±266.7 mg/m<sup>3</sup> and 242.2±80.4 mg/m<sup>3</sup> respectively while at Chattam (355.3±194.8 mg/m<sup>3</sup>) during northeast monsoon season.

#### **4.2.6.3. Dry weight biomass**

The dry weight biomass of mixed zooplankton ranged from 3.7 to 49.7 mg/m<sup>3</sup> at Burmanallah and 4.0 to 37.4 mg/m<sup>3</sup> at Junglighat (Table 4.5). The average biomass was found to be maximum during the inter monsoon season at both the stations with 23.1±17.3 mg/m<sup>3</sup> at Burmanallah and 16.0±10.1 mg/m<sup>3</sup> at Junglighat. However in other stations such as Carbyn's Cove, Chattam and Chidiyatapu, the biomass ranged from 3.6 to 152.0 mg/m<sup>3</sup>, 2.3 to 32.1 mg/m<sup>3</sup> and 6.1 to 39.9 mg/m<sup>3</sup> respectively, in addition, the higher biomass was recorded during southwest monsoon season with 44.7±71.6 mg/m<sup>3</sup>, 22.9±9.9 mg/m<sup>3</sup> and 22.4±12.3 mg/m<sup>3</sup> at Carbyn's Cove, Chattam and Chidiyatapu respectively.

#### **4.2.6.4. Elemental composition of zooplankton from Chattam (St.3)**

Carbon content varied from 35-62% of dry weight (DW) and maximum Carbon was recorded during September 2013 due to the abundance of copepods in this area (St.3: Chattam). Hydrogen content varied from 1.8-3.1% of DW. Nitrogen content varied from 3.5-6.5% of DW. It showed similar trend as that of Carbon content (Table 4.6).

#### **4.2.7. Relationship between zooplankton with Chlorophyll *a* and other environmental parameters**

Negative correlation was observed between Chlorophyll *a* and zooplankton density in Burmanallah and Chidiyatapu. In addition, the relationship of Chl *a* with biomass of mesozooplankton in terms of displacement volume, wet weight and dry weight were also negative in both the stations. However the correlation was moderate and significant at Burmanallah ( $r = -0.661$ ;  $p < 0.05$ ) whereas in Chidiyatapu it was very weak ( $r = -0.025$ ) (Table 4.10). Further, the relationship showed no significant relation



between Chl *a* and zooplankton density and were very weak in rest of the stations. The figure 4.6 also shows the similar results. Here, the value of Chl *a* were least during the peak in the density of zooplankton and copepods at Burmanallah (Fig. 4.6a).

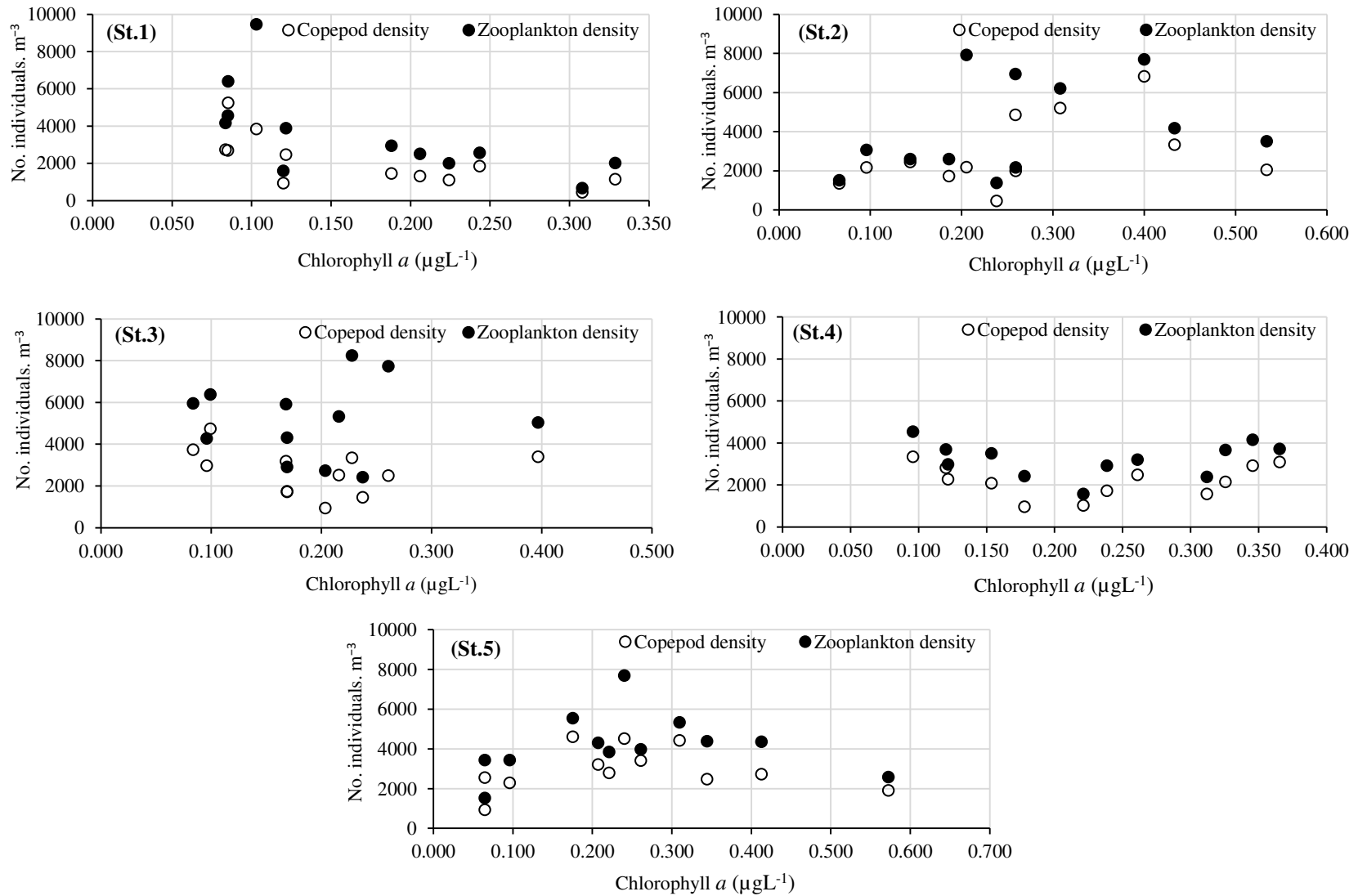
The correlation between environmental parameters and density and biomass of zooplankton were weak in Burmanallah (St.1) (Table 4.7). In Carbyn's Cove (St.2) the density was moderately correlated with all parameters except salinity, while positive with temperature and negative with pH and DO. In addition, the biomass values showed moderately negative correlation with pH (Table 4.8). A strong negative correlation ( $r = -0.767$ ;  $p < 0.01$ ;  $n = 12$ ) was found between density and DO whereas moderately positive correlation with salinity in Chidiyatapu (St.4) (Table 4.10). However, in Chattam (St.3) both density and biomass showed moderately positive correlation while in Junglighat (St.5) the density moderately negative correlation with DO ( $r = -0.409$ ;  $p > 0.05$ ) and salinity ( $r = -0.362$ ;  $p > 0.05$ ) (Tables 4.9 and 4.11).

**Table 4.5. The range of mesozooplankton biomass at different stations.**

Stations	Displacement Volume (ml.m <sup>-3</sup> )		Wet Weight (mg.m <sup>-3</sup> )		Dry Weight (mg.m <sup>-3</sup> )	
	Range	$\bar{X} \pm SD$	Range	$\bar{X} \pm SD$	Range	$\bar{X} \pm SD$
Burmanallah (St.1)	0.059-0.655	0.259±0.150	55.3-583.1	221.1±142.4	3.7-49.7	20.5±13.0
Carbyn's Cove (St.2)	0.086-0.611	0.215±0.166	43.3-669.8	195.7±164.8	3.6-152.0	22.7±36.4
Chattam (St.3)	0.102-0.869	0.381±0.252	85.4-597.3	295.4±174.4	2.3-32.1	20.6±9.9
Chidiyatapu (St.4)	0.088-0.484	0.300±0.092	75.0-347.7	214.2±69.6	6.1-39.9	18.9±8.2
Junglighat (St.5)	0.073-1.164	0.318±0.263	79.9-850.8	233.3±189.8	4.0-37.4	13.4±8.0

**Table 4.6. Density, biomass and elemental composition of mesozooplankton in Chattam (St.3).**

Percentage of dry weight			Zooplankton ind. m <sup>-3</sup>	Copepod ind. m <sup>-3</sup>	Dry weight
Carbon	Nitrogen	Hydrogen			mg. m <sup>-3</sup>
49	5	2.4	6380.2	4732.3	16.15
56	5.8	2.8	2910.2	1723.6	12.78
57	6	2.9	8247.9	3344.5	30.78
48	5	2.4	7736.3	2491.7	31.95
62	6.5	3.1	5039.9	3393.7	17.09
44	4.5	2.2	4306.8	1739.3	19.28
56.7	6	2.8	5956.2	3731.9	10.77
35	3.5	1.8	2730.9	943.6	28.66
53	5.5	2.7	5321.0	2516.3	26.89
52	5.6	2.6	4276.7	2970.3	2.25
39	4.1	2	5918.8	3178.6	32.10
53	5.5	2.7	2425.5	1457.7	8.34



**Fig. 4.6. Relationship between copepod and zooplankton density with chlorophyll *a* in the study area.**

**Table 4.7. Correlation between environmental parameters and biological parameters in Burmanallah (St.1).**

Burmanallah	SST	SSS	pH	DO	Chl <i>a</i>	Density	DV	WW	DW
SST	1								
SSS	0.176	1							
pH	0.292	0.259	1						
DO	-.639*	-0.054	-0.256	1					
Chl <i>a</i>	0.558	0.289	0.32	-0.347	1				
Zp. Density	-0.231	0.024	-0.035	-0.026	-.661*	1			
DV	-0.216	0.257	0.125	0.021	-.620*	.907**	1		
WW	-0.242	0.184	0.132	0.052	-.672*	.919**	.973**	1	
DW	-0.355	0.179	0.199	0.013	-.684*	.858**	.927**	.964**	1

\*. Correlation is significant at the 0.05 level.

\*\*.. Correlation is significant at the 0.01 level.

DV: displacement volume; WW: wet weight; DW: dry weight; Zp.: zooplankton

**Table 4.8. Correlation between environmental parameters and biological parameters in Carbyn's Cove (St.2).**

Carbyn's Cove	SST	SSS	pH	DO	Chl <i>a</i>	Density	DV	WW	DW
SST	1								
SSS	.116	1							
pH	-.103	-.060	1						
DO	-.645*	-.274	.050	1					
Chl <i>a</i>	.050	.413	-.416	-.250	1				
Zp. Density	.503	.204	-.371	-.472	.342	1			
DV	.269	-.218	-.458	-.005	-.178	.225	1		
WW	.234	-.195	-.459	.041	-.158	.302	.974**	1	
DW	.214	-.197	-.339	.084	-.131	.492	.715**	.847**	1

\*. Correlation is significant at the 0.05 level.

\*\*.. Correlation is significant at the 0.01 level.

DV: displacement volume; WW: wet weight; DW: dry weight; Zp.: zooplankton

**Table 4.9: Correlation between environmental parameters and biological parameters in Chattam (St.3).**

Chattam	SST	SSS	pH	DO	Chl <i>a</i>	Density	DV	WW	DW
SST	1								
SSS	.380	1							
pH	-.028	.211	1						
DO	-.251	.063	-.146	1					
Chl <i>a</i>	-.179	-.003	-.471	.453	1				
Zp. Density	.233	.248	-.033	.461	.031	1			
DV	-.169	.249	.061	.433	.173	.002	1		
WW	-.026	.259	.074	.468	.199	.209	.952**	1	
DW	.087	.132	-.114	.440	.343	.504	.734**	.856**	1

\*. Correlation is significant at the 0.05 level.

\*\*.. Correlation is significant at the 0.01 level.

DV: displacement volume; WW: wet weight; DW: dry weight; Zp.: zooplankton

**Table 4.10. Correlation between environmental parameters and biological parameters in Chidiyatapu (St.4).**

Chidiyatapu	SST	SSS	pH	DO	Chl <i>a</i>	Density	DV	WW	DW
SST	1								
SSS	-.316	1							
pH	-.428	.660*	1						
DO	-.019	-.200	.037	1					
Chl <i>a</i>	.333	-.194	-.270	-.005	1				
Zp. Density	.012	.416	-.085	-.767**	-.025	1			
DV	.240	-.256	-.180	-.111	-.307	.250	1		
WW	.029	-.144	-.060	-.252	-.371	.447	.867**	1	
DW	.305	-.087	-.212	-.399	-.366	.492	.727**	.709**	1

\* . Correlation is significant at the 0.05 level.

\*\* . Correlation is significant at the 0.01 level.

DV: displacement volume; WW: wet weight; DW: dry weight; Zp.: zooplankton

**Table 4.11. Correlation between environmental parameters and biological parameters in Junglighat (St.5).**

Junglighat	SST	SSS	pH	DO	Chl <i>a</i>	Density	DV	WW	DW
SST	1								
SSS	-.414	1							
pH	-.352	.079	1						
DO	-.604*	.420	.164	1					
Chl <i>a</i>	-.361	.603*	-.282	.130	1				
Zp. Density	.255	-.362	-.290	-.409	.083	1			
DV	.071	-.071	.112	-.241	-.063	.206	1		
WW	-.025	-.063	.035	-.207	-.034	.247	.973**	1	
DW	.133	-.130	.031	-.344	-.095	.395	.923**	.957**	1

\* . Correlation is significant at the 0.05 level.

\*\* . Correlation is significant at the 0.01 level.

DV: displacement volume; WW: wet weight; DW: dry weight; Zp.: zooplankton

### 4.3. Discussion

Andaman Sea is a tropical sea and oligotrophic in nature with low production of planktonic biomass (Qazim and Anzari, 1981) however, the coastal waters of Andaman Islands have been considered as productive in zooplankton biomass (Marichamy, 1983), research has been scarcely focused on the border regions and particularly around the oceanic islands (Conway, 2005). Moreover, the oceanic species of zooplankton and their distribution have been well described compared to that of the coastal species from Indian Ocean (Conway, 2005). Research on the planktonic dynamics of Andaman Sea was largely focused on the primary productivity and phytoplankton of these regions (Kabanova, 1964; Prasad, 1966; Qazim, 1977; Bhattathiri and Devassy, 1981; Devassy and Bhattathiri, 1983; Bhattathiri, 1984; Sarojini and Sarma, 2001; Vinithkumar *et al.*, 2010; Sivasankar and Padmavati, 2012; Karthik *et al.*, 2012). Phytoplankton in the Andaman Sea is very high in species composition and abundance and studies have been

reported on many bloom forming species (Arun Kumar *et al.*, 2012; Karthik and Padmavati, 2014; Karthik *et al.*, 2014a; b). In addition, the importance of microzooplankton in the coastal waters of Andaman Sea have recently been recognized and received attention (Jyothibabu *et al.*, 2003; Sai Elangovan *et al.*, 2012; Sai Elangovan, 2015, Ph.D. Thesis). Since, the information on the seasonal distribution of zooplankton from the coastal regions of these islands is scarce (Marichamy, 1983) studies were carried out to gain information on the role of copepod community in the marine food web. In addition, continuous monitoring of zooplankton biomass in the neritic regime of the Andaman and Nicobar Islands have been the neglected subject of Indian Ocean plankton research.

This study presents mesozooplankton abundance and biomass from 3 seasons and different coastal stations in South Andaman Island. The mesozooplankton were comprised of 29 taxa under 10 phyla namely *Cnidaria*, *Chordata*, *Echinodermata*, *Chaetognatha*, *Arthropoda*, *Bryozoa*, *Annelida*, *Mollusca*, *Platyhelminthes* and *Retaria*. A large proportion of zooplankton abundance was contributed by copepods followed by crustacean nauplii, gastropod and bivalve veliger larvae, appendicularians, decapod larvae and chaetognaths.

There are only few studies in zooplankton composition of Andaman and Nicobar marine system (Goswami and Rao, 1981; Madhupratap *et al.*, 1981a; b; Nair *et al.*, 1981; 2002; 2008; Marichamy, 1983; Madhupratap and Haridas, 1986; Gopalakrishnan *et al.*, 1996; Antony *et al.*, 1997; Jyothibabu *et al.*, 2003; Madhu *et al.*, 2003; Pai, 2007; Padmavati *et al.*, 2008; Nair and Gireesh, 2010; Santhanakumar *et al.*, 2010; Karuppasamy *et al.*, 2011; Pillai *et al.*, 2011, 2014; Jha *et al.*, 2012) invariably reported that copepods were dominant component of the zooplankton in Andaman Sea as found in the present study.

Among the mesozooplankton, chaetognaths have been extensively studied in oceanic and neritic regimes of Indian waters and Andaman and Nicobar Islands (Nair *et al.*, 1981; 2002; 2008; Nair and Gireesh, 2010; Pillai *et al.*, 2014). Although, chaetognaths of deeper waters of the seas around India and those of Andaman and Nicobar islands are not well known (Venkataraman and Wafar, 2005). Population of chaetognaths were much higher in coastal waters as compared to the oceanic zone (Nair *et al.*, 1981). In coastal waters of South Andaman the abundance of chaetognaths was higher as compared to the report of Nair *et al.* (1981), that ranged from 1.26 to 19.59 ind. m<sup>-3</sup> (IIOE data of chaetognaths of Andaman Sea, Indian Ocean Biological Centre,

1972; Nair *et al.*, 2002) whereas in the present study the population ranged from 1.6 to 580 ind. m<sup>-3</sup> with average density of 63.57 ind. m<sup>-3</sup> and maximum density at Junglighat (St.5). The higher abundance of chaetognath population may be attributed due to the net used in the present investigation that was smaller (200µm) than the earlier work (Nair *et al.*, 1981; Indian Ocean Biological Centre, 1972). In general, chaetognaths has been the second dominant group in the mesozooplankton (Nair *et al.*, 1981; Madhupratap *et al.*, 1981a), however, the study recorded the dominance of copepods (66.0%) followed by crustacean nauplii (7.7%), gastropod veliger larva (6.0%), bivalve veliger larvae (4.6%), appendicularians (4.3%), decapods larvae (2.9%) and chaetognaths (1.6%) in the South Andaman coastal waters as reported earlier from the area (Pillai *et al.*, 2014).

Related zooplankton data in this region appropriate for comparison with the present results are largely unavailable. Zooplankton composition is quite similar to what has been reported in Pillai *et al.* (2011; 2014), Madhupratap *et al.* (1981a; b) and Goswami and Rao (1981). In all stations, the mesozooplankton comprised of 29 taxa except Junglighat, where, the groups such as flat worms and cumaceans were found to be absent reasonably due to the steep depth of this coastal station. However the cumaceans, a hyperbenthic fauna (Raymont, 1983; Omori and Ikeda, 1992; Goswami, 2004) was a regular component of the mesozooplankton in the South Andaman coast is quite remarkable, since, there has been no such reports were available from the Indian Ocean as suggested by Pillai *et al.* (2011). The presence of cumaceans in the surface waters may be due to the shallow depth of the study stations and some kind of disturbance to bottom (Pillai *et al.*, 2011). Additionally, periodic cyclones in the Bay of Bengal and associated strong surface winds cause lateral stirring leading to upward movement of deep waters species (Nair, 2007). Zooplankton studies in the Andaman Sea have been mainly on community structure and distribution. The secondary data from various studies revealed 228 species belonged to 88 genera and 14 phyla. Jitchum *et al.* (2006) studied species composition, density and distribution of zooplankton in the Andaman Sea in 2004. They reported 65 groups of holoplankton and meroplankton, in which copepod were dominant and common without apparent spatial pattern. The vertical distribution of micronektonic fauna (myctophids and pelagic shrimps) were studied with the help of 200µm mesh plankton net (Karuppasamy *et al.*, 2011). Nine species of myctophids and 8 species of shrimps were identified in their study however

in the present study, weightage was given to copepods and other groups were grouped into their broad category like fish larva and decapod larva.

Zooplankton occurrence and distribution influence pelagic fishery potential. Mostly fishes breed in areas where the planktonic organisms are abundant so that their larval forms could get sufficient food for survival and growth and failure of fishery resources is attributed to the reduced copepod population (Støttrup, 2000). In general, the estimate of the fishery resources of the oceans can be made through the study of its zooplankton production. The mesozooplankton community in this study area showed significant difference among the stations in terms of assemblage structure. All stations differed significantly in the assemblage of zooplankton except Burmanallah (St.1) and Chidiyatapu (St.4) (Table 4.2), likely reflecting hydrological differences in these respective environments. A strong regional gradient in the faunal assemblage, may be driven by the major ecosystem like corals, mangroves and seagrass at each study site of this region that increase the biological production in the coastal waters as these ecosystems play a vital role in primary production and in turn provides food and shelter for zooplankters and thereby accelerating the secondary production (Gopinathan and Rajagopalan, 1983; Pillai, 1983; Santhanakumar *et al.*, 2010; Jayabarathi *et al.* 2012, 2015; Pillai *et al.*, 2014).

Although, the density varied between monthly collection, statistically no significance or clear pattern of seasonal variation was found neither with copepods nor mesozooplankton groups (one-way ANOVA,  $p > 0.05$ ). The distribution of zooplankton biomass in the Arabian Sea shows marked variation during the southwest and northeast monsoons, whereas in the Bay of Bengal there is no definite variation (Prasad, 1968). The copepods were higher during inter monsoon period followed by southwest monsoon (Table 4.3). However, the copepod density was found higher during the month of April 2013 at Chattam (St.3) and Junglighat (St.5). In Carbyn's Cove (St.2), the average copepod density was in peak during January 2012 and April and August 2013 while, in Burmanallah (St.1) the density was higher during January, June and October 2012 and in October 2013. In addition, the abundance of chaetognaths had the highest average density at Port Blair during inter monsoon followed by northeast monsoon (Nair and Gireesh, 2010) however, in the present investigation, chaetognaths were relatively abundant during southwest and northeast monsoon that may be due to the variation in the site of the collection. Overall, the zooplankton groups namely chaetognaths, ostracods, isopods and fish eggs and larvae were relatively abundant

during southwest monsoon whereas, foraminifera, amphipods, cumaceans, polychaete larva, bipinnaria larva and flatworm were higher during inter monsoon period. While, groups such as narcomedusae, stomatopods, bryozoan larva, pluteus larva, gastropod veliger and bivalve veliger were dominant during inter monsoon and southwest monsoon while, decapod larvae, appendicularians and nauplius were dominant during northeast monsoon period.

The zooplankton population occurred in high abundance when the surface waters were characterized by low temperature and salinity (Antony *et al.*, 1997). Occurrence of eggs and larvae of finfishes, pelagic tunicates, euphausiids, copepods, amphipods, foraminifers and lucifers in abundance accounted for the northeast monsoon maximum whereas, southwest monsoon (June-September) was the least productive season (Antony *et al.*, 1997). The seasonal variation of mesozooplankton standing stock in this area showed insignificant variation which is similar to the earlier observations made from different coastal regions of the Andaman Islands. In general, the spatial and temporal variation of productivity in different Indian coastal waters are owing to the influence of heavy river runoff, coastal upwelling and land drainage (Pillai *et al.*, 2014). In fact, as suggested by Pillai *et al.* (2014), earlier reports from the coastal regions of these oceanic islands were meagre that forms a major constraint for a comparative study.

Determination of plankton biomass is essential preliminary for the measurement of energy flow within the plankton community. Several methods have been developed for estimating indices of biomass such as gravimetric method (Beers, 1976), dry weight (Grove, 1966) and organic carbon or calorific value based on ash free dry weight (Wiebe *et al.*, 1975). Volumetric methods have involved the direct measurement of the zooplankton sample by settlement or displacement (Ahlstrom and Thraillkill, 1963) and, although limited in terms of accuracy, they are relatively simple procedures, requiring a minimum of equipment. The results of biomass indices such as displacement volume ranged from  $0.215 \pm 0.166 \text{ ml. m}^{-3}$  at Carbyn's cove and  $0.381 \pm 0.252 \text{ ml. m}^{-3}$  at Chattam, wet weight ranged from  $195.7 \pm 164.8 \text{ mg. m}^{-3}$  to  $295.4 \pm 174.4 \text{ mg. m}^{-3}$  at Carbyn's cove (St.2) and Chattam (St.3) respectively and the dry weight biomass ranged between  $13.4 \pm 8.0 \text{ mg. m}^{-3}$  at Junglighat (St.5) and  $22.7 \pm 36.4 \text{ mg. m}^{-3}$  at Carbyn's Cove. The density and biomass of zooplankton reported by Madhupratap *et al.* (1981a) was quite lower compared to the present investigation reasonably due to the net (500  $\mu\text{m}$ ) used in their study that was quite larger than the present study. In



addition, zooplankton biomass varied from 0.64 to 0.98 ml. m<sup>-3</sup> in Andaman Sea (Goswami and Rao, 1981) was quite higher than the present study was mainly due to huge swarms of larger size copepod family Pontellidae with swarm density of 25974 to 138420 ind. m<sup>-3</sup> (Goswami and Rao, 1981). Similarly, high surface biomass values that varied from 3.87 ml. m<sup>-3</sup> (western side) and 2.65 ml m<sup>-3</sup> (eastern side) was observed near Barren Island (Pillai *et al.*, 2011). Total wet biomass (displacement volume) of zooplankton was ranged from 0.14 ml. m<sup>-3</sup> to 4.0 ml. m<sup>-3</sup> with maximum biomass was observed from the inshore waters than open sea stations was comparatively higher than this study. The population density and biomass in the stations around northern Andaman Islands showed that these areas were comparatively productive than southern Nicobar group of islands (Santhanakumar *et al.*, 2010). This could be attributed to the abundance of productive mangrove areas of Andaman group of islands (Santhanakumar *et al.*, 2010). Further, the displacement volume of zooplankton biomass reported by other studies were comparable to the present results (Gopalakrishnan *et al.*, 1996; Jha *et al.*, 2012).

In the present study, higher values of displacement volume and wet weight was recorded at Chattam (St.3) and Junglighat (St.5) while the dry weight indices was maximum at Carbyn's Cove (St.2) followed by Chattam resulted in the study reasonably due to the abundance gelatinous zooplanktons, such as Siphonophora, Appendicularia and Hydromedusae in Chattam and Junglighat, although, large medusa were removed before the estimation of biomass. However, relatively lower numbers of such groups and abundance of copepods (74 %) and other crustaceans in Carbyn's Cove resulted in lower values of displacement volume and wet weight and higher values of dry weight biomass. The elemental composition of mixed zooplankton was estimated for the first time from the Andaman Sea coastal waters. Biochemical compositions of Andaman Sea zooplankton were studied by Goswami *et al.* (1981) and Arun Kumar *et al.* (2013). Therefore, no data in this region appropriate for comparison with the present results are available. The results revealed that Carbon content varied from 35-62% DW and maximum Carbon was recorded during September 2013 due to the abundance of copepods. Hydrogen content varied from 1.8-3.1% DW. Nitrogen content varied from 3.5-6.5% DW. It showed similar trend to that of Carbon content in this study. The analysis of elementary composition and biochemical constituents are most useful, given their importance for metabolic and biogeochemical studies (Corner and Davies 1971; Alcaraz *et al.*, 2003).

The results of correlation between copepod and zooplankton density with Chl-*a* was negative at Burmanallah and Chidiyatapu, while significantly negative at Burmanallah. Whereas in the rest of the stations the correlation remains weak may be due to the preference of alternative pathway of feeding on the microzooplanktons in these stations. Sai Elangovan *et al.* (2012) and Sai Elangovan (2015; Ph.D.Thesis) have been reported higher abundance of microzooplankton community among the coastal waters of South Andaman. The method of collection of zooplankton at early morning (before dawn) in present investigation may be the reason for the negative relationship in Burmanallah and Chidiyatapu indicating the grazing pressure by zooplankton in these area, however requires more investigation. Although, the relationship was statistically significant however moderate at Burmanallah, whereas weak in Chidiyatapu (St.4). The correlation between environmental parameters and density and biomass of zooplankton were weak in Burmanallah (St.1). In Carbyn's Cove (St.2) the biomass values were negatively moderate with pH. A strong negative correlation ( $r = -0.767$ ;  $p < 0.01$ ;  $n = 12$ ) was found between density and DO whereas moderately positive with salinity in Chidiyatapu (St.4). However, in Chattam (St.3) both density and biomass were moderately positive while in Junglighat the density was moderately negative with DO and salinity. In general the water mass changes does not affect the epipelagic plankton as found in this study has been reported earlier from the northeast Indian Ocean (Madhupratap and Haridas, 1986).

Zooplankton are more varied as compared to phytoplankton, their variability in any aquatic ecosystem is influenced mainly by patchiness, diurnal vertical migration and seasons. Information on the variability of zooplankton biomass are important for understanding natural and anthropogenic effects on ecosystems. The increase in zooplankton biomass was a result of various factors like, availability of food, water temperature, and changes in salinity on zooplankton community (Litvinchuk, 2010). The present study attempts to understand the distribution and diversity of mesozooplankton with special emphasis on epipelagic copepods in the coastal waters South Andaman Island.

**CHAPTER 5**

**DIVERSITY AND SPATIO-TEMPORAL DISTRIBUTION OF  
COPEPODS**

**5.1. Introduction**

Copepods form the major component of mesozooplankton with a great economic value, as veritable "insects of the sea" and frames as one of the principle secondary producers of marine system (Wheeler, 1900; George, 1953; Huys and Boxshall, 1991). They represent an important link between phytoplankton, microzooplankton and higher trophic levels such as fish and mammals. The pioneer exertion of literatures from world oceans by copepodologist have contributed an extensive knowledge on the systematics and biogeography of Copepoda, in particular the literatures by Cleve (1901), Scott (1902), Thompson and Scott (1903), Wolfenden (1906; 1911), Brady (1910), Sewell (1912; 1914; 1929b; 1932; 1933; 1947; 1948), Kasturirangan (1963), Silas (1972) and Conway *et al.* (2003) from Indian waters which made the identification and study of copepod species in the vicinity has developed into a pleasant task.

The coastal region of South Andaman is characterized by the presence of highly diverse habitats such as coral reefs, mangrove forests, tidal creeks, seagrass patches, sandy and rocky beaches. The coastal waters are highly dynamic habitat than the oceanic realm and subjected to fluctuations of environmental condition. Nutrient enrichment caused by rainfall and storm incidence during monsoon periods and associated upwelling events in tropical coastal waters (Smith, 1982; Schalk, 1987; Baars *et al.*, 1990; Chisholm and Roff, 1990) leads to proliferation of phytoplankton and swarming of filter feeders (Goswami, 1985) that eventually benefits many larval forms of economically important groups in the coastal zooplankton community (Houde and Lovdal, 1982; Balbontin *et al.*, 1986; Anderson, 1994). Thus, in the context of biodiversity conservation, coastal region should have the highest priority (Costello, 1998; Ramanibai, 2015).

Studies on biological features especially zooplankton of Andaman Sea, northeast Indian Ocean are mainly limited to oceanic regions (Goswami and Rao, 1981; Madhupratap *et al.*, 1981a; b; Nair *et al.*, 1981; 2002; 2008; Fleminger *et al.*, 1982; Madhupratap and Haridas, 1986; Antony *et al.*, 1997; Jyothibabu *et al.*, 2003; Madhu *et*

*al.*, 2003; Pai, 2007; Padmavati *et al.*, 2008; Nair and Gireesh, 2010; Karuppasamy *et al.*, 2011). Most of the studies focused on copepod taxonomy (Sewell, 1919; 1932; 1933; Roy, 1977; Pillai, 1980; Reddy and Radhakrishna, 1982; Walter, 1984; Madhupratap and Haridas, 1986; 1989; 1992). The knowledge on spatio-temporal distribution and variation of major component of mesozooplankton, i.e. copepods from Andaman Sea has been meager and less informative from Andaman Archipelago may be due to the remoteness of these islands from mainland of the Indian subcontinent. In addition, the species composition, density and distribution of copepods have direct relevance to fishery resources. Adequate knowledge on the diversity, spatio-temporal distribution and variation of copepod population were lacking from the Andaman Sea. As such it is essential to delineate the effects of environmental factors on the copepod species of coastal waters of the Andaman Island are exclusively studied for this purpose.

## **5.2. Result**

### **5.2.1. Population structure of copepods**

In total 356285 adult copepods and copepodids were identified in the study area. The bulk of the individuals belonged to the Order Calanoida (55.6%) followed by Cyclopoida (40.4%), and Harpacticoida (3.96%). Monstrilloida was least encountered with 114 individuals (0.03%). The copepod community in the coastal waters of South Andaman was comprised of 97 taxa and 29 families, of which 73 were Calanoida, 14 were Cyclopoida, and 9 were Harpacticoida. Of these, 89 were identified till the level of species, seven were identified up to genera and single representative from Monstrilloida that was identified to family level (Appendix II).

The calanoids were comprised of 73 species, represented over 31 genera and 17 families. The dominant families were Paracalanidae (77.4%), Pseudodiaptomidae (10.22%) followed by Acartiidae and Centropagidae made up to 2.61% and 2.0% to copepod population respectively. Families such as Calanidae, Pontellidae, Clausocalanidae and Arietellidae were between 1.28% and 1.64% and other families constituted <1% to the overall abundance of copepods. However, the families with highest diversity were Pontellidae with 16 species, followed by Paracalanidae with 13 species, among them *Parvocalanus* was considered only to genus level. The families, Calanidae and Subeucalanidae were represented by 5 species and other families namely Acartiidae, Centropagidae, Pseudodiaptomidae and Tortanidae were contributed up to 4

species respectively (Table 5.1). The Cyclopoida represented with 14 species, included over 7 genera and 5 families, dominated by families such as Oithonidae (46.9%), Corycaeidae (29.2%) and Oncaeidae (22.2%). Oithonidae and Sapphirinidae represented by 7 and 3 species respectively while other families such as Corycaeidae, Oncaeidae and Clausidiidae were considered till genera. The harpacticoids were composed of 6 families, in which the families such as Miraciidae (14.2%), Ectinosomatidae (8.4%), Euterpinidae (74.0%) and Clytemnestridae (1.4%) were represented by 3, 2, 1 and 1 species respectively, and other families were identified upto only genera (Table 5.1).

Overall, the bulk of the individuals were belonged to *Parvocalanus* sp. (22.58%) and *Bestiolina similis* (11.92%) and were dominant with  $472.1 \pm 804.9 \text{ ind.m}^{-3}$  (n=128) and  $249.2 \pm 401.1 \text{ ind.m}^{-3}$  (n=128) respectively, followed by *Corycaeus* spp. (9.89%), *Oncaea* spp. (8.84%), *Oithona oculata* (7.58%), *Oithona brevicornis* (6.68%), *Pseudodiaptomus* sp. (5.15%), *Euterpina acutifrons* (3.12%), *Paracalanus parvus* (2.42%), *Farranula gibbula* (1.72%), *Oithona rigida* (1.61%), *Acrocalanus gibber* (1.40%), *Oithona plumifera* (1.37%) and *Calocalanus pavo* (1.25%). Among the calanoids, species such as *Acartia erythraea*, *Metacalanus aurivilli*, *Canthocalanus pauper*, *Centropages orsinii*, *Clausocalanus furcatus*, *Acrocalanus longicornis*, *Paracalanus aculiatu*s and *Paracalanus indicus* contributed between 1.04% and 1.81%.

The following species of copepods were commonly found along the coastal waters during the study period: *Acartia erythraea*, *Metacalanus aurivilli*, *Canthocalanus pauper*, *Mesocalanus tenuicornis*, *Centropages furcatus*, *Centropages orsinii*, *Subeucalanus subcrassus*, *Acrocalanus gibber*, *Acrocalanus longicornis*, *Bestiolina similis*, *Calocalanus pavo*, *Paracalanus parvus*, *Paracalanus aculiatu*s, *Parvocalanus* sp., *Calanopia elliptica*, *Labidocera madurae*, *Temora discaudata*, *Corycaeus* spp., *Farranula gibbula*, *Oithona oculata*, *Oithona rigida*, *Oithona spinirostris*, *Oithona plumifera*, *Oncaea* spp., *Hemicyclops* sp., *Microsetella norvegica*, *Microsetella rosea*, *Euterpina acutifrons*, *Macrosetella gracilis*, *Clytemnestra scutellata*, *Acartia bispinosa*, *Clausocalanus furcatus*, *Clausocalanus arcuicornis*, *Lucicutia flavicornis*, *Acrocalanus gracilis*, *Calocalanus plumulosus*, *Calanopia minor*, *Labidocera acuta*, *Labidocera minuta*, *Temora turbinata*, *Tortanus (Tortanus) gracilis*, *Oithona brevicornis*, *Oithona linearis*, *Copilia mirabilis*, *Sapphirina stellata*, *Distiocus minor* and *Tegastes* sp.

## Diversity and spatio-temporal distribution of copepods

The species such as, *Acartia spinicauda*, *Cosmocalanus darwini*, *Euchaeta concinna*, *Paracalanus denudatus*, *Calanopia aurivilli*, *Calanopia thompsoni*, *Labidocera detruncata*, *Labidocera bataviae*, *Labidocera acutifrons*, *Pontellopsis macronyx*, *Pontella fera*, *Pontella denticauda*, *Pseudodiaptomus marinus*, *Tortanus (Atortus) andamanensis*, *Tortanus (Atortus) sigmoides*, *Tortanus (Atortus) murrayi* and *Peltidium* sp. were found to be rare and occurred in a particular area (St.4) of the study area.

**Table 5.1. List of families and number of genera and species recorded from the study area.**

Family	Number of genera	Number of species
Acartiidae	1 (2)	4
Arietellidae	1	1
Calanidae	5	5
Candaciidae	2	4
Centropagidae	1	4
Clausocalanidae	1	2
Eucalanidae	1	2
Subeucalanidae	1	5
Euchaetidae	1	2
Lucicutiidae	1	1
Paracalanidae	5	13
Pontellidae	5	16
Pseudocyclopidae	1	1
Pseudodiaptomidae	1	4
Scolecitrichidae	2	2
Temoridae	1	3
Tortanidae	1 (2)	4
Corycaeidae	2	2
Oithonidae	1	7
Oncaeidae	1	1
Sapphirinidae	2	3
Clausidiidae	1	1
Ectinosomatidae	1	2
Euterpinidae	1	1
Miraciidae	3	3
Clytemnestridae	1	1
Tegastidae	1	1
Peltidiidae	1	1
Monstrillidae	1	1

**Appendix II Species list of planktonic copepods collected in the study area. Species with triple asterisk (\*\*\*) denote the new species, with single asterisk (\*) represent first record to Andaman waters and double asterisk (\*\*) is new to Indian Ocean.**

Subphylum **Crustacea** Brünnich, 1772

Class **Maxillopoda** Dahl, 1956

Subclass **Copepoda** Milne-Edwards, 1840

Infraclass **Neocopepoda** Huys and Boxshall, 1991

Superorder **Gymnoplea** Giesbrecht, 1882

Order **Calanoida** Sars, 1903

Family **Acartiidae** Sars, 1900

1. *Acartia (Odontacartia) erythraea* Giesbrecht, 1889
2. *Acartia (Odontacartia) bispinosa* Carl, 1907
3. *Acartia (Odontacartia) spinicauda* Giesbrecht, 1889
4. *Acartia (Planktacartia) negligens* Dana, 1849

Family **Arietellidae** Sars, 1902

5. *Metacalanus aurivilli* Cleve, 1909

Family **Calanidae** Dana, 1846

6. *Canthocalanus pauper* (Giesbrecht, 1888)
7. *Mesocalanus tenuicornis* (Dana, 1849)
8. *Nannocalanus minor* (Claus, 1863)
9. *Undinula vulgaris* (Dana, 1849)
10. *Cosmocalanus darwini* (Lubbock, 1860)

Family **Candaciidae** Giesbrecht, 1893

11. *Candacia bradyi* A. Scott, 1902
12. *Candacia catula* (Giesbrecht, 1892)
13. *Candacia discaudata* A. Scott, 1909
14. *Paracandacia truncata* (Dana, 1849)

Family **Centropagidae** Giesbrecht, 1893

15. *Centropages furcatus* (Dana, 1849)
16. *Centropages orsinii* Giesbrecht, 1889
17. *Centropages calaninus* (Dana, 1849)
18. *Centropages elongatus* Giesbrecht, 1896

Family **Clausocalanidae** Giesbrecht, 1893

19. *Clausocalanus furcatus* (Brady, 1883)
20. *Clausocalanus arcuicornis* (Dana, 1849)

Family **Eucalanidae** Giesbrecht, 1893

Diversity and spatio-temporal distribution of copepods

21. *Eucalanus attenuatus* (Dana, 1849)

22. *Eucalanus monachus* Giesbrecht, 1892

Family **Euchaetidae** Giesbrecht, 1893

23. *Euchaeta indica* Wolfenden, 1905

24. *Euchaeta concinna* (Dana, 1849)

Family **Lucicutiidae** Sars, 1902

25. *Lucicutia flavicornis* (Claus, 1863)

Family **Paracalanidae** Giesbrecht, 1893

26. *Acrocalanus gibber* Giesbrecht, 1888

27. *Acrocalanus longicornis* Giesbrecht, 1888

28. *Acrocalanus gracilis* Giesbrecht, 1888

29. *Bestiolina similis* Sewell, 1914

30. *Calocalanus pavo* (Dana, 1849)

31. *Calocalanus longispinus* Shmeleva, 1978

32. *Calocalanus plumulosus* (Claus, 1863)

33. *Calocalanus styliremis* Giesbrecht, 1888

34. *Paracalanus parvus* (Claus, 1863)

35. *Paracalanus aculiatu*s Giesbrecht, 1888

36. *Paracalanus indicus* Wolfenden, 1905

37. *Paracalanus denudatus* Sewell, 1929

38. *Parvocalanus* Dahl, 1894

Family **Pontellidae** Dana, 1853

39. *Calanopia minor* A. Scott, 1902

40. *Calanopia aurivilli* Cleve, 1901

41. *Calanopia elliptica* (Dana, 1849)

42. *Calanopia thompsoni* A. Scott, 1909

43. *Labidocera acuta* (Dana, 1849)

44. *Labidocera pavo* Giesbrecht, 1889

45. *Labidocera minuta* Giesbrecht, 1889

46. *Labidocera madurae* A. Scott, 1909

47. *Labidocera laevidentata* (Brady, 1883)

48. *Labidocera detruncata* (Dana, 1849)

49. *Labidocera bataviae* A. Scott, 1909

50. *Labidocera acutifrons* (Dana, 1849)



Diversity and spatio-temporal distribution of copepods

51. *Pontellina plumata* (Dana, 1849)
52. *Pontellopsis macronyx* A. Scott, 1909
53. *Pontella denticauda* A. Scott, 1909
54. *Pontella fera* Dana, 1849

Family **Pseudocyclopidae** Giesbrecht, 1893

55. *Pseudocyclops* Brady, 1872

Family **Pseudodiaptomidae** Sars, 1902

56. *Pseudodiaptomus annandalei* Sewell, 1919 \*
57. *Pseudodiaptomus* sp. (communicated) \*\*\*
58. *Pseudodiaptomus compactus* Walter, 1984
59. *Pseudodiaptomus marinus* Sato, 1913

Family **Scolecitrichidae** Giesbrecht, 1893

60. *Scoleciothrix danae* (Giesbrecht, 1888)
61. *Scolecithricella minor* (Brady, 1883)

Family **Subeucalanidae** Giesbrecht, 1893

62. *Subeucalanus subcrassus* (Giesbrecht, 1888)
63. *Subeucalanus crassus* (Giesbrecht, 1888)
64. *Subeucalanus pileatus* (Giesbrecht, 1888)
65. *Subeucalanus mucronatus* (Giesbrecht, 1888)
66. *Subeucalanus subtenuis* (Giesbrecht, 1888)

Family **Temoridae** Giesbrecht, 1893

67. *Temora turbinata* (Dana, 1849)
68. *Temora discaudata* Giesbrecht, 1889
69. *Temora stylifera* (Dana, 1849)

Family **Tortanidae** Sars, 1902

70. *Tortanus (Tortanus) gracilis* (Brady, 1883)\*
71. *Tortanus (Atortus) murrayi* A. Scott, 1909\*\*
72. *Tortanus (Atortus) andamanensis* Nishida, Anandavelu & Padmavati, 2015 \*\*\*
73. *Tortanus (Atortus) sigmoides* Nishida, Anandavelu & Padmavati, 2015 \*\*\*

Superorder **Podoplea** Giesbrecht, 1882

Order **Cyclopoida** Burmeister, 1834

Family **Corycaeidae** Dana, 1852

74. *Corycaeus* Dana, 1845
75. *Farranula gibbula* (Giesbrecht, 1891)

Diversity and spatio-temporal distribution of copepods

Family **Oithonidae** Dana, 1853

- 76. *Oithona oculata* Farran, 1913
- 77. *Oithona rigida* Giesbrecht, 1896
- 78. *Oithona spinirostris* Claus 1863
- 79. *Oithona plumifera* Baird, 1843
- 80. *Oithona similis* Claus, 1866
- 81. *Oithona brevicornis* Giesbrecht, 1891
- 82. *Oithona linearis* Giesbrecht, 1891

Family **Oncaeiidae** Giesbrecht, 1893

- 83. *Oncaea* Philippi, 1843

Family **Sapphirinidae** Thorell, 1860

- 84. *Copilia vitrea* (Haeckel, 1964)
- 85. *Copilia mirabilis* Dana, 1949
- 86. *Sapphirina stellata* Giesbrecht, 1891

Family **Clausidiidae** Embleton, 1901

- 87. *Hemicyclops* Boeck, 1872

Order **Harpacticoida** Sars, 1903

Family **Ectinosomatidae** Sars, 1903

- 88. *Microsetella norvegica* (Boeck, 1864)
- 89. *Microsetella rosea* (Dana, 1848)

Family **Euterpinidae** Brian, 1921

- 90. *Euterpina acutifrons* (Dana, 1848)

Family **Miraciidae** Dana, 1846

- 91. *Miracia efferata* Dana, 1849
- 92. *Macrosetella gracilis* (Dana, 1848)
- 93. *Distioculus minor* (T. Scott, 1894)

Family **Clytemnestridae** A. Scott, 1909

- 94. *Clytemnestra scutellata* Dana, 1848

Family **Peltidiidae** Sars, 1904

- 95. *Peltidium* Philippi, 1839

Family **Tegastidae** Sars, 1904

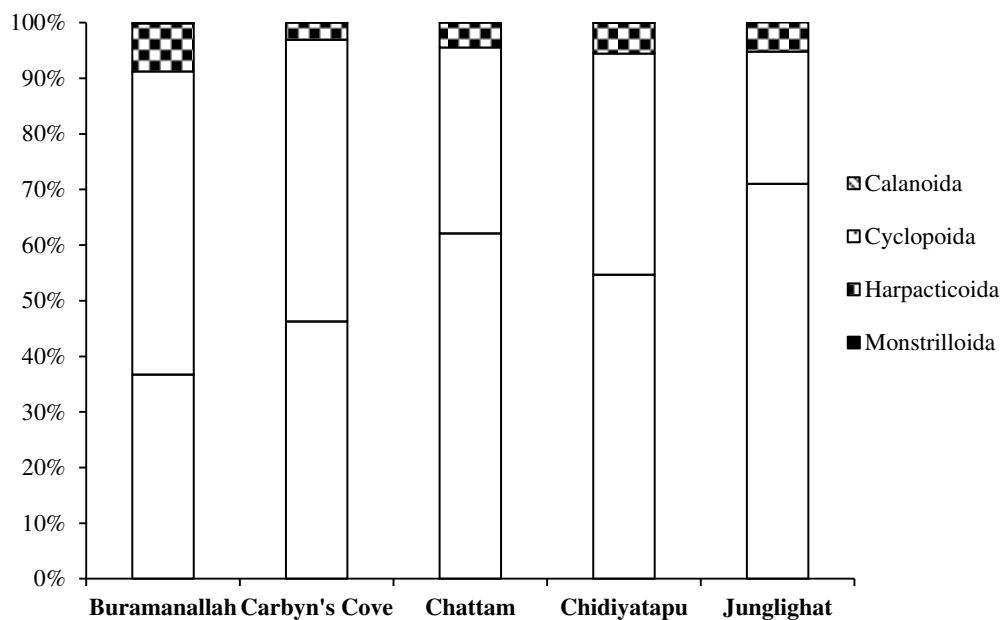
- 96. *Tegastes* Norman, 1903

Order **Monstrilloida** Sars, 1901

Family **Monstrillidae** Dana, 1849

### 5.2.2. Spatial variation of copepods

The percentage contribution of Calanoida, Cyclopoida, Harpacticoida and Monstrilloida between the stations is represented in Fig. 5.1. Higher proportion of Cyclopoida was found in Burmanallah (St.1) and Carbyn's Cove (St.2) (54.5% and 50.6% respectively) followed by Calanoida (36.7% and 46.3% respectively), however, the relative abundance of Calanoida was higher in the remaining stations with 71% in Junglighat (St.5), 62.1% in Chattam (St.3) and 54.7% in Chidiyatapu (St.4) followed by Cyclopoida and Harpacticoida. The monstrilloid copepods were least encountered at all the stations whereas, totally unavailable in Junglighat (St.5). The highest proportion of Harpacticoid copepods was found in Burmanallah (St.1) (8.7%) followed by Chidiyatapu (St.4) and Junglighat (St.5) with 5.5% and 5.2% respectively (Fig. 5.1). Of the 29 families recorded, 19 were found at all stations and 5 families such as Candaciidae, Clausocalanidae, Eucalanidae, Lucicutiidae and Tegastidae were absent among one of the 5 stations. While, the families Euchaetidae, Pseudocyclopidae and Peltidiidae were occurred at one or two of the stations. In addition, the analysis of variance showed that the families did not differ significantly in the average abundance between stations (One-way ANOVA,  $F_{(1,140)} = 0.092$ ,  $p = 0.985$ ).



**Fig. 5.1. Relative abundance of copepod orders at different stations.**

Overall, 30 species of copepods, *Acartia erythraea*, *Metacalanus aurivilli*, *Canthocalanus pauper*, *Mesocalanus tenuicornis*, *Centropages furcatus*, *C. orsinii*,

*Subeucalanus subcrassus*, *Acrocalanus gibber*, *A. longicornis*, *Bestiolina similis*, *Calocalanus pavo*, *Paracalanus parvus*, *P. aculiatu*s, *Parvocalanus* sp., *Calanopia elliptica*, *Labidocera madurae*, *Temora discaudata*, *Corycaeus* spp., *Farranula gibbula*, *Oithona oculata*, *O. rigida*, *O. spinostris*, *O. plumifera*, *Oncaea* spp., *Hemicyclops* sp., *Microsetella norvegica*, *M. rosea*, *Euterpina acutifrons*, *Macrosetella gracilis* and *Clytemnestra scutellata* were found to be common in all the stations (Table 5.2). In addition, *Acartia bispinosa*, *Clausocalanus furcatus*, *C. arcuicornis*, *Lucicutia flavicornis*, *Acrocalanus gracilis*, *Calocalanus plumulosus*, *Calanopia minor*, *Labidocera acuta*, *L. minuta*, *Temora turbinata*, *Tortanus (Tortanus) gracilis*, *O. brevicornis*, *O. linearis*, *Copilia mirabilis*, *Sapphirina stellata*, *Distiocus minor* and *Tegastes* sp. were generally found to be occurred in four stations and absent at least in one of the station.

The following 17 species of copepods namely *Acartia spinicauda*, *Cosmocalanus darwini*, *Euchaeta concinna*, *Paracalanus denudatus*, *Calanopia aurivilli*, *C. thompsoni*, *Labidocera detruncata*, *L. bataviae*, *L. acutifrons*, *Pontellopsis macronyx*, *Pontella fera*, *P. denticauda*, *Pseudodiaptomus marinus*, *T. (Atortus) andamanensis*, *T. (A.) sigmoides*, *T. (A.) murrayi* and *Peltidium* sp. were found to be rare and restricted to any one among the stations and the remaining 31 species were generally occurred in almost all the stations (Table 5.2). The adult copepods and copepodids do not differ significantly in average abundance among the stations (One-way ANOVA,  $F_{(1,560)} = 0.288$ ,  $p = 0.885$ ). In addition, copepodids contributed a considerable number of individuals to the total abundance, overall, more than 80% of the copepodids were shared by the three copepodids such as Oithonid (40.59%), Calanoid (35.77%) and Pseudodiaptomid (8.97%) followed by *Centropages* (3.37%), Harpacticoid (3.00%), *Acartia* (2.38%), *Eucalanus* (2.25%) and *Labidocera* (1.94%) species.

#### 5.2.2.1. Burmanallah (St.1)

Family such as Paracalanidae, Oncaeidae, Oithonidae and Corycaeidae were the dominant in the area followed by Euterpinae, Pseudodiaptomidae and Miraciidae (Fig. 5.2a) out of the 26 families recorded in Burmanallah. Some families such as Eucalanidae, Scolecitrichidae and Peltidiidae were absent in this area. Other families such as Acartiidae, Clausocalanidae, Calanidae, Centropagidae, Subeucalanidae and Pontellidae were contributed between 0.97% and 1.32% to the total copepod

population. Burmanallah (St.1) have been enriched with 74 species, among them 6 species (*Paracalanus denudatus*, *Calanopia aurivilli*, *Labidocera detruncata*, *T. (A.) andamanensis*, *T. (A.) sigmoides* and *T. (A.) murrayi*) were found to be rare and occurred only in this area (Table 5.2). Copepod species namely, *Labidocera minuta*, *T. (Tortanus) gracilis*, *Oithona brevicornis* and *O. linearis* were absent from Burmanallah. In Burmanallah, *Oncaea* spp. (19.82%), *O. oculata* (14.34%), *Corycaeus* spp. (11.58%), *Bestiolina similis* (8.25%), *Parvocalanus* sp. (7.89%) and *Farranula gibbula* (4.03%) were relatively dominant species with average density ranged to  $69.2 \pm 97.4$  to  $340.5 \pm 543.4$  ind.m<sup>-3</sup> (n=28) followed by *Euterpina acutifrons*, *Oithona plumifera*, *Pseudodiaptomus* nov. sp., *Calocalanus pavo*, *Paracalanus aculiatu*s and *Macrosetella gracilis* (Table 5.3). The second dominant species such as *Acrocalanus longicornis*, *A. gibber*, *Clausocalanus furcatus*, *O. spinirostris*, *O. rigida*, and *Paracalanus parvus* were contributed with relative abundance between 1.01% and 1.64%. The rest of the species ranged from 0.01% to 0.81% and contributed by *Hemicyclops* sp. (0.97%), *Acartia erythraea* (0.81%), *T. (A.) andamanensis* (0.65%), *Subeucalanus pileatus* (0.60%), *Canthocalanus pauper* (0.61%) and *Centropages orsinii* (0.59%).

#### 5.2.2.2. Carbyn's Cove (St.2)

In this region, 4 families namely Clausocalanidae, Pseudocyclopidae, Tegastidae and Peltidiidae were not recorded. Families such as Oithonidae, Pseudodiaptomidae and Paracalanidae were dominant followed by Corycaeidae, Oncaeidae, Acartiidae, Centropagidae and Euterpinidae (Fig. 5.2b). Carbyn's Cove area found to be enriched with 66 species, of which 4 species (*Acartia spinicauda*, *Cosmocalanus darwini*, *Euchaeta concinna* and *Labidocera bataviae*) were found to be rare and occurred only in this area (Table 5.3). Species such as, *Clausocalanus furcatus*, *C. arcuicornis*, *Acrocalanus gracilis*, *Labidocera acuta*, *Distiocus minor* and *Tegastes* sp. were absent in this area. In Carbyn's Cove, *Pseudodiaptomus* nov. sp. (20.83%), *Oithona brevicornis* (19.67%), *O. oculata* (15.05%), *Parvocalanus* sp. (5.93%), *Bestiolina similis* (5.08%) and *Corycaeus* spp. (4.63%) were relatively dominant species with average density ranged from  $100.4 \pm 107.0$  to  $452.1 \pm 688.3$  ind.m<sup>-3</sup> (n=28) followed by *Paracalanus parvus*, *Oncaea* spp., *Centropages orsinii*, *Euterpina acutifrons*, *Acartia erythraea* and *O. rigida* (Table 5.3). The second dominant species such as *O. plumifera*, *Farranula gibbula*, *O. spinirostris*, *Acartia bispinosa*, *Acrocalanus gibber*, *A. longicornis* and *Calocalanus pavo* contributed 0.52% and

1.50%. The rest of the constituents ranged from 0.01% to 0.46%, made by *Calocalanus plumulosus* (0.46%), *Paracalanus aculiatu*s (0.45%) and *Oithona linearis* (0.42%).

### 5.2.2.3. Chattam (St.3)

In Chattam, the bulk of the individuals belonged to the family Paracalanidae with 55.08% followed by Corycaeidae, Oncaeidae, Oithonidae, Euterpinidae, Arietellidae and Pseudodiaptomidae (Fig. 5.2c). Families such as, Euchaetidae, Pseudocyclopidae, Peltidiidae and Monstrillidae were not recorded in this area. Other families such as Acartiidae, Calanidae, Centropagidae, Clausocalanidae and Pontellidae were contributed between 0.50% and 0.87%. Chattam was found to be enriched with 67 species, of which 2 species (*Pontella fera* and *Pontella denticauda*) were found to be rare and occurred only in this area. In Chattam, the bulk of abundance belonged to four species (72.26%), *Parvocalanus* sp. (33.24%), *Bestiolina similis* (15.75%), *Corycaeus* spp. (14.29%) and *Oncaea* spp. (8.98) followed by *Euterpina acutifrons*, *Oithona brevicornis* and *Paracalanus indicus* with average abundance ranged from  $53.9 \pm 79.1$  to  $836.8 \pm 1277.2$  ind.m<sup>-3</sup> (n=28). Other dominant species included *Metacalanus aurivilli*, *O. plumifera*, *O. oculata*, *Acrocalanus gibber*, *O. rigida*, *Pseudodiaptomus compactus*, *Farranula gibbula*, *O. similis*, *O. spinirostris*, *Acartia erythraea*, *Canthocalanus pauper*, *Calocalanus pavo* and *A. longicornis* were made up to 0.61% and 1.94%.

### 5.2.2.4. Chidiyatapu (St.4)

The families namely, Paracalanidae, Corycaeidae, Oncaeidae and Oithonidae were dominant followed by Pontellidae, Clausocalanidae, Euterpinidae, Calanidae, Acartiidae and Centropagidae (Fig. 5.2d). Other families like, Miraciidae, Clausidiidae, Ectinosomatidae were contributed 0.99%, 0.84% and 0.63% respectively to the total copepod abundance. Only, Euchaetidae was not recorded in this station. This area enriched with 70 species, of which 4 species viz. (*Calanopia thompsoni*, *Labidocera acutifrons*, *Pontellopsis macronyx* and *Peltidium* sp.) were found to be rare and occurred only in this area while, *Temora turbinata* was absent only from Chidiyatapu. In Chidiyatapu, *Corycaeus* spp. (12.90%), *Bestiolina similis* (12.38%), *Oncaea* spp. (11.43%), *Paracalanus parvus* (10.40%), *Parvocalanus* sp. (9.20%), *Calocalanus pavo* (4.76%) and *Farranula gibbula* (4.10%) were relatively dominant species with average density ranged from  $70.1 \pm 51.0$  to  $221.0 \pm 155.7$  ind.m<sup>-3</sup> (n=16) (Table 5.3) followed by *Oithona brevicornis*, *O. oculata*, *Acrocalanus gibber*, *Clausocalanus furcatus*,

*Euterpina acutifrons*, *Calocalanus longispinus*, *Calanopia minor*, *Canthocalanus pauper*, *O. similis*, *O. rigida*, *A. longicornis* and *Acartia bispinosa* made up to 1.21% and 3.67%. The second dominant species such as *Macrosetella gracilis*, *Hemicyclops* sp., *Acartia erythraea*, *Centropages orsinii* and *Calocalanus plumulosus* contributed with low abundance (0.51% and 0.93%).

#### 5.2.2.5. Junglighat (St.5)

The bulk of the individuals belonged to the family Paracalanidae and contributed 67.85% to the copepod population followed by Oithonidae, Corycaeidae, Euterpinidae and Oncaeidae (Fig. 5.2e). In Junglighat, 8 families namely, Candaciidae, Euchaetidae, Lucicutiidae, Pseudocyclopidae, Scolecitrichidae, Sapphirinidae, Peltidiidae and Monstrillidae did not recorded during the study period. Other families were contributed low and ranged between 0.01% and 0.60%. Junglighat was found to be enriched with 46 species, of which *Pseudodiaptomus marinus* recorded only in this area while, *Acartia bispinosa*, *Lucicutia flavicornis*, *Calocalanus plumulosus*, *Calanopia minor*, *Copilia mirabilis* and *Sapphirina stellata* were not recorded in Junglighat. In this area, the bulk of density belonged to *Parvocalanus* sp. (46.81%) with average density of  $966.8 \pm 815.1 \text{ ind.m}^{-3}$  (n=28) followed by *Bestiolina similis* (17.90%), *Corycaeus* spp. (7.75%), *Oithona brevicornis* (5.73%), *Euterpina acutifrons* (4.24%), *Oncaea* spp. (3.87%) and *O. oculata* (3.27%) (Table 5.3). The second dominant species were *O. rigida*, *A. gibber*, *Pseudodiaptomus compactus*, *A. longicornis*, *O. linearis*, *Paracalanus parvus*, *Canthocalanus pauper*, *Acartia erythraea* and *Metacalanus aurivilli* and contributed with relative abundance between 0.49% and 1.90%.

#### 5.2.3. Copepod species diversity

The average values of Shannon diversity ( $H'$ ) and evenness ( $J'$ ) were found to be higher at Chidiyatapu (St.4) followed by Burmanallah (St.1) and Chattam (St.3) (Table 5.4). The average richness value ( $4.594 \pm 1.481$ ) and number of species ( $34.2 \pm 9.8$ ) was maximum in Burmanallah (St.1) with the range of 21 to 56 species and the highest

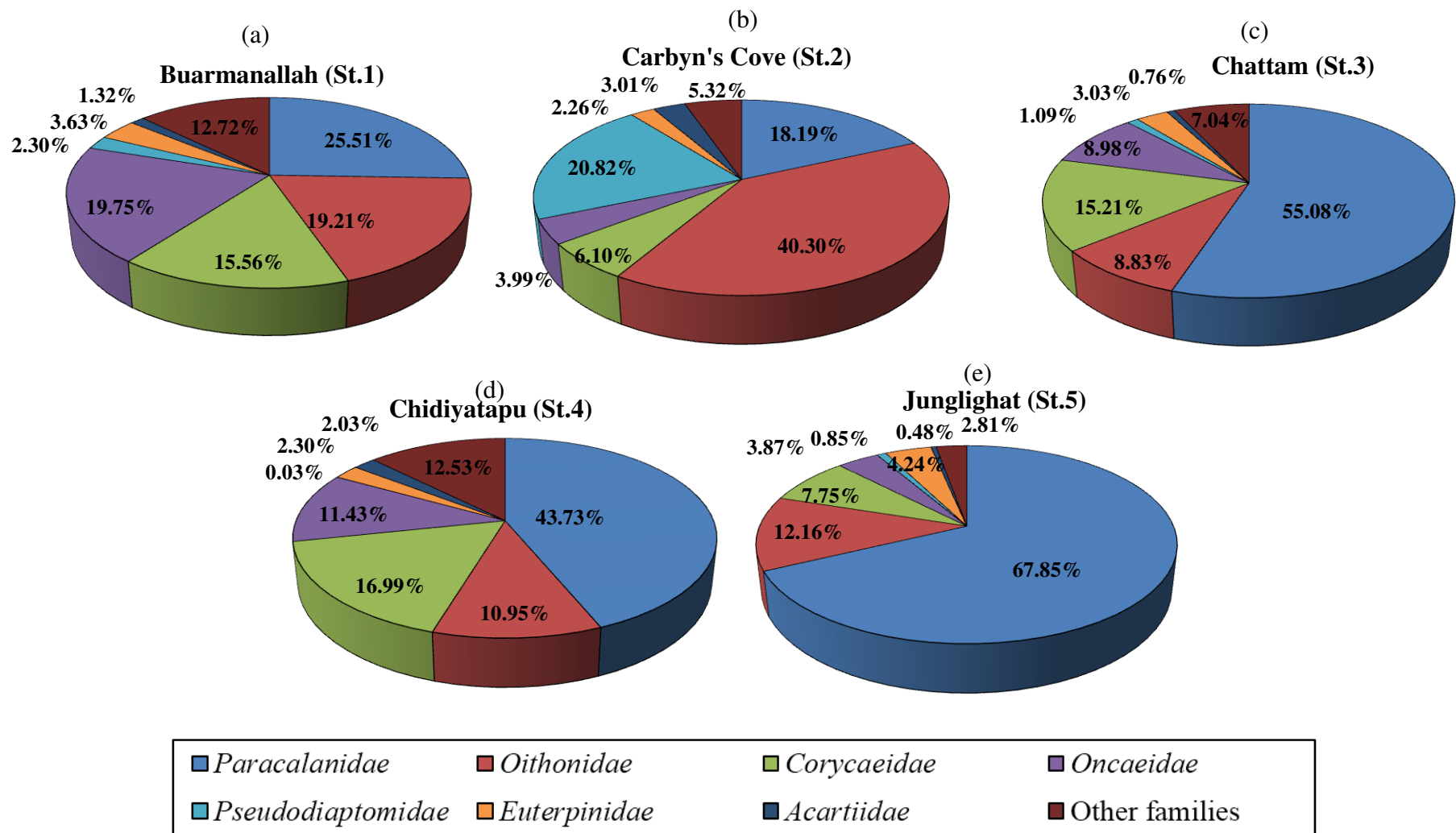


Fig. 5.2. Relative abundance of copepod families at different stations in the study area.



**Table 5.2. Occurrence of copepod species recorded in the study area.**

Species	Burmanallah (St.1)	Carbyn's Cove (St.2)	Chattam (St.3)	Chidyatapu (St.4)	Junglightat (St.5)
<i>Acartia erythraea</i>	*	*	*	*	*
<i>A. bispinosa</i>	**	**	**	**	-
<i>A. negligens</i>	+	+	-	+	-
<i>A. spinicauda</i>	-	***	-	-	-
<i>Metacalanus aurivilli</i>	*	*	*	*	*
<i>Canthocalanus pauper</i>	*	*	*	*	*
<i>Mesocalanus tenuicornis</i>	*	*	*	*	*
<i>Nannocalanus minor</i>	+	+	-	+	-
<i>Undinula vulgaris</i>	+	+	-	+	-
<i>Cosmocalanus darwini</i>	-	***	-	-	-
<i>Candacia bradyi</i>	+	-	+	-	-
<i>C. catula</i>	+	-	+	+	-
<i>C. discaudata</i>	+	+	+	-	-
<i>Paracandacia truncata</i>	-	+	-	+	-
<i>Centropages furcatus</i>	*	*	*	*	*
<i>C. orsinii</i>	*	*	*	*	*
<i>C. calaninus</i>	+	+	+	-	-
<i>C. elongatus</i>	+	-	+	+	-
<i>Clausocalanus furcatus</i>	**	-	**	**	**
<i>C. arcuicornis</i>	**	-	**	**	**
<i>Eucalanus attenuatus</i>	-	+	-	+	-
<i>E. monachus</i>	-	-	+	-	+
<i>Subeucalanus subcrassus</i>	*	*	*	*	*
<i>S. crassus</i>	+	+	-	-	-
<i>S. pileatus</i>	+	-	+	-	+
<i>S. mucronatus</i>	+	+	+	-	-
<i>S. subtenuis</i>	+	-	+	+	-
<i>Euchaeta concinna</i>		***	-	-	-
<i>E. indica</i>	+	+	-	-	-
<i>Lucicutia flavicornis</i>	**	**	**	**	-
<i>Acrocalanus gibber</i>	*	*	*	*	*
<i>A. longicornis</i>	*	*	*	*	*
<i>A. gracilis</i>	**	-	**	**	**
<i>Bestiolina similis</i>	*	*	*	*	*
<i>Calocalanus pavo</i>	*	*	*	*	*
<i>C. longispinus</i>	+	-	+	+	-
<i>C. plumulosus</i>	**	**	**	**	-
<i>C. styliremis</i>	+	+	+	-	-
<i>Paracalanus parvus</i>	*	*	*	*	*
<i>P. aculiatu</i>	*	*	*	*	*

Diversity and spatio-temporal distribution of copepods

Species	Burmanallah (St.1)	Carbyn's Cove (St.2)	Chattam (St.3)	Chidyatapu (St.4)	Junglighat (St.5)
<i>P. indicus</i>	+	+	+	-	-
<i>P. denudatus</i>	***	-	-	-	-
<i>Parvocalanus</i> sp.	*	*	*	*	*
<i>Calanopia minor</i>	**	**	**	**	-
<i>C. aurivilli</i>	***	-	-	-	-
<i>C. elliptica</i>	*	*	*	*	*
<i>C. thompsoni</i>	-	-	-	***	-
<i>Labidocera acuta</i>	**	-	**	**	**
<i>L. pavo</i>	+	+	-	+	-
<i>L. minuta</i>	-	**	**	**	**
<i>L. madurae</i>	*	*	*	*	*
<i>L. laevidentata</i>	+	+	-	+	-
<i>L. detruncata</i>	***	-	-	-	-
<i>L. bataviae</i>	-	***	-	-	-
<i>L. acutifrons</i>	-	-	-	***	-
<i>Pontellina plumata</i>	+	-	+	+	-
<i>Pontellopsis macronyx</i>	-	-	-	***	-
<i>Pontella fera</i>	-	-	***	-	-
<i>P. denticauda</i>	-	-	***	-	-
<i>Pseudocyclops</i> sp.	+	-	-	+	-
<i>Pseudodiaptomus</i> nov. sp.	+	+	-	+	-
<i>P. compactus</i>	-	-	+	-	+
<i>P. marinus</i>	-	-	-	-	***
<i>Scoleciothrix danae</i>	-	+	+	+	-
<i>Scolecithricella minor</i>	-	+	+	+	-
<i>Temora turbinata</i>	**	**	**	-	**
<i>T. discaudata</i>	*	*	*	*	*
<i>T. stylifera</i>	+	+	-	-	-
<i>Tortanus (Atortus) andamanensis</i>	***	-	-	-	-
<i>T. (A.) sigmoides</i>	***	-	-	-	-
<i>T. (A.) murrayi</i>	***	-	-	-	-
<i>T. (Tortanus) gracilis</i>	-	**	**	**	**
<i>Corycaeus</i> spp.	*	*	*	*	*
<i>Farranula gibbula</i>	*	*	*	*	*
<i>Oithona oculata</i>	*	*	*	*	*
<i>O. similis</i>	-	+	+	+	-
<i>O. brevicornis</i>	-	**	**	**	**
<i>O. rigida</i>	*	*	*	*	*
<i>O. spinirostris</i>	*	*	*	*	*
<i>O. plumifera</i>	*	*	*	*	*
<i>O. linearis</i>	-	**	**	**	**
<i>Oncaea</i> spp.	*	*	*	*	*

Diversity and spatio-temporal distribution of copepods

Species	Burmanallah (St.1)	Carbyn's Cove (St.2)	Chattam (St.3)	Chidiyatapu (St.4)	Junglighat (St.5)
<i>Copilia vitrea</i>	+	+	-	-	+
<i>C. mirabilis</i>	**	**	**	**	-
<i>Sapphirina stellata</i>	**	**	**	**	-
<i>Hemicyclops</i> sp.	*	*	*	*	*
<i>Microsetella norvegica</i>	*	*	*	*	*
<i>M. rosea</i>	*	*	*	*	*
<i>Euterpina acutifrons</i>	*	*	*	*	*
<i>Miracia efferata</i>	+	-	-	+	-
<i>Macrosetella gracilis</i>	*	*	*	*	*
<i>Distiocolus minor</i>	**	-	**	**	**
<i>Clytemnestra scutellata</i>	*	*	*	*	*
<i>Tegastes</i> sp.	**	-	**	**	**
<i>Peltidium</i> sp.	-	-	-	***	-
Monstrilloida	*	*	*	*	*

+: present; - : absent; \*: common to all stations; \*\*: present in 4 stations; \*\*\*: rare

number of species was found during the month of April 2014 (S= 56) followed by 51 and 50 species in the May and June 2013 respectively. The lowest number of species was found in Junglighat (St.5) followed by Carbyn's Cove (St.2) with  $16.6 \pm 5.4$  (n=28) and  $22.7 \pm 7.5$  (n=28) respectively (Table 5.4). Shannon diversity index showed that the copepod species diversity was maximum in Chidiyatapu ( $3.756 \pm 0.380$ , n=16) that ranged from 3.185 and 4.332, followed by Burmanallah ( $3.520 \pm 0.678$ , n=28) and Chattam ( $3.102 \pm 0.678$ , n=28) (Fig. 5.3a). The values of Margalef species richness at Burmanallah ranged from 2.473 to 7.808, Chidiyatapu ranged from 2.873 to 6.481 followed by Chattam (2.184 to 7.577), Carbyn's Cove (1.039 to 5.283) and Juglighat (1.045 to 4.178) (Fig. 5.3b). The Pielou's evenness ( $J'$ ) index was maximum in the station Chidiyatapu ( $0.739 \pm 0.056$ , n=16) followed by Burmanallah ( $0.699 \pm 0.120$ , n=28) and the remaining stations followed similar pattern as that of diversity and richness. In Junglighat, all diversity indices were found to be least, except the Simpson dominance (Lambda) index (Fig. 5.3). The average of dominance index was maximum in Junglighat ( $0.321 \pm 0.173$ , n=28) followed by Catbyn's Cove ( $0.299 \pm 0.195$ , n=28).

**Table 5.3. Density and relative abundance of copepod species recorded in the study area.**

Species	Burmanallah (St.1)		Carbyn's Cove (St.2)		Chattam (St.3)		Chidiyatapu (St.4)		Junglighat (St.5)	
	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%
<i>Acartia erythraea</i>	13.9±25.9	0.81	45.2±51.6	2.08	18.3±29.7	0.73	13.4±20.9	0.78	9.9±12.5	0.48
<i>A. bispinosa</i>	6.3±10.9	0.36	14.7±20.9	0.68	0.8±2.1	0.03	20.7±51.8	1.21	-	-
<i>A. negligens</i>	2.7±8.5	0.16	1.8±3.3	0.08	-	-	0.7±1.4	0.04	-	-
<i>A. spinicauda</i>	-	-	3.7±19.3	0.17	-	-	-	-	-	-
<i>Metacalanus aurivilli</i>	5.2±10.1	0.30	1.8±4.4	0.08	48.9±86.7	1.94	2.3±4.3	0.13	10.0±10.2	0.49
<i>Canthocalanus pauper</i>	10.4±12.2	0.61	7.4±10.0	0.34	19.2±37.7	0.76	30.2±34.0	1.76	10.5±17.4	0.51
<i>Mesocalanus tenuicornis</i>	2.6±3.5	0.15	1.6±3.5	0.07	2.7±3.3	0.11	3.7±4.2	0.22	1.9±6.4	0.09
<i>Nannocalanus minor</i>	0.5±2.8	0.03	0.8±2.6	0.04	-	-	0.2±0.6	0.01	-	-
<i>Undinula vulgaris</i>	6.6±14.1	0.39	0.8±3.9	0.04	-	-	1.6±2.6	0.09	-	-
<i>Cosmocalanus darwini</i>	-	-	0.6±1.8	0.03	-	-	-	-	-	-
<i>Candacia bradyi</i>	0.4±2.3	0.03	-	-	0.1±0.6	0.00	-	-	-	-
<i>C. catula</i>	1.2±2.0	0.07	-	-	1.5±3.6	0.06	0.4±1.0	0.02	-	-
<i>C. discaudata</i>	0.2±0.9	0.01	2.7±5.6	0.12	2.4±4.1	0.09	-	-	-	-
<i>Paracandacia truncata</i>	-	-	0.1±0.4	0.00	-	-	0.2±0.6	0.01	-	-
<i>Centropages furcatus</i>	2.8±4.2	0.16	0.7±1.7	0.03	8.7±11.4	0.34	4.1±4.8	0.24	5.1±8.1	0.25
<i>C. orsinii</i>	10.1±13.5	0.59	54.8±121.8	2.52	3.1±4.9	0.12	11.3±16.5	0.66	3.9±11.9	0.19
<i>C. calaninus</i>	0.2±1.3	0.01	0.6±1.7	0.03	0.3±0.8	0.01	-	-	-	-
<i>C. elongatus</i>	4.2±6.3	0.24	-	-	0.7±2.6	0.03	1.9±6.6	0.11	-	-
<i>Clausocalanus furcatus</i>	24.6±28.4	1.43	-	-	10.1±12.1	0.40	39.7±39.1	2.32	3.1±5.4	0.15
<i>C. arcuicornis</i>	5.9±6.3	0.34	-	-	2.4±4.3	0.10	2.1±2.9	0.12	0.2±1.1	0.01

Diversity and spatio-temporal distribution of copepods

Table continued

Species	Burmanallah (St.1)		Carbyn's Cove (St.2)		Chattam (St.3)		Chidiyatapu (St.4)		Junglighat (St.5)	
	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%
<i>Eucalanus attenuatus</i>	-	-	4.3±12.2	0.20	-	-	0.5±1.2	0.03	-	-
<i>E. monachus</i>	-	-	-	-	0.7±3.5	0.03	-	-	3.2±11.1	0.15
<i>Subeucalanus subcrassus</i>	3.4±4.9	0.20	2.6±5.0	0.12	3.5±6.8	0.14	0.1±0.5	0.01	4.1±7.9	0.20
<i>S. crassus</i>	1.4±2.8	0.08	0.9±4.2	0.04	-	-	-	-	-	-
<i>S. pileatus</i>	10.3±26.8	0.60	-	-	4.4±11.3	0.17	-	-	1.4±4.65	0.07
<i>S. mucronatus</i>	0.9±1.9	0.05	0.5±1.60	0.02	0.5±1.5	0.02	-	-	-	-
<i>S. subtenuis</i>	2.1±3.3	0.12	-	-	1.8±5.2	0.07	1.9±7.8	0.11	-	-
<i>Euchaeta concinna</i>	-	-	0.6±1.6	0.03	-	-	-	-	-	-
<i>E. indica</i>	1.6±2.1	0.09	0.8±2.0	0.04	-	-	-	-	-	-
<i>Lucicutia flavicornis</i>	6.3±7.9	0.37	0.4±1.1	0.02	3.1±5.1	0.12	1.8±2.5	0.10	-	-
<i>Acrocalanus gibber</i>	26.8±41.5	1.56	13.1±21.8	0.60	37.6±32.7	1.49	42.8±30.4	2.50	31.4±50.3	1.52
<i>A. longicornis</i>	28.2±22.9	1.64	11.2±14.9	0.52	15.2±16.7	0.61	25.7±28.9	1.50	14.9±30.6	0.72
<i>A. gracilis</i>	4.2±8.4	0.25	-	-	7.5±22.7	0.30	1.5±2.5	0.09	3.2±10.3	0.15
<i>Bestiolina similis</i>	141.8±185.9	8.25	110.2±137.6	5.08	396.5±707.4	15.75	212.1±226.2	12.38	369.7±322.6	17.90
<i>Calocalanus pavo</i>	36.8±36.5	2.14	21.0±28.9	0.97	15.2±29.1	0.60	81.6±94.9	4.76	0.1±0.5	0.00
<i>C. longispinus</i>	2.4±4.5	0.14	-	-	2.1±3.7	0.08	37.0±85.7	2.16	-	-
<i>C. plumulosus</i>	0.8±1.8	0.04	9.9±19.3	0.46	2.8±5.8	0.11	8.7±10.8	0.51	-	-
<i>C. styliremis</i>	2.7±7.3	0.16	0.9±5.0	0.04	3.5±5.2	0.14	-	-	-	-
<i>Paracalanus parvus</i>	17.3±17.1	1.01	88.5±174.1	4.08	10.8±9.3	0.43	178.1±163.4	10.40	13.1±17.2	0.63
<i>P. aculiatus</i>	35.5±72.6	2.07	9.9±16.9	0.45	4.5±9.6	0.18	4.2±5.5	0.24	2.1±3.6	0.10

Diversity and spatio-temporal distribution of copepods

Table continued

Species	Burmanallah (St.1)		Carbyn's Cove (St.2)		Chattam (St.3)		Chidiyatapu (St.4)		Junglighat (St.5)	
	$\bar{X}\pm\text{SD}$	%	$\bar{X}\pm\text{SD}$	%	$\bar{X}\pm\text{SD}$	%	$\bar{X}\pm\text{SD}$	%	$\bar{X}\pm\text{SD}$	%
<i>P. indicus</i>	7.4±10.4	0.43	1.4±4.9	0.06	53.9±79.1	2.14	-	-	-	-
<i>P. denudatus</i>	0.4±1.9	0.02	-	-	-	-	-	-	-	-
<i>Parvocalanus</i> sp.	135.5±144.9	7.89	128.8±172.6	5.93	836.8±1277.7	33.24	157.6±131.3	9.20	966.8±815.1	46.81
<i>Calanopia minor</i>	3.7±4.9	0.22	2.31±3.79	0.11	4.4±7.3	0.17	34.8±53.0	2.03	-	-
<i>C. aurivilli</i>	0.2±1.0	0.01	-	-	-	-	-	-	-	-
<i>C. elliptica</i>	2.1±2.7	0.12	1.4±3.9	0.06	2.1±4.2	0.08	4.1±4.7	0.24	0.5±1.2	0.02
<i>C. thompsoni</i>	-	-	-	-	-	-	3.8±11.9	0.22	-	-
<i>Labidocera acuta</i>	2.7±5.7	0.16	-	-	1.1±2.3	0.04	1.7±2.9	0.10	1.4±2.6	0.07
<i>L. pavo</i>	2.6±4.1	0.15	0.5±1.8	0.02	-	-	0.2±0.6	0.01	-	-
<i>L. minuta</i>	-	-	0.1±0.5	0.00	4.6±6.7	0.18	5.8±7.9	0.34	1.1±2.7	0.05
<i>L. madurae</i>	1.6±2.4	0.09	1.8±3.9	0.08	1.8±3.0	0.07	1.5±2.3	0.09	0.1±0.5	0.00
<i>L. laevidentata</i>	1.7±3.8	0.10	0.5±2.2	0.02	-	-	0.9±1.9	0.05	-	-
<i>L. detruncata</i>	1.0±3.2	0.06	-	-	-	-	-	-	-	-
<i>L. bataviae</i>	-	-	0.1±0.4	0.00	-	-	-	-	-	-
<i>L. acutifrons</i>	-	-	-	-	-	-	0.7±1.7	0.04	-	-
<i>Pontellina plumata</i>	1.2±1.9	0.07	-	-	0.7±2.0	0.03	0.4±1.2	0.02	-	-
<i>Pontellopsis macronyx</i>	-	-	-	-	-	-	0.8±1.6	0.04	-	-
<i>Pontella fera</i>	-	-	-	-	1.4±3.4	0.06	-	-	-	-
<i>P. denticauda</i>	-	-	-	-	0.9±3.2	0.04	-	-	-	-
<i>Pseudocyclops</i> sp.	5.0±10.2	0.29	-	-	-	-	0.4±1.1	0.02	-	-
<i>Pseudodiaptomus</i> nov. sp.	39.6±96.8	2.31	452.1±688.3	20.83	-	-	0.1±0.2	0.00	-	-

Diversity and spatio-temporal distribution of copepods

Table continued

Species	Burmanallah (St.1)		Carbyn's Cove (St.2)		Chattam (St.3)		Chidiyatapu (St.4)		Junglighat (St.5)	
	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%
<i>P. compactus</i>	-	-	-	-	27.4±71.1	1.09	-	-	17.4±39.6	0.84
<i>P. marinus</i>	-	-	-	-	-	-	-	-	0.1±0.7	0.01
<i>Scoleciothrix danae</i>	-	-	2.2±5.8	0.10	1.2±1.9	0.05	1.3±3.6	0.07	-	-
<i>Scolecithricella minor</i>	-	-	0.9±2.2	0.04	3.9±11.2	0.15	2.6±3.4	0.15	-	-
<i>Temora turbinata</i>	1.2±2.3	0.07	3.3±8.7	0.15	0.3±1.0	0.01	-	-	1.5±7.0	0.07
<i>T. discaudata</i>	3.3±6.6	0.19	0.3±1.4	0.02	1.2±3.3	0.05	4.0±5.5	0.23	0.2±1.1	0.01
<i>T. stylifera</i>	0.1±0.5	0.01	0.4±1.4	0.02	-	-	-	-	-	-
<i>Tortanus (Atortus) andamanensis</i>	11.1±31.8	0.65	-	-	-	-	-	-	-	-
<i>T. (A.) sigmoides</i>	0.8±2.1	0.05	-	-	-	-	-	-	-	-
<i>T. (Tortanus) gracilis</i>	-	-	0.3±1.1	0.01	3.4±6.1	0.14	1.6±2.8	0.09	0.2±0.8	0.01
<i>T. (A.) murrayi</i>	0.3±1.4	0.02	-	-	-	-	-	-	-	-
<i>Corycaeus</i> spp.	199.0±180.8	11.58	100.4±106.9	4.63	359.7±372.3	14.29	221.0±155.7	12.90	160.0±119.3	7.75
<i>Farranula gibbula</i>	69.2±97.4	4.03	32.2±79.2	1.48	23.1±26.2	0.92	70.2±51.0	4.10	-	-
<i>Oithona oculata</i>	246.4±440.5	14.34	326.6±1015.8	15.05	41.5±93.6	1.65	57.4±63.2	3.35	67.6±117.2	3.27
<i>O. similis</i>	-	-	7.1±11.8	0.33	15.7±43.5	0.62	28.9±25.5	1.69	-	-
<i>O. brevicornis</i>	-	-	426.8±706.3	19.67	57.2±114.5	2.27	62.8±49.1	3.67	118.4±260.5	5.73
<i>O. rigida</i>	18.2±58.3	1.06	44.9±95.9	2.07	36.4±53.1	1.44	25.8±27.9	1.51	39.2±96.9	1.90
<i>O. spinirostris</i>	22.3±35.4	1.29	27.9±66.5	1.29	16.9±52.0	0.67	5.9±8.4	0.35	4.3±17.9	0.21
<i>O. plumifera</i>	44.5±101.3	2.59	32.6±56.4	1.50	43.8±70.9	1.74	5.1±7.9	0.30	6.7±7.4	0.33
<i>O. linearis</i>	-	-	9.2±14.9	0.42	10.8±20.2	0.43	1.7±2.9	0.10	14.9±60.4	0.72
<i>Oncaea</i> spp.	340.5±543.4	19.82	86.7±99.9	4.00	225.9±276.1	8.98	195.9±84.6	11.43	79.9±189.9	3.87

Diversity and spatio-temporal distribution of copepods

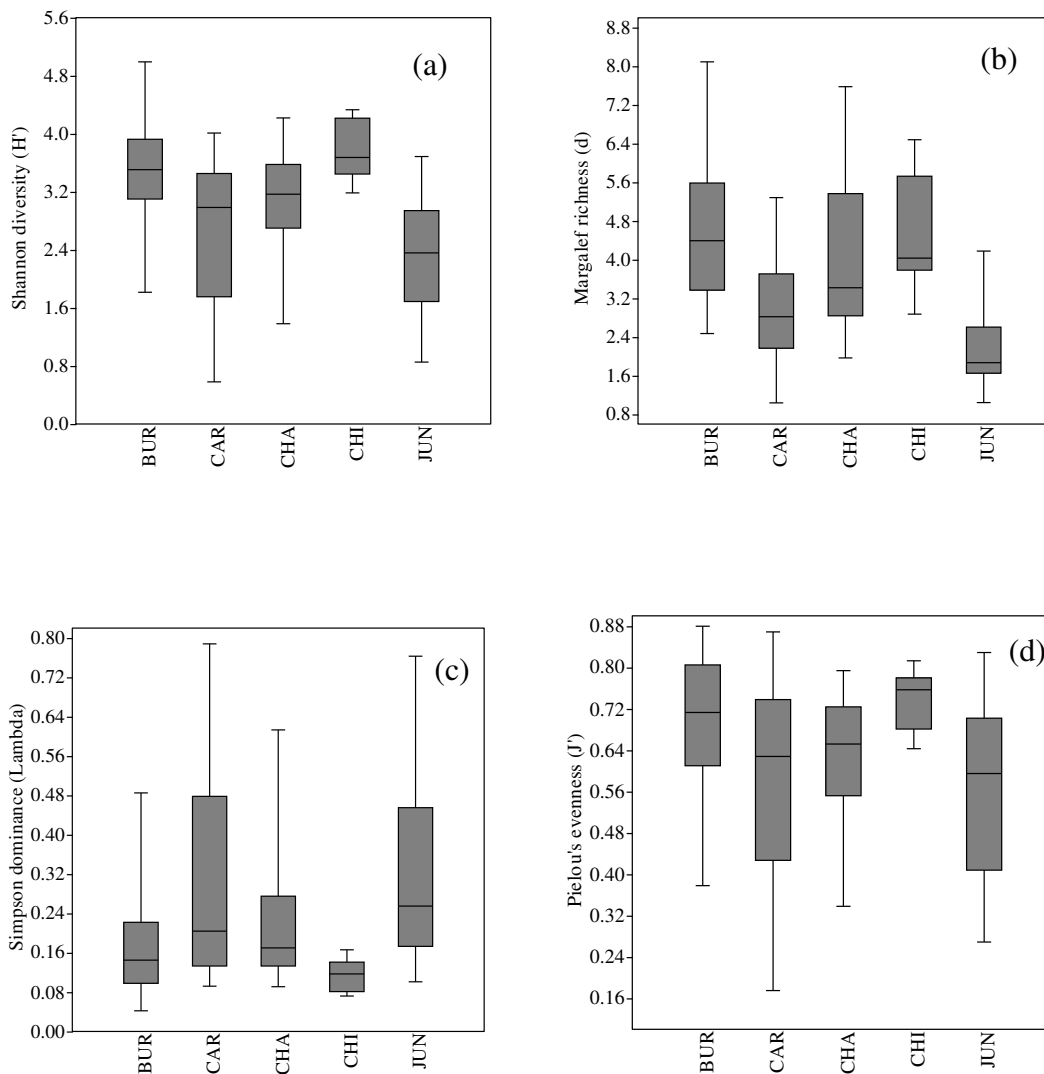
Table continued

Species	Burmanallah (St.1)		Carbyn's Cove (St.2)		Chattam (St.3)		Chidiyatapu (St.4)		Junglighat (St.5)	
	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%	$\bar{X}\pm SD$	%
<i>Copilia vitrea</i>	1.2±2.8	0.07	1.5±4.2	0.07	-	-	-	-	0.1±0.5	0.00
<i>C. mirabilis</i>	0.9±2.4	0.05	0.3±0.9	0.01	1.8±3.5	0.07	2.0±2.1	0.12	-	-
<i>Sapphirina stellata</i>	1.7±2.1	0.10	0.1±0.6	0.01	1.9±2.6	0.08	0.9±1.6	0.05	-	-
<i>Hemicyclops</i> sp.	16.7±24.1	0.97	8.4±13.0	0.38	12.4±15.7	0.49	14.3±21.9	0.84	4.3±5.9	0.21
<i>Microsetella norvegica</i>	1.9±4.5	0.11	1.4±2.4	0.06	3.8±6.9	0.15	7.3±14.7	0.43	0.8±1.8	0.04
<i>M. rosea</i>	5.4±5.7	0.31	5.2±8.7	0.24	6.3±10.5	0.25	3.4±4.1	0.20	1.5±3.7	0.07
<i>Euterpina acutifrons</i>	62.6±170.2	3.64	49.2±74.4	2.27	76.2±92.5	3.03	39.5±29.8	2.30	87.6±128.3	4.24
<i>Miracia efferata</i>	0.3±1.4	0.02	-	-	-	-	0.5±1.1	0.03	-	-
<i>Macrosetella gracilis</i>	35.5±61.8	2.06	1.0±2.7	0.05	4.8±9.6	0.19	15.9±18.5	0.93	1.5±4.4	0.07
<i>Distioculus minor</i>	2.3±3.9	0.13	-	-	1.7±3.0	0.07	0.5±1.1	0.03	0.4±1.2	0.02
<i>Clytemnestra scutellata</i>	2.1±6.4	0.12	0.4±1.9	0.02	2.3±6.4	0.09	0.8±1.4	0.05	0.3±1.1	0.01
<i>Tegastes</i> sp.	3.3±4.9	0.19	-	-	1.1±2.5	0.04	0.6±1.2	0.04	0.8±3.4	0.04
<i>Peltidium</i> sp.	-	-	-	-	-	-	0.6±1.7	0.04	-	-
Monstrilloida	2.7±3.8	0.16	0.4±1.4	0.02	0.1±0.6	0.00	1.5±2.1	0.08	-	-



**Table 5.4. Variation in the copepod species diversity ( $\bar{x}\pm SD$ ) in the study area.**

Indices	Burmanallah	Carbyn's Cove	Chattam	Chidiyatapu	Junglighthat
S	34.2±9.8	22.7±7.5	30.7±10.2	34.9±8.5	16.6±5.4
N	1718.3±956.9	2170.3±1317.4	2517.3±2383.1	1713.3±541.1	2065.4±1142.1
d	4.594±1.481	2.887±0.961	3.963±1.438	4.580±1.119	2.086±0.731
J'	0.699±0.120	0.598±0.177	0.634±0.109	0.739±0.056	0.578±0.162
H'(log2)	3.520±0.678	2.685±0.928	3.102±0.678	3.756±0.380	2.322±0.741
Lambda	0.164±0.095	0.299±0.195	0.209±0.112	0.116±0.032	0.321±0.173



**Fig. 5.3. Monthly variation in copepod species (a) diversity, (b) richness, (c) evenness, (d) dominance in the study area.**

In general, the Burmanallah and Chidiyatapu were rich in copepod species with higher diversity and evenness indices followed by Chattam. However, Carbyn's Cove and Junglighthat area was found with higher dominance and lower evenness values and

lower values of Shannon diversity indices which indicate poor diversity among the stations in the coastal waters of south Andaman (Table 5.4). The number of species and the diversity indices were significantly varied between the station (One-way ANOVA,  $p < 0.01$ ) however, the number of individuals between the stations did not show significant variation ( $p = 0.265$ ). While, the Tukey's pairwise comparison indicated that no significant variation in the number of individuals (N) between the stations. All other diversity indices were significantly varied between Burmanallah (St.1) with Carbyn's Cove (St.2) and Junglighat (St.5), except evenness (J') between Burmanallah Carbyn's Cove. A similar trend was observed between Carbyn's Cove with Chidiyatapu (St.4) and Chattam (St.3) and also, Junglighat with Chidiyatapu and Chattam. In addition, there was no significant difference in the copepod species diversity indices between the Burmanallah, Chattam and Chidiyatapu and between Carbyn's Cove and Junglighat (Table 5.5).

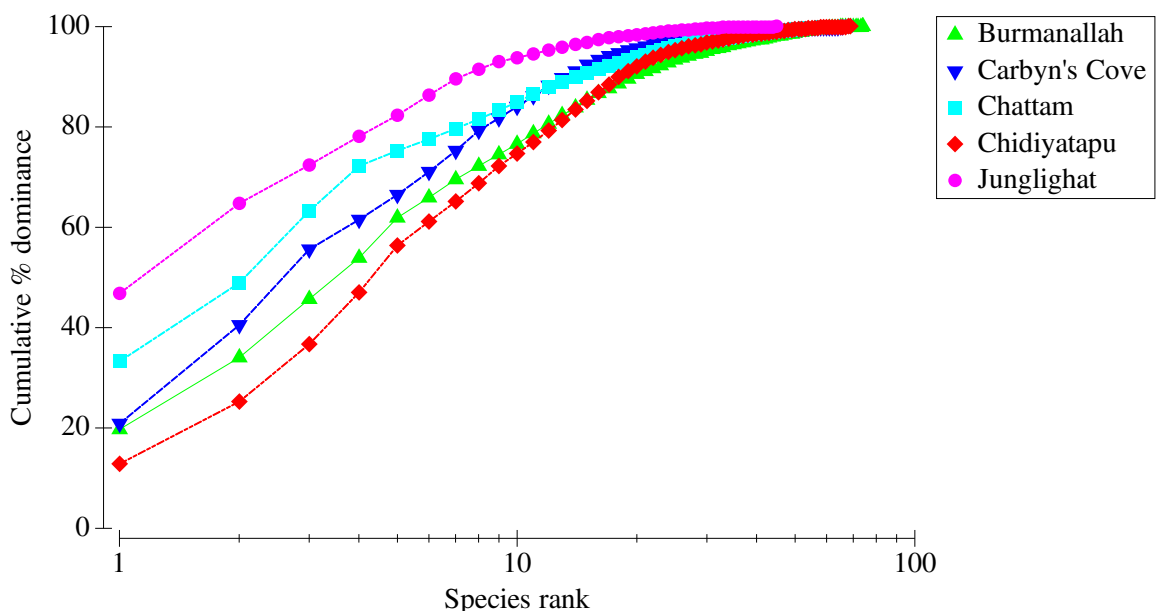
**Table 5.5. Tukey's pairwise comparison of biodiversity indices of copepod species between the stations, the values are significance levels ( $p$ ) of comparison.**

Stations		Diversity indices					
		S	N	H'(log2)	d	J'	Lambda
Burmanallah	Carbyn's Cove	**	0.819	**	**	0.075	*
	Chattam	0.601	0.316	0.263	0.341	0.469	0.803
	Chidiyatapu	0.998	1.000	0.789	1.000	0.851	0.747
	Junglighat	**	0.922	**	**	*	*
Carbyn's Cove	Chattam	*	0.922	0.266	*	0.886	0.162
	Chidiyatapu	**	0.813	**	**	*	**
	Junglighat	0.084	0.999	0.405	0.127	0.987	0.984
Chattam	Chidiyatapu	0.417	0.310	*	0.364	0.061	0.140
	Junglighat	**	0.819	*	**	0.611	*
Chidiyatapu	Junglighat	**	0.918	**	**	**	**

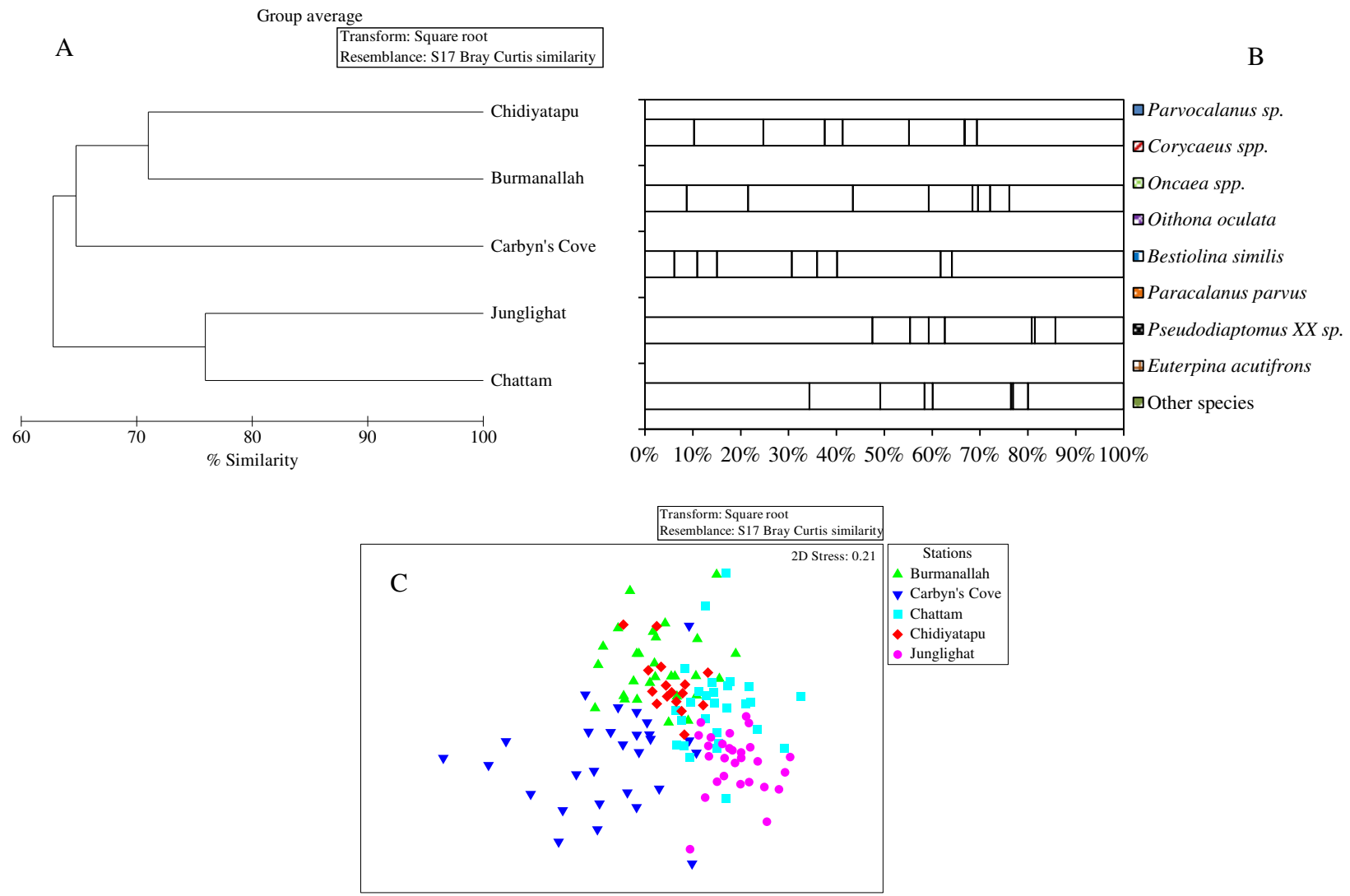
\*\*  $p < 0.001$ ; \*  $p < 0.05$

$K$ -dominance (ABC) curve (Clarke and Warwick, 1994) facilitated discrimination of copepods according to species' relative contribution to the total abundance. While up to 11 and 10 species formed 75% of the total copepod numbers in Chidiyatapu and Burmanallah respectively, it was only 4, 5, and 7 copepod species made up this portion at other stations such as Junglighat, Carbyn's Cove, and Chattam respectively (Fig. 5.4). In all the stations, copepod species composition was analyzed to a higher taxonomic level and subjected to Hierarchical Cluster analysis. The dendrogram of Bray-Curtis similarity indicates that copepod assemblage differed

between the stations. Two distinct groups of stations were delineated with 62.78% similarity (Fig. 5.5a). The group 1 includes Chattam and Junglighat with 75.95% similarity while the group 2 includes Burmanallah, Chidiyatapu and Carbyn's Cove with 64.78% similarity, within Burmanallah and Chidiyatapu was found 71.02% similarity. The population structure varied with sampling stations with distinct separation between the study areas in terms of abundance data of copepod species as illustrated in the non-metric Multidimensional Scaling (nMDS) plots (Fig. 5.5c). The cluster analysis and nMDS was confirmed by one-way ANOSIM which confirmed that copepod population structure were significantly varied between study sites (Global  $R=0.457$ ;  $p=0.001$ ). Multiple pairwise tests also revealed that population structures were significantly different among stations during the study period (Table 5.6). According to a SIMPER analysis, the indicator species mainly contributed to the station that characterized the local habitat are *Oncaea* spp., *Corycaeus* spp. and *Parvocalanus* sp. in Burmanallah with average similarity of 50.55%, *Pseudodiaptomus* nov. sp., *Corycaeus* spp. and *Oithona brevicornis* in Carbyn's Cove (41.82%), *Parvocalanus* sp. and *Corycaeus* spp. in Chattam (51.01%), *Oncaea* spp., *Corycaeus* spp., *Paracalanus parvus* and *Parvocalanus* sp. in Chidiyatapu (60.63%), and *Parvocalanus* sp. in Junglighat with average similarity of 56.44% (Table 5.7).



**Fig. 5.4.** *k*-dominance curve for copepod species abundance data in relation to the stations in the study area.



**Fig. 5.5. (a) Results of cluster analysis for copepod species (b) Relative abundance of important copepod species (c) Multidimensional scaling ordinations of copepod species in the study area.**

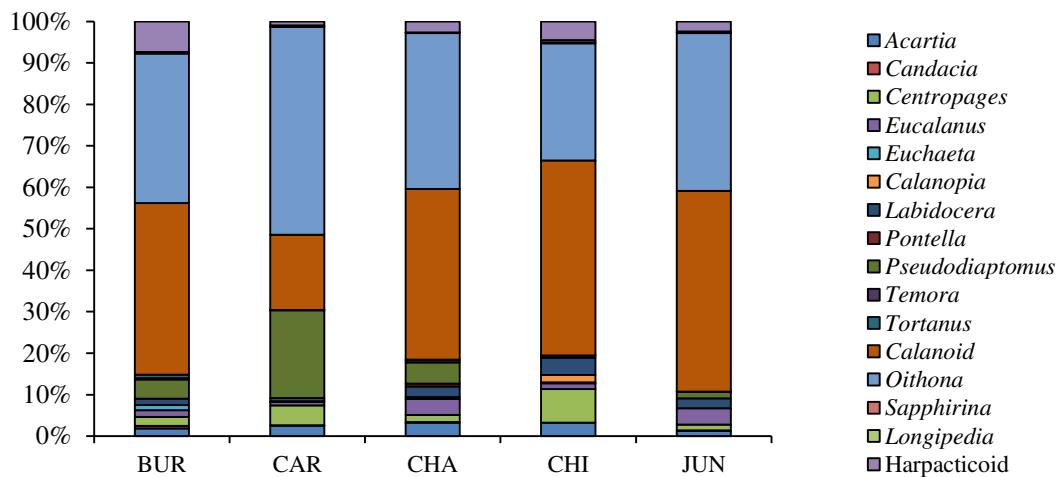
**Table 5.6. Pairwise test of ANOSIM for copepod abundance at different stations. R-statistic value (below diagonal) and corresponding *p* levels (above diagonal).**

Stations	Burmanallah	Carbyn's Cove	Chattam	Chidiyatapu	Junglighat
Burmanallah		**	**	**	**
Carbyn's Cove	0.452		**	*	**
Chattam	0.400	0.464		**	**
Chidiyatapu	0.316	0.240	0.293		**
Junglighat	0.739	0.595	0.306	0.756	

\*\* :  $p=0.001$ ; \* :  $p=0.002$

#### 5.2.4. Copepodids

Among the copepodids, the calanoid and *Oithona* copepodids were most dominant (77.42%) with average abundance of  $224.0 \pm 284.1 \text{ ind.m}^{-3}$  and  $195.1 \pm 227.1 \text{ ind.m}^{-3}$  ( $n=28$ ) respectively followed by harpacticoids (7.36%), *Pseudodiaptomus* copepodids (4.58%) and *Centropages* copepodids (2.11%) in Burmanallah. Whereas, oithonid copepodids were outnumbered (50.20%) in Carbyn's Cove followed by *Pseudodiaptomus* and calanoids with relative abundance of 21.10% and 18.10% respectively, followed by *Centropages* (4.82%) and *Acartia* (2.55%). Also, at other stations, a similar trend as in Burmanallah was observed in the abundance of copepodids with greater contribution by calanoids and *Oithona* copepodids which ranged from 41.11% to 48.38% and 28.23% to 38.10% respectively. In Chattam, abundance of *Pseudodiaptomus* (5.15%), *Eucalanus* (3.81%), *Acartia* (3.28%), harpacticoid (2.62%) and *Labidocera* (2.50%) was noted. *Centropages*, Harpacticoid, *Labidocera* and *Acartia* showed higher abundance at Chidiyatapu (8.10%, 4.50%, 4.20% and 3.27% respectively). At Junglighat, *Eucalanus* (3.91%), *Labidocera* (2.41%), harpacticoid (2.40%), *Pseudodiaptomus* (1.52%), *Centropages* (1.43%) and *Acartia* (1.21%) were relatively more (Fig. 5.6).



**Fig. 5.6. Relative abundance of copepodids among the stations in the study area.**

**Table 5.7. Dissimilarity results from the SIMPER analysis between study stations and copepod species that are responsible for the estimated differences. SIMPER analysis run with a 30% cut off for low contributions.**

Stations	Dissimilarity %	Species	Contribution %	Cumulative %
Burmanallah (St.1) & Carbyn's Cove (St.2)	63.14	<i>Pseudodiaptomus</i> nov. sp.	7.38	7.38
		<i>Oithona brevicornis</i>	7.11	14.49
		<i>Oithona oculata</i>	6.88	21.37
		<i>Oncaea</i> spp.	5.12	26.48
		<i>Parvocalanus</i> sp.	3.78	30.26
Burmanallah (St.1) & Chattam (St.3)	55.82	<i>Parvocalanus</i> sp.	8.03	8.03
		<i>Bestiolina similis</i>	5.29	13.32
		<i>Oithona oculata</i>	5.13	18.44
		<i>Oncaea</i> spp.	5.11	23.56
		<i>Corycaeus</i> spp.	4.01	27.57
		<i>Euterpina acutifrons</i>	3.1	30.66
Carbyn's Cove (St.2) & Chattam (St.3)	63.52	<i>Parvocalanus</i> sp.	8.23	8.23
		<i>Pseudodiaptomus</i> nov. sp.	8.19	16.42
		<i>Oithona brevicornis</i>	6.39	22.81
		<i>Bestiolina similis</i>	5.31	28.12
		<i>Oithona oculata</i>	4.99	33.11
Burmanallah (St.1) & Chidiyatapu (St.4)	51.87	<i>Paracalanus parvus</i>	4.91	4.91
		<i>Oithona oculata</i>	4.9	9.81
		<i>Bestiolina similis</i>	4.56	14.37
		<i>Oncaea</i> spp.	4.03	18.4
		<i>Oithona brevicornis</i>	3.69	22.09
		<i>Parvocalanus</i> sp.	3.48	25.57
		<i>Corycaeus</i> spp.	3.29	28.86
		<i>Farranula gibbula</i>	3.09	31.95
Carbyn's Cove (St.2) & Chidiyatapu (St.4)	59.22	<i>Pseudodiaptomus</i> nov. sp.	8.36	8.36
		<i>Oithona brevicornis</i>	6.37	14.73
		<i>Oithona oculata</i>	5.42	20.16
		<i>Bestiolina similis</i>	4.59	24.74
		<i>Paracalanus parvus</i>	4.13	28.87
		<i>Oncaea</i> spp.	4.07	32.94

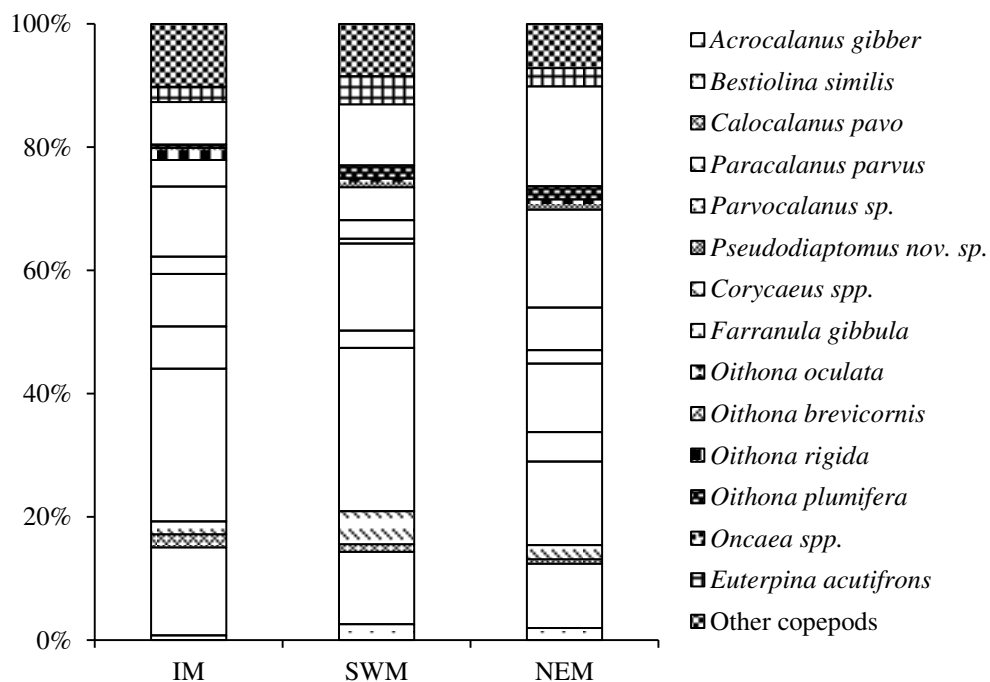
Diversity and spatio-temporal distribution of copepods

Table continued: **Dissimilarity results from the SIMPER analysis between study stations and copepod species that are responsible for the estimated differences. SIMPER analysis run with a 30% cut off for low contributions.**

Stations	Dissimilarity %	Species	Contribution %	Cumulative %
Chattam (St.3) & Chidiyatapu (St.4)	51.24	<i>Parvocalanus</i> sp.	7.61	7.61
		<i>Bestiolina similis</i>	6	13.62
		<i>Paracalanus parvus</i>	5.41	19.02
		<i>Oncaea</i> spp.	4.09	23.12
		<i>Corycaeus</i> spp.	3.97	27.09
		<i>Calocalanus pavo</i>	3.36	30.45
Burmanallah (St.1) & Junglighat (St.5)	61.99	<i>Parvocalanus</i> sp.	10.98	10.98
		<i>Oncaea</i> spp.	6.09	17.07
		<i>Bestiolina similis</i>	5.56	22.63
		<i>Oithona oculata</i>	5.26	27.9
		<i>Oithona brevicornis</i>	3.62	31.51
Carbyn's Cove (St.2) & Junglighat (St.5)	65.02	<i>Parvocalanus</i> sp.	12.2	12.2
		<i>Pseudodiaptomus</i> nov. sp.	9.48	21.69
		<i>Oithona brevicornis</i>	7.77	29.45
		<i>Bestiolina similis</i>	6.61	36.07
Chattam (St.3) & Junglighat (St.5)	51.89	<i>Parvocalanus</i> sp.	10.18	10.18
		<i>Bestiolina similis</i>	7.59	17.76
		<i>Oncaea</i> spp.	5.96	23.72
		<i>Corycaeus</i> spp.	5.16	28.88
		<i>Oithona brevicornis</i>	4.57	33.45
Chidiyatapu (St.4) & Junglighat (St.5)	57.84	<i>Parvocalanus</i> sp.	10.24	10.24
		<i>Bestiolina similis</i>	5.59	15.84
		<i>Paracalanus parvus</i>	5.53	21.37
		<i>Oncaea</i> spp.	5.3	26.67
		<i>Calocalanus pavo</i>	4.36	31.03

### 5.3. Seasonal variation of copepods

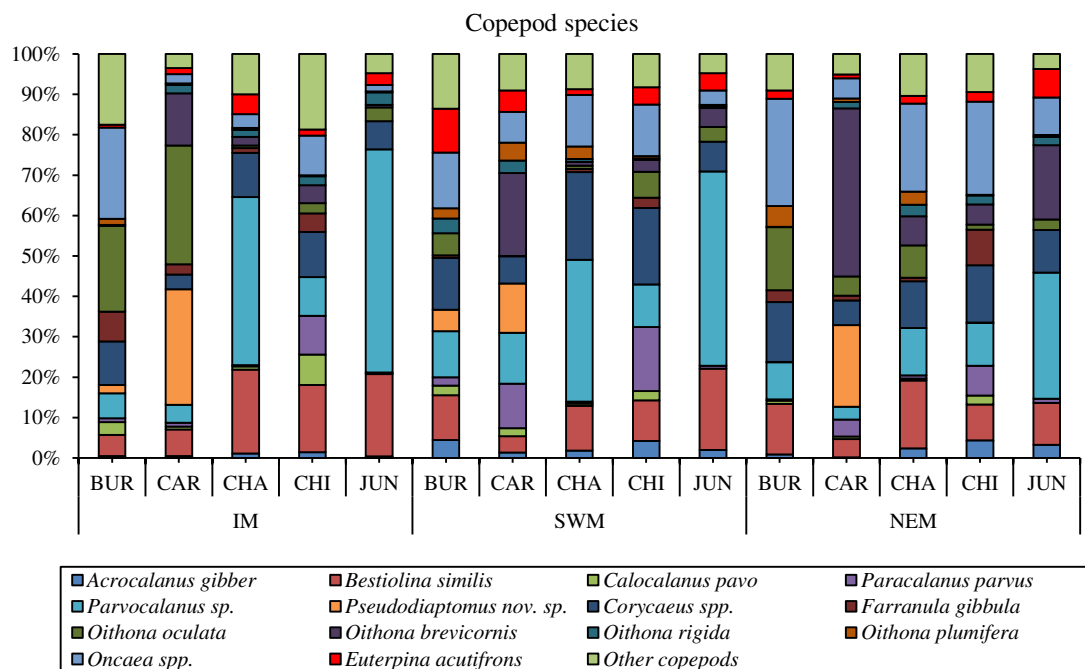
In the present study the seasons were classified into inter monsoon (IM, January-April), southwest monsoon (SWM, May-September) and northeast monsoon (NEM, October-December). Species such as, *Acrocalanus gibber*, *Bestiolina similis*, *Calocalanus pavo*, *Paracalanus parvus*, *Parvocalanus* sp., *Pseudodiaptomus* nov. sp., *Corycaeus* spp., *Farranula gibbula*, *Oithona oculata*, *Oithona rigida*, *Oithona brevicornis*, *Oithona plumifera*, *Oncaea* spp. and *Euterpina acutifrons* which showed maximum contributor to the total abundance of copepods were accessed to find variation among the seasons. Overall, *Parvocalanus* sp. was dominated in IM and SWM with an average abundance of  $525.2 \pm 547.0 \text{ ind.m}^{-3}$  (23.4%) and  $474.6 \pm 421.1 \text{ ind.m}^{-3}$  (24.2%) respectively. In NEM, *Oncaea* spp. was higher (15.3%) followed by *Oithona brevicornis* (15%), *Parvocalanus* sp. (12.7%) *Corycaeus* spp. (10.5%) and *Bestiolina similis* (9.8%) with average abundance of  $275.6 \pm 347.4$ ,  $234.6 \pm 225.9$ ,  $192.8 \pm 67.2$  and  $181.3 \pm 83 \text{ ind.m}^{-3}$  respectively. In IM period, other species namely *Bestiolina similis*, *Oithona oculata*, *Corycaeus* spp. and *Oncaea* spp. recorded with relative abundance of 13.5%, 10.8%, 8% and 6.5% respectively. While in SWM, *Corycaeus* spp. (12.9%), *Bestiolina similis* (10.8%) and *Oncaea* spp. (9.1%) contributed to the relative abundance of copepods (Fig. 5.7).



**Fig. 5.7. Relative abundance of copepod species among the seasons in the study area.**



The species such as *Acrocalanus gibber*, *Paracalanus parvus* and *Euterpina acutifrons* were relatively higher during SWM period at all stations except at Junglight where all three species were higher during NEM and at Chattam, *Paracalanus parvus* and *Euterpina acutifrons* were higher during NEM and IM respectively. *Parvocalanus* sp. was invariably higher during all the seasons and in all stations and relatively lower during NEM that ranged between 64.6 ind.m<sup>-3</sup> to 628.5 ind.m<sup>-3</sup> except at Burmanallah (185.5 ind.m<sup>-3</sup>). *Pseudodiaptomus* nov. sp. was maximum during IM and NEM at Carbyn’s Cove, whereas, at Burmanallah during SWM. *Bestiolina similis*, *Oithona rigida* and *Farranula gibbula* were relatively higher during IM whereas at Burmanallah, the former two species were higher during NEM and SWM respectively and *Farranula gibbula* was maximum during NEM at Chidiyatapu. *Calocalanus pavo* was higher during IM period while during SWM at Carbyn’s Cove. *Corycaeus* spp. and *Oncaea* spp. were abundant during NEM period where as at Chattam and Chidiyatapu where *Corycaeus* spp. was recorded in peak during SWM so also *Oncaea* spp. at Carbyn’s Cove (Fig. 5.8). Overall, maximum production of copepod was found during IM period with average abundance of 2119.4±443.7 ind. m<sup>-3</sup>, however, the seasonal variation of copepod species was not statistically significant (One-way ANOVA,  $p>0.05$ ).



**Fig. 5.8. Relative abundance of major copepod species at different stations in the study area showing seasonal variation.**

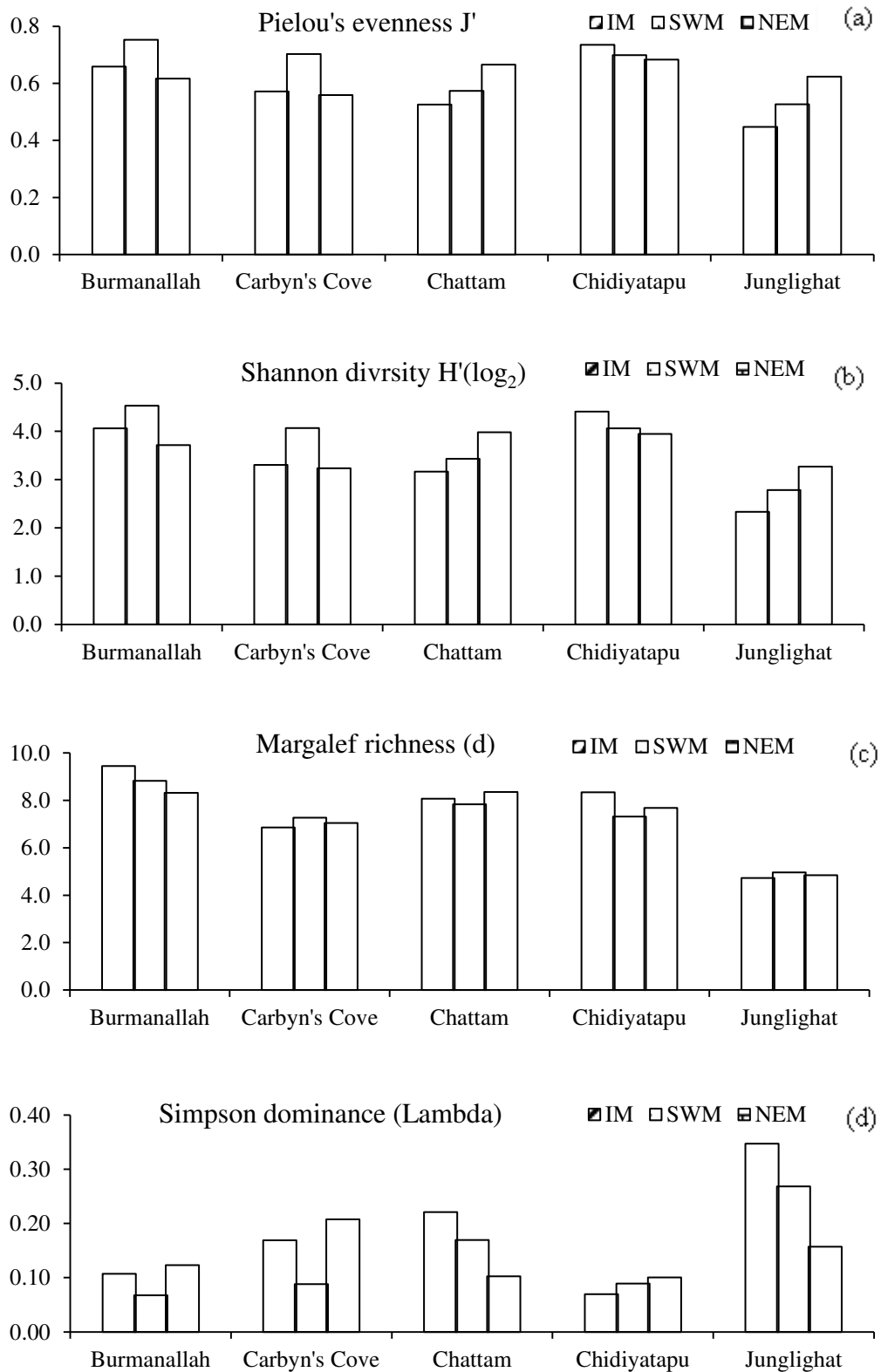
The list of copepod species that showed seasonal variation is presented in the Table 5.8. Some of the species in the table were rarely occurred in the present study namely, *Acartia spinicauda*, *Cosmocalanus darwini*, *Paracalanus denudatus*, *Calanopia aurivilli*, *C. thompsoni*, *Labidocera detruncata*, *L. bataviae*, *Labidocera acutifrons*, *Pontella fera*, *P. denticauda*, *Pseudodiaptomus marinus*, *Tortanus (Atortus) sigmoides*, *T. (A.) murrayi* and *Peltidium* sp.

Few species such as, *Cosmocalanus darwini*, *Paracalanus denudatus*, *Calanopia aurivilli*, *Labidocera detruncata*, *L. bataviae*, *Pontella fera*, *P. denticauda*, *Pseudodiaptomus marinus* and *Tortanus (Atortus) murrayi* were found only during the IM period, whereas *Acartia spinicauda* and *Candacia bradyi* were recorded only during SWM while *Temora stylifera* was obtained during NEM. Other species such as *Nannocalanus minor*, *Calanopia thompsoni* and *Miracia efferata* were found during IM and SWM period and *Paracandacia truncata* and *Eucalanus monachus* were found during SWM and NEM. Three species such as, *Labidocera acutifrons*, *T. (A.) sigmoides* and *Peltidium* sp. did not occur in the SWM. Other species occurred rarely such as *Euchaeta concinna*, *Pontellopsis macronyx* and *Tortanus (Atortus) andamanensis* were recorded in all the seasons (Table 5.8).

Temporal differences in copepod population structure, in terms of abundance data based on Bray-Curtis similarity by Hierarchical Cluster analysis is given in Fig. 5.9. The population structure in terms of abundance varied with sampling stations with distinct separation between the study areas (Fig. 5.9). The cluster analysis indicates that copepod assemblage differed between the stations and within stations separations were obtained between the seasons. The dendrogram formed 2 major clusters delineating Carbyn's Cove from rest of the stations. Further within Carbyn's Cove (St.2), the SWM period of both the years (2012 and 2013) has 76.6% similarity and separated from rest of the seasons grouped with 64.9% similarity. The second cluster is further grouped to form two clusters that separating Junglighat from other areas and within the stations, IM period and others were separated and a similar trend was observed in Burmanallah. In Chattam, assemblage of copepods at NEM period was clearly separated however, in Chidiyatapu, the seasons were clearly separated (Fig. 5.9). The cluster analysis was confirmed for statistical significance by using One-way ANOSIM and multiple pairwise tests that revealed the population structure was not significantly (Global R= -0.005;  $p=0.47$ ) different between the seasons indicating that spatial dynamics are critical in structuring the species assemblage along this coastal regions of island system.



Diversity and spatio-temporal distribution of copepods



**Fig. 5.10. Seasonal diversity of copepod species at different stations. (a: Peilou's evenness; b: Shannon diversity; c: Margalef richness; d: Shannon dominance). IM: Inter monsoon; SWM: Southwest monsoon; NEM: Northeast monsoon.**

#### 5.4. Seasonal diversity of copepods

At Burmanallah and Carbyn's Cove, average copepod species diversity ( $H' = 3.85 \pm 0.62$  and  $3.07 \pm 0.69$  respectively) and evenness ( $J' = 0.77 \pm 0.08$  and  $0.69 \pm 0.13$  respectively) was maximum and dominance was lower ( $0.12 \pm 0.05$  and  $0.22 \pm 0.15$  respectively) during SWM while at Chattam ( $H' = 3.42 \pm 0.63$ ;  $J' = 0.70 \pm 0.09$ ) and Junglighat ( $H' = 2.53 \pm 0.89$ ;  $J' = 0.61 \pm 0.18$ ) was higher during NEM. Whereas at Chidiyatapu, the indices were peak during IM ( $H' = 3.95 \pm 0.35$ ;  $J' = 0.76 \pm 0.04$ ). At Burmanallah and Chidiyatapu, richness was higher during IM period with average values of  $5.13 \pm 1.71$  and  $4.92 \pm 1.31$  respectively while at Carbyn's cove and Junglighat, richness was maximum during SWM, whereas at Chattam during NEM (Fig. 5.10). Dominance indices were maximum during IM in Chattam and Junglighat. In rest of the stations the index was higher during NEM (Fig. 5.10; Table 5.9). At all the stations, the dominance index was either higher during NEM or IM periods and with the onset of SWM during May copepod dominance index was relatively lower at Burmanallah, Carbyn's Cove and Chidiyatapu. However at Chattam and Junglighat, dominance was least during NEM.

#### 5.5. Correlation with environmental parameters

The table of correlation matrix reveals that significant correlation occurred for only 9 species out of the 26 widely distributed copepod species that has been influenced by the environmental parameters measured during the study period (Table 5.10). *Bestiolina similis* (with temperature,  $r = 0.267$ ;  $p < 0.01$ ) and *Parvocalanus* sp. (temperature,  $r = 0.381$ ;  $p < 0.01$ ) were significantly positively correlated and 8 species namely *Metacalanus aurivilli*, *Canthocalanus pauper*, *Acrocalanus gibber*, *Calocalanus pavo*, *Paracalanus parvus*, *Paracalanus indicus*, *Calanopia minor* and *Hemicyclops* sp. also showed positively correlation with temperature but weak and rest of the species were negatively correlated with temperature. The species, *Acrocalanus gibber* (salinity,  $r = -0.258$ ;  $p < 0.01$ ) and *Corycaeus* spp. (salinity,  $r = -0.224$ ;  $p < 0.05$ ) were negatively correlated with salinity. *Clausocalanus furcatus* (pH,  $r = -0.239$ ;  $p < 0.01$ ), *Calocalanus pavo* (pH,  $r = 0.259$ ;  $p < 0.01$ ; DO,  $r = -0.181$ ;  $p < 0.05$ ), *Oncaea* spp. (pH,  $r = 0.201$ ;  $p < 0.05$ ; DO,  $r = 0.253$ ;  $p < 0.01$ ) and *Oithona plumifera* (pH,  $r = -0.256$ ;  $p < 0.01$ ; DO,  $r = 0.201$ ;  $p < 0.05$ ) were significantly correlated with pH and dissolved oxygen (Table 5.10) however, all correlation between parameters and the species showed weak correlation during the study period.

**Table 5.9. Seasonal diversity of copepod species among the stations (S: number of species; N: number of individuals; d: Margalef richness; J': Peilou's evenness; H' (log2): Shannon diversity; Lambda: Shannon dominance) in the study area.**

Stations	Season	n	S	N	d	J'	H'(log2)	Lambda
			Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Burmanallah (St.1)	IM	12	38.2±10.5 (22-56)	1842±1035 (301-3714)	5.13±1.71 (3.07-8.41)	0.70±0.11 (0.49-0.82)	3.62±0.61 (2.68-4.71)	0.16±0.08 (0.07-0.36)
	SWM	10	33.7±11.8 (22-53)	1407±667 (749-2973)	4.57±1.66 (2.47-7.61)	0.77±0.08 (0.65-0.88)	3.85±0.62 (2.9-5.03)	0.12±0.05 (0.04-0.23)
	NEM	6	32.2±5.3 (24-39)	2203±1347 (349-3986)	4.21±0.71 (3.22-4.95)	0.61±0.14 (0.40-0.77)	3.05±0.62 (1.94-3.60)	0.23±0.12 (0.13-0.46)
Carbyn's Cove (St.2)	IM	12	22.9±10.0 (11-40)	2620±1694 (390-5791)	2.86±1.29 (1.15-5.41)	0.54±0.18 (0.17-0.76)	2.45±1.06 (0.59-4.71)	0.35±0.22 (0.11-0.79)
	SWM	10	22.3±5.6 (14-30)	1688±720 (404-2919)	2.90±0.72 (2.17-4.12)	0.69±0.13 (0.46-0.87)	3.07±0.69 (1.97-4.01)	0.22±0.15 (0.09-0.51)
	NEM	6	26.7±5.3 (20-36)	2125±1082 (1122-3886)	3.39±0.60 (2.71-4.49)	0.57±0.19 (0.27-0.73)	2.68±0.95 (1.32-3.69)	0.31±0.21 (0.15-0.67)
Chattam (St.3)	IM	12	33.5±11.7 (17-54)	2794±3520 (460-12991)	4.39±1.61 (2.61-7.70)	0.65±0.09 (0.46-0.74)	3.22±0.60 (2.20-4.27)	0.19±0.07 (0.10-0.33)
	SWM	10	29.2±8.4 (18-45)	2744±835 (1517-3807)	3.60±1.16 (2.09-5.96)	0.59±0.13 (0.33-0.76)	2.87±0.77 (1.4-3.70)	0.25±0.16 (0.12-0.61)
	NEM	6	31.0±10.4 (20-45)	1671±1055 (637-3464)	4.15±1.49 (2.72-6.28)	0.70±0.09 (0.55-0.80)	3.42±0.63 (2.42-4.17)	0.16±0.08 (0.09-0.31)
Chidiyatapu (St.4)	IM	4	38.1±10.3 (29-52)	1910±487 (1219-2743)	4.92±1.31 (3.01-6.59)	0.76±0.04 (0.68-0.81)	3.95±0.35 (3.48-4.40)	0.10±0.03 (0.07-0.13)
	SWM	5	34.0±6.9 (28-46)	1833±468 (1274-2392)	4.42±1.01 (3.47-6.13)	0.73±0.07 (0.64-0.81)	3.71±0.47 (3.20-4.07)	0.12±0.04 (0.07-0.17)
	NEM	3	31.3±5.8 (28-38)	1125±509 (776-1709)	4.39±1.03 (3.63-5.56)	0.72±0.07 (0.67-0.80)	3.54±0.29 (3.27-3.85)	0.13±0.04 (0.09-0.16)
Jungligah (St.5)	IM	12	17.5±5.8 (10-25)	2047±1385 (357-5523)	2.23±0.77 (1.16-3.44)	0.55±0.16 (0.35-0.83)	2.22±0.69 (1.15-3.17)	0.34±0.16 (0.14-0.62)
	SWM	10	16.3±3.5 (11-22)	2117±905 (632-4108)	2.03±0.47 (1.20-2.76)	0.59±0.17 (0.33-0.83)	2.41±0.80 (1.14-3.69)	0.30±0.17 (0.10-0.57)
	NEM	6	18.3±8.1 (9-34)	2089±1159 (741-3473)	2.30±1.09 (1.21-4.31)	0.61±0.18 (0.27-0.80)	2.53±0.89 (0.85-3.39)	0.29±0.23 (0.14-0.76)

IM: Inter monsoon; SWM: Southwest monsoon; NEM: Northeast monsoon

**Table 5.10. Correlation of environmental parameters with copepod species found common and contributed >1% to the total abundance.**

Species		SST	SSS	pH	DO	Species		SST	SSS	pH	DO
<i>Acartia erythraea</i>	r	-.104	-.023	.013	-.032	<i>Calanopia minor</i>	r	.092	.028	-.205*	-.166
	p	.243	.794	.885	.721		p	.304	.758	.021	.062
<i>Metacalanus aurivilli</i>	r	.130	-.044	-.094	-.033	<i>Pseudodiaptomus nov. sp.</i>	r	-.082	.078	-.004	-.016
	p	.143	.620	.291	.709		p	.358	.379	.966	.855
<i>Canthocalanus pauper</i>	r	.051	-.058	-.107	.029	<i>Corycaeus spp.</i>	r	-.041	-.224*	-.106	.073
	p	.567	.515	.229	.747		p	.643	.011	.233	.415
<i>Centropages orsinii</i>	r	-.063	.038	.038	.023	<i>Farranula gibbula</i>	r	-.150	.114	.063	.024
	p	.478	.671	.670	.795		p	.091	.201	.483	.788
<i>Acrocalanus gibber</i>	r	.055	-.258**	-.023	.069	<i>Oithona brevicornis</i>	r	-.020	.039	.080	.016
	p	.539	.003	.800	.442		p	.823	.662	.372	.859
<i>A. longicornis</i>	r	-.031	.000	.119	.019	<i>O. oculata</i>	r	-.004	-.011	-.038	-.061
	p	.725	.999	.182	.830		p	.961	.902	.668	.495
<i>Bestiolina similis</i>	r	.267**	.071	-.126	-.148	<i>O. rigida</i>	r	-.001	.101	.127	-.039
	p	.002	.426	.156	.095		p	.994	.255	.155	.662
<i>Clausocalanus furcatus</i>	r	-.069	.119	.239**	-.128	<i>O. spinirostris</i>	r	-.144	.002	-.016	.063
	p	.436	.182	.007	.151		p	.106	.983	.861	.481
<i>Calocalanus pavo</i>	r	.095	.124	.259**	-.181*	<i>O. plumifera</i>	r	-.071	.000	-.256**	.201*
	p	.284	.164	.003	.041		p	.427	.996	.004	.023
<i>Paracalanus parvus</i>	r	.115	.046	-.080	-.148	<i>Oncaea spp.</i>	r	-.114	-.144	-.187*	.253**
	p	.195	.603	.370	.096		p	.201	.105	.034	.004
<i>P. aculiatu</i> s	r	-.126	.018	.097	.079	<i>Hemicyclops sp.</i>	r	.008	.079	-.006	-.080
	p	.157	.841	.276	.377		p	.931	.373	.945	.369
<i>P. indicus</i>	r	.007	-.157	-.121	.104	<i>Euterpina acutifrons</i>	r	-.007	.042	-.015	-.054
	p	.935	.077	.175	.243		p	.933	.635	.865	.542
<i>Parvocalanus sp.</i>	r	.381**	.052	-.162	-.163	<i>Macrosetella gracilis</i>	r	-.132	.106	.094	.004
	p	.000	.560	.068	.067		p	.139	.236	.289	.966

\*\* . Correlation is significant at the 0.01 level (2-tailed); \* . Correlation is significant at the 0.05 level (2-tailed).

SST: Sea surface temperature; SSS: Sea surface salinity; pH: Hydrogen ion concentration; DO: Dissolved oxygen

## 5.6. Discussion

Most of the studies on copepods of Andaman Sea were merely focused on the taxonomy and description of new species and records that were collected during scientific cruise with few from the neritic regime, extensively on systematics and distribution of the genus *Pseudodiaptomus* from the coastal waters of India and Andaman and Nicobar regions (Sewell, 1919; 1932; Roy, 1977; Pillai, 1980; Reddy and Radhakrishna, 1982; Walter, 1984; Madhupratap and Haridas, 1986; 1989; 1992). Although, copepods form the major component of mesozooplankton in the Andaman Sea, studies on diversity and species composition were limited, mostly restricted to family level (Pillai *et al.*, 2014) with exception of the studies from Madhupratap and Haridas (1986), Satapoomin *et al.* (2004), Pillai *et al.* (2011) and Maiphae and Sa-artrit (2011). When compared with copepods, the species of chaetognaths in Andaman and Nicobar Islands have received a greater attention with considerable work from oceanic and neritic regimes (Nair *et al.*, 1981; 2002; 2008; Nair and Gireesh, 2010; Pillai *et al.*, 2014). The endemism in chaetognaths species namely, *Krohnitta balagopali* and *Sagitta meenakshiae* and seasonal variability of chaetognath species were reported from Andaman Sea (Nair *et al.*, 2008; Nair and Gireesh, 2010). Population of chaetognaths was much higher in coastal waters as compared to the oceanic zone. In addition, the abundance of chaetognaths had the highest average density at Port Blair during inter monsoon followed by northeast monsoon (Nair and Gireesh, 2010).

In the present study, copepods were represented by 97 taxa and 29 families in which 89 were identified to the species level, seven were identified up to genera and single representative from Monstrilloida that was identified to family level. A review of marine zooplankton studies on Thailand revealed at least 94 species were reported from the Andaman Sea: 84 species from 15 families of Calanoida, 2 species from 2 families of Harpacticoida, 3 species from 1 families of Cyclopoida, and 5 species from 2 families of Poecillostomatoida (Satapoomin *et al.*, 2012). Pai (2007) reported 120 species of Calanoida, 27 species of Cyclopoida and 9 species of Harpacticoida from Andaman Sea. Calanoids accounted for more than two-thirds of the copepods, followed by cyclopoids (23%) and harpacticoids (8%), the copepods were strongly pigmented, appearing bright red in colour in Andaman Islands (Eashwar *et al.*, 2001).

Copepods were the major component of mesozooplankton (Davis, 1955; Padmavati *et al.*, 1998; Rakesh *et al.*, 2006; Fernandes and Ramaiah, 2009) with calanoids being the dominant form (54.72%) followed by cyclopoids (including



poeciliostomatoids) (40.92%) and harpacticoids (4.3%) in the coastal waters of South Andaman. The calanoids belonged to 73 species, represented over 31 genera and 17 families, Cyclopoida were represented by 14 species under 7 genera and 5 families and harpacticoids composed of 6 families and 9 species (Table 5.1). Of the 29 families recorded, 19 were invariably found at all stations, 5 families such as Candaciidae, Clausocalanidae, Eucalanidae, Lucicutiidae and Tegastidae did not occur in one of the 5 stations. While, families Euchaetidae (Burmanallah and Carbyn's Cove), Pseudocyclopidae (Burmanallah and Chidiyatapu) and Peltidiidae (Chidiyatapu) occurred in one or two of the stations. However, there was no statistical difference found in the average abundance of families between the stations ( $p>0.05$ ) during the investigation.

Families such as Calanidae and Pontellidae showed a clear dominance in the surface whereas small-sized copepods belonging to the families Clausocalanidae and Paracalanidae were observed as the predominant community in the mixed layer and thermocline layer depth (Pillai *et al.*, 2014). However, in the present study small-sized copepods, Paracalanidae (42.07%) was invariably dominated at all study stations (25.51 to 67.85%) except Carbyn's Cove, where the family Oithonidae (40.3%) dominated followed by Pseudodiaptomidae (20.82%) and Paracalanidae (18.19%). Other dominating copepod families in the study area included were Oithonidae, Corycaeidae and Oncaeidae with average relative abundance of 18.29%, 12.32% and 9.6% respectively.

In this study, three groups of species can be mentioned as dominant species that appear in most samples with high abundances, few rare species found in low abundance in a small number of samples and restricted to any one of the stations collected and some species that appear common in this area. The copepod fauna is dominated by small-sized, widely distributed species like *Parvocalanus* sp., *Bestiolina similis*, *Corycaeus* spp., *Oncaea* spp., *Oithona oculata*, *Oithona brevicornis*, *Pseudodiaptomus* nov. sp., *Euterpina acutifrons*, *Paracalanus parvus*, *Farranula gibbula*, *Oithona rigida*, *Acrocalanus gibber*, *Oithona plumifera* and *Calocalanus pavo*. The sum of these species abundance plays a fundamental role in establishing the changes in mesozooplankton abundances in the pelagic ecosystem of this study area.

Overall, 47 species were found to be in general common with 30 species were consistently common in the coastal waters of the study area. Species such as *Eucalanus subcrassus*, *Oithona plumifera*, *Calanus pauper*, *Centropages furcatus*, *Acartia*

*erythraea*, *Oithona rigida*, *Temora discaudata* and *Acartia negligens*, were described as common species in the Gulf of Thailand (Suvapepun and Suwanrumpha, 1968). In this study, seventeen (17) species were found to be occurred in any four stations and absent at least in one of the station and 31 species were occurred either 2 or 3 of the station. The remaining 17 species of copepods namely *Acartia spinicauda*, *Cosmocalanus darwini*, *Euchaeta concinna*, *Paracalanus denudatus*, *Calanopia aurivilli*, *C. thompsoni*, *Labidocera detruncata*, *L. bataviae*, *L. acutifrons*, *Pontellopsis macronyx*, *Pontella fera*, *P. denticauda*, *Pseudodiaptomus marinus*, *Tortanus (Atortus) andamanensis*, *T. (A.) sigmoides*, *T. (A.) murrayi* and *Peltidium* sp. were found to be rare and restricted to any one among the study stations. Pillai *et al.* (2011) recorded 52 species of calanoida belonging to 17 families from Andaman Sea and reported that the species *Undinula vulgaris*, *Cosmocalanus darwini*, *Pontella diogonalis*, *Pontella securifer* were the dominant species observed in the surface. In contrary to that *Cosmocalanus darwini* was rarely occurred and *Undinula vulgaris* was never a dominating species in this study, also absent in Chattam and Junglightat. The other 2 species *Pontella diogonalis*, *Pontella securifer* were not noticed in the present study. In addition, Pillai *et al.* (2011) attributed the vertical distribution of copepods and reported the occurrence of deep water (300 to 500m) species such as *Pleuromama indica*, *Euchirella pulchra*, *Gaetanus miles*, *Euaugaptilus indicus*, *Scaphocalanus* sp., *Pleuromamma xiphias*, *Amalothrix indica*, *Lophothrix frontalis* and *Lophothrix* sp., however in the present study not observed any of these species. Since, the present investigation was pertinent only to coastal waters of shallow region (10 to 20m), further the study have not made information on the vertical distribution of zooplankton and the copepod species.

Since taxonomic information in this region had been mostly based on the results from historical expeditions (Sewell, 1932), and there were many types of habitats that had received little attention in earlier studies which had focused only to the oceanic waters. In the course of this study on the biodiversity and community structure of zooplankton in the coastal waters of the south Andaman Sea have resulted in the discovery of three species of planktonic copepods that have been described as new to science, one species have been recorded as new from Indian Ocean and many copepod species have been found to be first report from the Andaman and Nicobar archipelago. The genus *Tortanus* is especially interesting as the review of literatures indicate that this genus has been noticed in limited studies in waters around the Andaman and

Nicobar Islands (Sewell, 1932) and four species were collected and found to be new record for this locality. The calanoid species, *Tortanus (Atortus) murrayi* A. Scott, 1909 is new to Indian Ocean, *Tortanus (Tortanus) gracilis* (Brady, 1883) is the first report to Andaman Sea and two species *Tortanus (Atortus) andamanensis* Nishida *et al.*, 2015 and *T. (A.) sigmoides* Nishida *et al.*, 2015 are new to science have been reported from this vicinity. The species namely *Tortanus barbatus* and *Tortanus forcipatus* were reported from Andaman Sea (Sewell, 1932; Madhupratap and Haridas, 1986) and Malay Archipelago (Sewell, 1933). *T. (A.) tropicus*, described as new species from Nankauri Harbour, Nicobar Islands (Sewell, 1932) have been the records of *Tortanus* species from the Andaman and Nicobar Islands. With the addition of the present report, seven species of *Tortanus* are known to occur in the coastal waters around the Andaman and Nicobar Islands.

Although, extensive study on systematics and distribution of the genus *Pseudodiaptomus* has been carried out from the coastal waters of India and Andaman and Nicobar regions (Sewell, 1919; 1932; Roy, 1977; Pillai, 1980; Reddy and Radhakrishna, 1982; Walter, 1984; Madhupratap and Haridas, 1986; 1989; 1992), the present study on the community structure of zooplankton resulted in the discovery of one new species of *Pseudodiaptomus* from the coastal waters of Andaman Sea. In addition *P. annandalei* and *P. compactus* were reported for the first time from the Andaman Islands. However, *P. annandalei* has been reported from estuarine and coastal waters of Bay of Bengal (Sewell, 1919; Reddy and Radhakrishna, 1982; Mishra and Panigrahy, 1999; Devi and Ramanibai, 2012) and Arabian Sea (Madhupratap *et al.*, 1979; Wellershaus, 1969; Nair and Ramaiah, 1995; Achuthankutty *et al.*, 1995) and from estuaries and offshore regions of Gulf of Thailand (Srinui *et al.*, 2013; Suvapepun *et al.*, 1979; Pinkaew, 2003; Maiphae and Sa-artrit, 2011), coastal waters off Panay Island, Philippines (Walter *et al.*, 2006), coastal brackish water pond of Taiwan (Dhanker *et al.*, 2013), south to Indonesia (Mulyadi, 2001) and Australia. Further *P. compactus* noticed from Andaman Sea was misidentified as *P. aurivilli* by Pillai (1980).

Calanoid species such as, *Acartia negligens*, *Subeucalanus pileatus*, *Eucalanus monachus*, *E. attenuates*, *E. subtenuis*, *Centropages calaninus*, *C. elongates*, *Temora turbinata*, *T. stylifera*, *Euchaeta indica*, *Calocalanus longispinus*, *Calanopia aurivilli*, *Labidocera acutifrons*, *L. pectinata*, *Paracandacia truncata*, *Candacia bradyi*, *C. discaudata*, *Calanus tenuicornis* and *Scolecithricella minor* have been not reported in the literatures of Andaman Islands were recorded in the present study however, most of

these species were reported from Bay of Bengal (Shanthi and Ramanibai, 2011; Jagadeesan *et al.*, 2013). Among them, *Temora discaudata*, *T. turbinata*, *T. stylifera* were recorded abundant in the middle and offshore stations and low in the near shore stations while *Acartia spinicauda* was abundant in the near shore station of Bay of Bengal (Shanthi and Ramanibai, 2011) and *A. negligens* was reported from Gulf of Thailand and Andaman Sea (Jitchum, 2010). Species *Centropages calaninus* and *Centropages elongatus* reported from Enewetak Atoll, Marshall Islands (Gerber, 1981). Only sporadic presence of high saline marine species like *Temora discaudata*, *Tortanus gracilis* and *Acartia negligens* were reported in this study from the coastal waters of South Andaman. Furthermore, the species composition described for the waters of South Andaman coast was consistent with that described by Madhupratap and Haridas (1986; 1989; 1992), Pillai *et al.* (2011), Jitchum (2010), Satapoomin *et al.* (2004) from Andaman Sea and the Gulf of Thailand (Suvapepun and Suwanrumpha, 1968; Jitchum, 2010).

Overall, the Burmanallah (St.1) and Chidiyatapu (St.4) were rich in copepod species with higher diversity and evenness indices. However, Carbyn's Cove (St.2) and Junglighat (St.5) were found with higher dominance and lower evenness values and lower values of Shannon diversity indices which indicate poor diversity among the stations in the coastal waters of south Andaman (Table 5.4). The low diversity of copepod species in the Junglighat and Carbyn's Cove compared to that of other stations may be due to the inflow of effluents, sewage and domestic waste discharged through tidal creeks and human settlements and other anthropogenic activities linked with fisheries. Especially, the coastal waters of Junglighat is an urban area subjected to huge pollution due to sewage discharge, domestic waste dumping and the wetland (mangrove) region in close proximity so also polluted. Here the microbial cycle may be playing a crucial role in the food chain and organic matter transfer and recycling, moreover as the site was dominated with small sized copepod families (Fig. 5.2) which contributed up to 97.19% with Paracalanidae (67.85%). In addition, the maximum values of temperature and highest abundance of gelatinous zooplankton such as appendicularians, hydrozoans and siphonophores were also found in Junglighat which may affected the large sized copepods. At Junglighat, the species richness and diversity was much lower compared to other stations. Moreover, Chidiyatapu and Burmanallah were far distance from the urban region with least exposure to the major anthropogenic activities and also the coastal region has been endowed with key ecosystems like corals,

seagrass and mangroves which further improve the diversity of the copepods species in the coastal region (Santhanakumar *et al.*, 2010; Pillai *et al.*, 2014). The number of species and all the diversity indices were significantly varied between the station (One-way ANOVA,  $p < 0.001$ ) however, the number of individuals between the stations were not significantly varied ( $p = 0.265$ ). While, the Tukey's pairwise comparison indicated that there was no significant variation in the number of individuals (N) between the stations. All other diversity indices except evenness (J') for Burmanallah significantly differed from that of Carbyn's Cove however, Junglighat was differed completely. A similar trend was observed between the Carbyn's Cove with Chidiyatapu and Chattam and also, Junglighat with Chidiyatapu and Chattam. In addition, there was no significant difference in the copepod species diversity between the Burmanallah, Chattam and Chidiyatapu and between Carbyn's Cove and Junglighat (Table 5.5).

The plankton production at Port Blair was high during the colder months and low during the period of high temperature and high salinity (Marichami, 1983). Similar results were observed in the present investigation on copepods with maximum abundance in NEM and also during IM compared to the SWM (Varkey *et al.*, 1996; Nair and Gireesh, 2010). The higher abundances of copepods in Carbyn's cove compared to other stations may be attributed to high abundance of *Pseudodiaptomus* species and the enrichment of the water caused by runoff from mangrove creek (Rezail *et al.*, 2004). Goswami and Rao (1981) reported a swarm of pontellid copepod with density of 25974 to 138420 ind.  $m^{-3}$  from Campbell Bay, Andaman Sea suggesting that combination of environmental factors and adaptive advantage are responsible for the swarming of copepods. Such huge swarms of copepods were not noticed in the present study however, in general, small copepods namely *Oithona oculata* and *Pseudodiaptomus* nov. sp. were outnumbered with 5094.8 ind. $m^{-3}$  and 3165.3 ind. $m^{-3}$  respectively at Carbyn's Cove while *Parvocalanus* sp. and *Bestiolina similis* were dominated with density of 6412.7 ind.  $m^{-3}$  and 3374.3 ind.  $m^{-3}$  respectively at Chattam.

In the present study the seasons were classified into inter monsoon (IM, January-April), southwest monsoon (SWM, May-September) and northeast monsoon (NEM, October-December) (Chakravarty *et al.*, 1987; Munk *et al.*, 2004; Satapoomin *et al.*, 2004; Jayaraj and Andrews, 2005; Nair and Gireesh, 2010). At Burmanallah and Carbyn's Cove, mean copepod species diversity and evenness were maximum during SWM while at Chattam and Junglighat was higher during NEM. Whereas at Chidiyatapu, the indices were peak during IM. At all the study stations, the dominance

index was either higher during NEM or IM periods and with the onset of SWM during May copepod dominance index was relatively lower at Burmanallah, Carbyn's Cove and Chidiyatapu. However in Chattam and Junglighat, dominance was least during NEM. Thirteen species, *Acrocalanus gibber*, *Bestiolina similis*, *Calocalanus pavo*, *Paracalanus parvus*, *Parvocalanus* sp., *Pseudodiaptomus* nov. sp., *Corycaeus* spp., *Farranula gibbula*, *Oithona oculata*, *O. rigida*, *O. brevicornis*, *O. plumifera*, *Oncaea* spp. and *Euterpina acutifrons* were found to be main contributor to the total copepod abundance. Among them, *Parvocalanus* sp. and *Corycaeus* spp. dominated in SWM, while, *Oncaea* spp. (15.3%) followed by *O. brevicornis* (15%) were observed higher abundance during NEM. In IM period, other species namely *Bestiolina similis* and *Oithona oculata* were found to be dominant with relative abundance of 13.5%, 10.8% and 8% respectively (Fig. 5.7). As found in this study, copepod species *Bestiolina similis*, *Paracalanus* sp., *Acrocalanus* sp. *Oncaea venusta* and *Corycaeus* sp. were observed throughout the year however, a high abundance of *Bestiolina similis* was noticed during NEM in earlier report from Andaman Sea (Pillai *et al.*, 2014). Dominance of *Acartia erythraea*, *A. spinicauda*, *Labidocera pavo* and *L. minuta* during IM season was reported earlier from Andaman Sea (Pillai *et al.*, 2014). In contrast, few species such as *Acartia erythraea* was found dominant during SWM ( $23.1 \pm 37.8 \text{ ind. m}^{-3}$ ) followed by IM period ( $21.8 \pm 33.0 \text{ ind. m}^{-3}$ ) and *A. spinicauda* was found to be occurred only from Carbyn's Cove during SWM.

Satapoomin *et al.* (2004) studied seasonal variation and compared the shallow coastal and deep oceanic waters by copepod population suggesting, no spatial and seasonal variation in the species composition of copepods were apparent. During the present investigation on copepod population along the shallow coastal waters of South Andaman, no statistical difference in seasonality in the species assemblage of Andaman Sea was observed. Similar results of absence of variation between seasons and areas have been reported from Arabian Sea (Madhupratap *et al.*, 1996). However, distinct copepod population was apparent with significant variation among the stations was found in the present investigation. Although, minor seasonal fluctuations in light and temperature observed in the tropics, are usually related to the variable pattern of rainfall and increased storm incidence during monsoon periods and associated upwelling events (Smith, 1982; Schalk, 1987; Baars *et al.*, 1990; Chisholm and Roff, 1990). There were no clear seasonal changes in the zooplankton biomass at the location sampled from the South Andaman. There is, however, a strong regional gradient in the species

assemblage of copepods, may be driven by differences in water column stratification and other major ecosystem like corals, mangroves and seagrass at each study site that increase the biological production in the coastal waters (Gopinathan and Rajagopalan, 1983; Pillai, 1983; Santhanakumar *et al.*, 2010; Jayabarathi *et al.*, 2012; 2015; Pillai *et al.*, 2014). In contrast, the copepod abundance remains stable among the stations. This study indicates that the biological characteristics of South Andaman coast differ among the areas and that spatial dynamics are more important than temporal dynamics in these Island ecosystems. Further, continuous study of both inshore and open sea waters for copepod and decadal collection and analysis of copepod is highly desirable to get more definite conclusions about copepod abundance, biodiversity, distribution, composition, seasonality and productivity.

Many factors such as temperature, salinity pH, dissolved oxygen, circulation and tides, availability of food and predation could influence the abundance and distribution of copepods (Sander, 1987; Roman *et al.*, 1993; Corvetto and Gaudy, 1999; Escribano and Hidalgo, 2000; Xie and Yang, 2000; Turner, 2004). However, in present study significant weak relationship was observed between few environmental parameters i.e. temperature, DO and abundance of the copepod species. A weak positive correlation was found between temperature and total abundance of the copepod species ( $r=0.215$ ;  $p<0.05$ ) and calanoids abundance ( $r=0.335$ ;  $p<0.01$ ) whereas, a weak negative correlation was found between DO and abundance of calanoid species ( $r= -0.186$ ;  $p<0.05$ ). As in the current study, no significant relationship was observed between other parameters like, salinity and pH and abundance of copepod species, which might have been due to the shallow depth which have well-mixed water (Naz *et al.*, 2012). The relationship between dissolved oxygen concentration and community structure indices of chaetognaths was negatively correlated, with lower DO values at higher community diversity indices (Nair *et al.*, 2002). Many experimental studies have shown that water temperature and food conditions are the most important factors which affect the life history of the copepods (Ban, 1994).

It is generally assumed that small copepods feed primarily upon small sized phytoplankton cells (Turner, 1984; 2000), however, there have been few studies that examined, copepod feeding natural phytoplankton and microzooplankton found in the sea (Stoecker and Capuzzo, 1990; Gifford and Dagg, 1991; Kleppel, 1993; Turner and Roff, 1993; Verity and Paffenhöfer, 1996; Paffenhöfer, 1998; Turner, 2000), have resulted that the small copepod genus, *Acartia*, *Oithona* and *Paracalanus* may feed

primarily as predators upon heterotrophic protists, rather than as grazers of phytoplankton (Turner and Anderson, 1983; Stoecker and Sanders, 1985; Stoecker and Egloff, 1987; Gifford and Dagg, 1988; Nakamura and Turner, 1997; Suzuki *et al.*, 1999; Lonsdale *et al.*, 2000; Granéli and Turner, 2002). In this study, a negative correlation between copepod and zooplankton density with Chl *a* was found at Burmanallah and Chidiyatapu, which was significant at Burmanallah. Whereas in the rest of the stations the correlation remains weak may be due to the preference of alternative pathway of feeding on the microzooplankton in these stations. In support of this, the small copepod families namely Paracalanidae, Oithonidae, Corycaeidae, Oncaeidae and Acartiidae were found higher in the stations such as Chattam and Junglighat with 92.06% and 97.19% respectively. While in Carbyn's Cove, the Pseudodiaptomidae falling under the small size category was contributed 20.82% resulting the total abundance of 94.68%. However, in Burmanallah and Chidiyatapu, they have contributed only up to 87.28% and 87.47% respectively. In Junglighat and Chattam, higher abundance of gelatinous zooplankton such as appendicularians, hydrozoans and siphonophores indicates a predation pressure over the larger copepod species. The studies on microzooplankton community of these regions have resulted in maximum density at Junglighat (Sai Elangovan *et al.*, 2012; Sai Elangovan, 2015, Ph.D. thesis), suggesting the eutrophic nature of this area. Further, the method of collection of zooplankton at early morning (before dawn) in present investigation may be the reason for the negative relationship in Burmanallah and Chidiyatapu indicating the grazing pressure of zooplankton over Chl *a* in these areas. Although, the relationship was statistically significant however moderate at Burmanallah whereas weak in Chidiyatapu. In order to test these hypotheses, gut content analysis of gelatinous zooplankton and comparison of samples collected after sunset from the study region is highly desirable. In addition, *in situ* experimental set-up would be a promising approach to reveal the above hypotheses warranting further studies from these region.

The primary knowledge in the study of biodiversity is knowing the species composition of the region over a period of time (Ramanibai, 2015). With the available species list, the rates of immigration, emigration and turnover of species in a community can be measured. The change in the ecological balance and the cause of the effect can be measured, whether natural or anthropogenic origin on natural resources of importance (Ramanibai, 2015). The list of species in the present study implies that copepods found in near shore areas extending from Chattam harbor in the north to



Chidiyatappu in the south of South Andaman. The present study will provide a first comprehensive overview of the zooplankton community with special reference to copepod population in coastal waters of south Andaman Sea. In the Andaman Sea, studies were done mainly in mangrove areas, coral islands and offshore areas (Satapoomin *et al.*, 2012). However studies in the coral communities and coastal waters are still meagre. Understanding of plankton ecology requires a good knowledge on species composition, abundance and distribution. Moreover, a significant sampling effort focused exclusively on this diverse geographical system suggesting a greater opportunity for future findings of even more new copepod species.

The plankton communities can vary on a wide range of space and time, particularly through seasonal, inter-annual, decadal and multidecadal cycles. In addition, the variability is also due to biological processes such as: competition, predation, vertical migration and also human impacts on the ecosystem and pollution. These variability produce fluctuations in zooplankton species abundance, which are not always easy to explain (Paffenhöfer *et al.*, 1989; Gamble and Hunt, 1992; Perry and McKinnell, 2005) initiating for observational programs of adequate temporal and spatial resolution to characterize variability in zooplankton populations. Long-term research programmes based on systematic observations have rendered significant results to the oceanography (Valdés *et al.*, 2007). This study represents a significant contribution to the understanding of biodiversity of a least studied island ecosystem and also emphasizes an example of the importance of the basic research (systematics and taxonomy) and biodiversity assessment as an indispensable tool which is responsible for management of natural resources under pressure.

In general, plankton is apparently a good indicator for ocean climate change and water movement with changes in the species distribution (Hays *et al.*, 2005; Greene and Pershing, 2000; Edwards and Richardson, 2004; Beaugrand *et al.*, 2002). The Andaman Sea is a median region which hosts and connects the waters of great Oceans. There is a free interchange of water from the Pacific Ocean through South China Sea and the Straits of Malacca and the Andaman Sea in to the Bay of Bengal and through the various openings in the Sumatra-Java-Borneo chain of islands in the Malay Archipelago into the southern part of Indian Ocean, especially during the period of north-east monsoon (Sewell, 1929b). However, planktons in relation with climatologic time scale from the Andaman Sea are still scarce, which limits our ability to detect ecological changes related to climate variability.

## TWO NEW SPECIES AND OTHER REPORTS OF *TORTANUS* (COPEPODA, CALANOIDA) FROM SOUTH ANDAMAN

### 6.1. Introduction

The species of calanoid genus *Tortanus* Giesbrecht, 1898 are predatory planktonic copepods (Anraku and Omori, 1963; Bowman, 1971; Ambler and Frost, 1974; Goswami, 1977), comprised of 40 nominal species in 5 subgenera that frequently inhabit in neritic waters of tropical to temperate regions in the Indo-Pacific and the northwestern Atlantic Ocean (Ohtsuka *et al.*, 1987; Ohtsuka and Kimoto, 1989; Ohtsuka, 1992; Chen and Hwang, 1999; Razouls *et al.*, 2005-2015; Nishida *et al.*, 2015). Thorough review of literatures suggested that the genus *Tortanus* has been noticed in limited studies in waters around the Andaman and Nicobar Islands (Sewell, 1932). In the present study on the biodiversity and community structure of zooplankton in the coastal waters of the Andaman Sea four species of *Tortanus* were collected and found to be new record for the locality. The calanoid species, *Tortanus* (*Atortus*) *murrayi* A. Scott, 1909 is new to Indian Ocean, *Tortanus* (*Tortanus*) *gracilis* (Brady, 1883) is first report to Andaman Sea and two species *Tortanus* (*Atortus*) *andamanensis* Nishida *et al.*, 2015 and *T. (A.) sigmoides* Nishida *et al.*, 2015 are new to science were found in this study.

The subgenus *Atortus* Ohtsuka, 1992, accommodating 25 nominal species, is regarded as one of the most advanced of the subgenera and is distributed exclusively in the Indo-West Pacific (Ohtsuka and Reid, 1998; Nishida *et al.*, 2015), wherein 7 species, *T. (A.) recticauda* (Giesbrecht, 1889), *T. (A.) tropicus* Sewell, 1932, *T. (A.) nishidai* Ohtsuka *et al.*, 2000, *T. (A.) insularis* Ohtsuka and Conway, 2003, *T. (A.) magnonyx* Ohtsuka and Conway, 2005, *T. (A.) andamanensis* and *T. (A.) sigmoides*, and the three species *T. (T.) gracilis*, *T. (T.) barbatus* (Brady, 1883), *T. (T.) forcipatus* (Giesbrecht, 1889), which included in the subgenus *Tortanus* (Giesbrecht and Schmeil, 1898) have been regarded as Indo-Pacific species were identified from the Indian Ocean. *Tortanus* (*T.*) *gracilis* was reported from western and eastern Indian Ocean (Ganapathi and Santhakumari, 1961; Saraswathy, 1966; Patel, 1975; Madhupratap and Haridas, 1986; Ramaiah and Nair, 1997; Mishra and Panigrahy, 1999; Vareethiah, 1999; Tiwari and Nair, 2002; Conway *et al.*, 2003; Gaonkar *et al.*, 2010; Roy, 2010),

yet unknown from Andaman waters, whereas *T. (A.) murrayi* is new to Indian Ocean, it has been inhabitant of the waters around Malay Archipelago, Philippines and south China Sea (A. Scott, 1909; Bowman, 1971; Chen and Hwang, 1999). *T. (A.) tropicus*, described as new by Sewell (1932), was collected by surface tow of a net at Nankauri Harbour, Nicobar Islands and *Tortanus (T.) barbatus* collected from Port Blair in Andaman. With the addition of the present report, seven species of *Tortanus* are known to occur in the coastal waters around the Andaman and Nicobar Islands.

## 6.2. Systematic account

Subclass COPEPODA Milne Edwards, 1840

Order CALANOIDA Sars, 1903

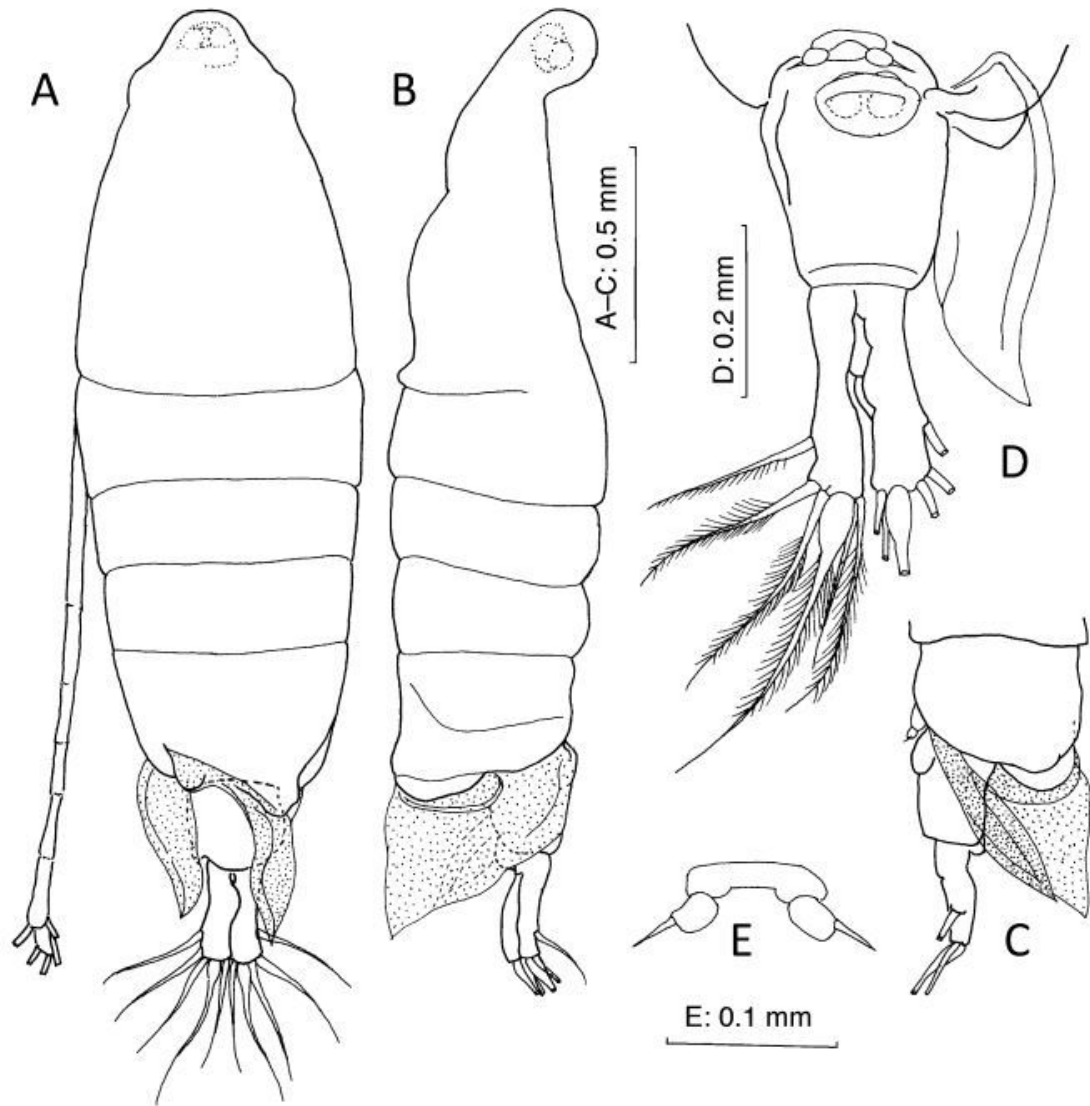
Family Tortanidae Sars, 1902

Genus *Tortanus* Giesbrecht, 1898

## 6.3. *Tortanus (Atortus) andamanensis* new species (Figs. 6.1-6.3)

Material studied: Specimens were collected on 27 March 2012 at Burmanallah (11°33'N, 92°43'E), South Andaman Island, India. Holotype: female (ZSI-ANRC: 11071). Paratypes: 1 dissected female, 2 dissected males, 3 intact females, and 2 intact males (ZSI-ANRC: 11073). Specimens are preserved in vials in 2% formaldehyde/seawater with a drop of glycerol added.

Female (Figs. 6.1-6.3) Total length 2.00–2.23 mm ( $\bar{x} \pm SD = 2.12 \text{ mm} \pm 0.09$ , n=8; holotype, 2.19 mm). Prosome length 1.59–1.81 mm (holotype, 1.74 mm), width 0.61–0.70 mm (holotype, 0.66 mm). Habitus (Fig. 6.1A, B). Prosome about 3.8 times as long as urosome. Cephalosome and first pediger separate; fourth and fifth pediger fused. Fifth pediger asymmetrical with semicircular dorsolateral processes near posterior margin, right process being produced more posteriorly than left. Urosome 2-segmented, second urosomite completely coalesced with caudal rami. Genital compound somite about as long as wide in dorsal view with right anterolateral margin slightly swollen; genital operculum (Fig. 6.1D) semicircular, located ventrally at anterior 1/4 of genital compound somite. Caudal rami asymmetrical with left ramus slightly produced medially midway and corresponding margin of right ramus slightly concave. All specimens have transparent coupling device (Fig. 6.1A-C, see also Ohtsuka *et al.*, 2000) with right vane larger than left, covering dorsolateral processes of fifth pediger and right lateral surface of genital compound somite.



**Fig. 6.1.** *Tortanus (Atortus) andamanensis*, n. sp., female. (holotype). **A**, habitus, dorsal view; **B**, habitus, lateral view; **C**, genital complex, left lateral view; **D**, pediger 5 and genital complex, ventral view; **E**, leg 5. Coupling device is dotted in A-C.

Antennule (Fig. 6.2A, B) symmetrical, reaching posterior margin of caudal ramus; ancestral segments I–IX, XI–XIV, XXVI–XXVIII totally or partially fused. Armature as follows: I, 1; II–IX, 8+2ae (aesthetascs); X, 2; XI, 2+ae; XII, 1; XIII, 1; XIV, 2; XV, 1; XVI, 1+ae; XVII, 0; XVIII, 2+ae; XIX, ae; XX, 2; XXI, ae; XXII, 1; XXIII, 1; XXIV, 1; XXV, 1+1+ae; XXVI–XXVIII, 6+ae. Antenna (Fig. 6.2C) coxa without seta; basis with medial seta; basis and endopod completely fused; endopod 3-segmented, proximal segment with distomedial seta and distolateral row of spinules,

second and distal segment incompletely fused, distal segment with proximolateral tuft of setules and 6 terminal setae; exopod 3-segmented, proximal segment short and unarmed, middle and distal segment incompletely fused, with 3 and 2 setae, respectively. Mandible (Fig. 6.2D, E) gnathobase with 5 cusped teeth, 2 ventralmost teeth with articulated tip, ventralmost tooth monocuspidate while remaining 4 teeth bicuspidate, 3 dorsalmost teeth with 4 longitudinal spinule rows proximally; basis elongate and unarmed; endopod 2-segmented, proximal segment unarmed, distal segment with 6 setae; exopod with 5 setae. Maxillule (Fig. 6.2F) basis and rami completely absent; praecoxal arthrite with 12 spinulose setae and 1 minute seta; coxal endite with 3 stout, spinulose terminal setae. Maxilla (Fig. 6.2G) syncoxal endites with 1, 2, 2, and 3 setae from proximal to distal; basal endite with 1 developed and 2 rudimentary setae; endopod with 5 stout setae with claw-like tip and 2 rudimentary setae. Maxilliped (Fig. 6.2H) syncoxa with two endites, each with spinulose seta; basis unarmed; endopod with 3 medial spinulose setae and lateral seta.

Legs 1-4 (Fig. 6.3A-D) biramous with 3-segmented exopod and 2-segmented endopod; distal endopod segment of legs 1-4 with hair tuft on subdistal, anterior surface. Seta (in Arabic numeral) and spine (in Roman) formula as follows:

	Coxa	Basis	Exopod segment 1; 2; 3	Endopod segment 1; 2
Leg 1	0-1	1-0	0-1; 0-1; I, I, 4	0-3; 1, 2, 3
Leg 2	0-1	0-0	I-1; I-1; III, I, 5	0-3; 1, 2, 3
Leg 3	0-1	0-0	I-1; I-1; III, I, 5	0-3; 1, 2, 3
Leg 4	0-1	1-0	I-1; I-1; III, I, 5	0-3; 1, 2, 3

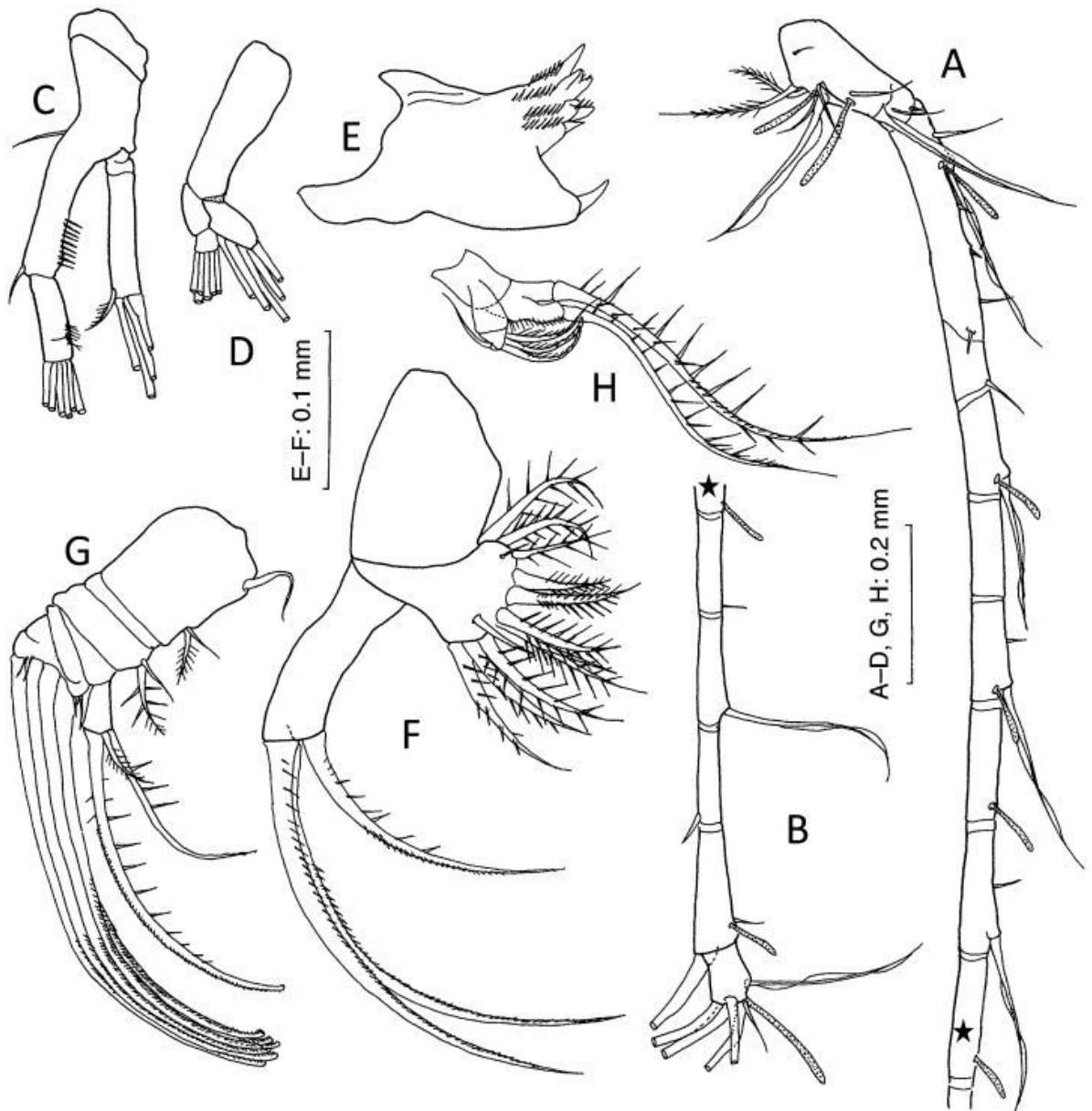
Outer seta on leg 1 basis minute.

Leg 5 (Fig. 6.1D, E) uniramous, 2-segmented, and symmetrical with basis of right and left legs fused; ramus roundish rectangular, with distolateral seta.

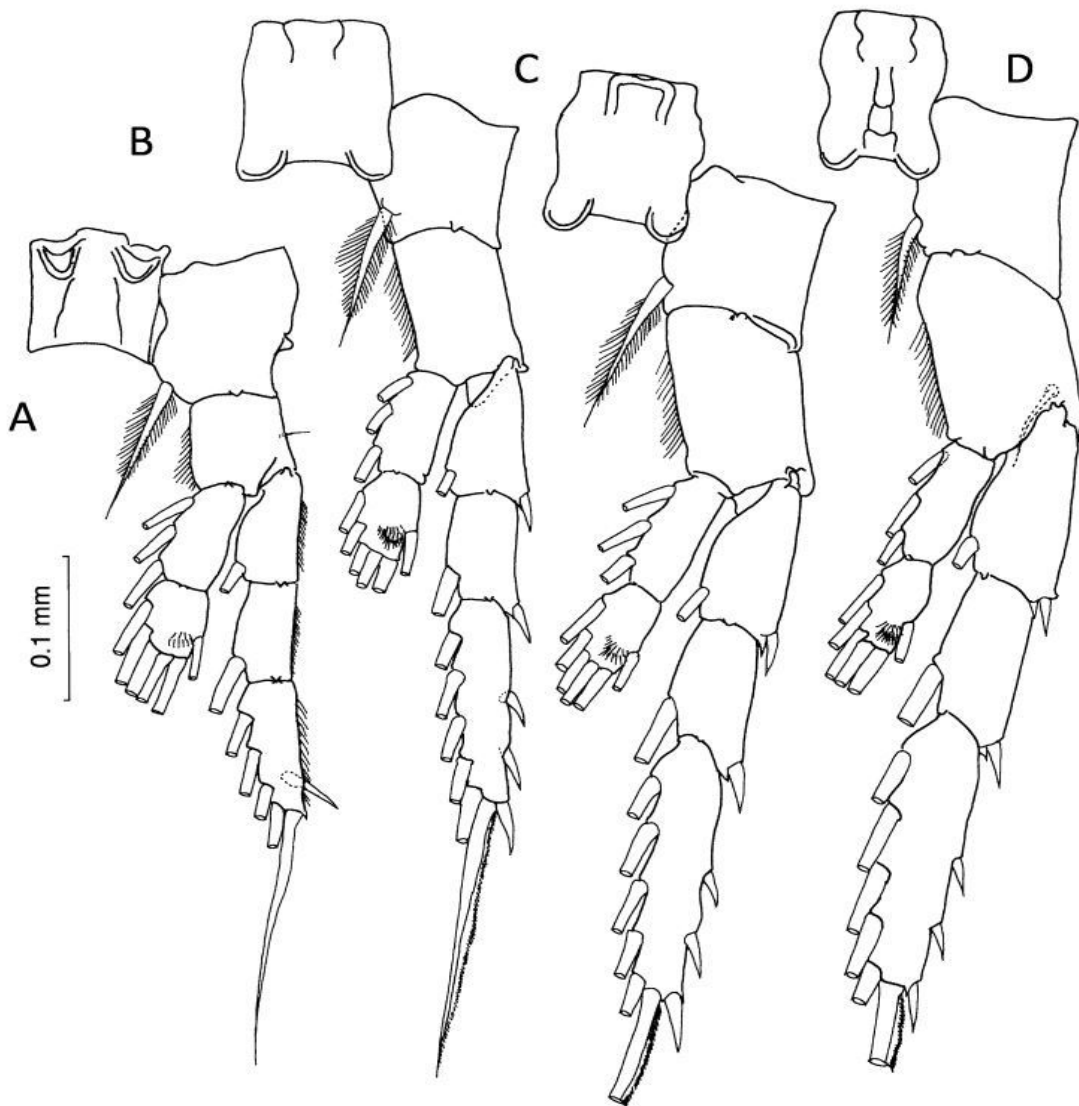
Male (Figs. 6.4) Total length 1.67–1.78 mm ( $\bar{x} \pm SD = 1.74 \pm 0.04$ , n=5). Prosome length 1.25–1.32 mm, width 0.44–0.50 mm. Habitus (Fig. 6.4A, B). Prosome about 3 times as long as urosome. Posterior corners of fifth pediger rounded and symmetrical. Urosome 5-segmented. Proportional lengths of urosomites and caudal ramus 17: 17: 14: 12: 10: 30 (= 100); width to length ratios 1.6, 1.5, 1.6, 1.9, 2.3 and

0.32. Second urosomite with posterolateral and posteroventral processes on right side (Fig. 6.4A-C), of which the latter smaller, each with minute seta on tip, and tip of the former not reaching end of second somite in dorsal view but reaching in lateral view (Fig. 6.4A-C). Caudal rami symmetrical.

Appendages similar to those of female except right antennule and leg 5.

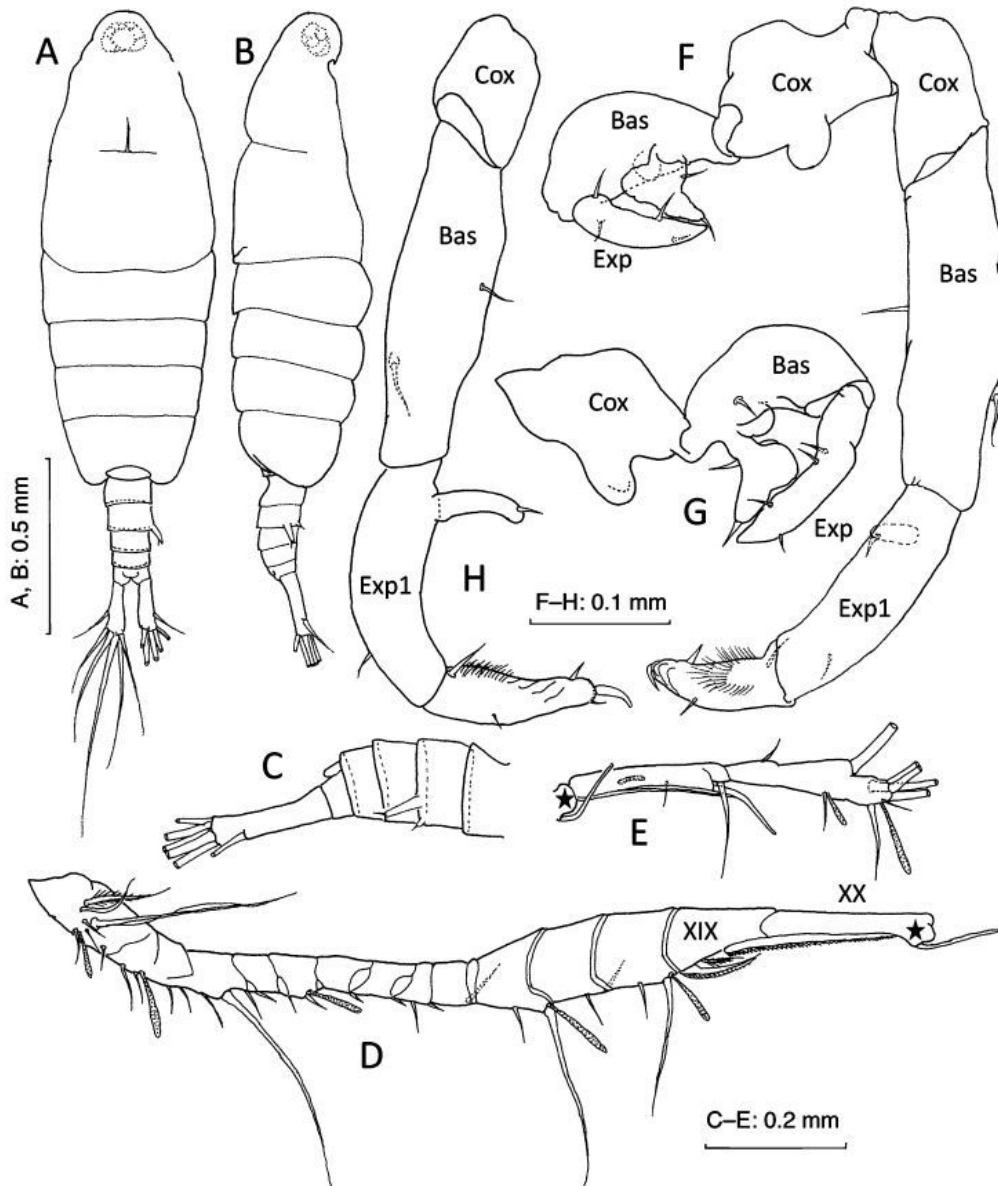


**Fig. 6.2.** *Tortanus (Atortus) andamanensis*, n. sp., female (holotype). A, B, antennule, star indicates segment XXI; C, antenna; D, mandible palp; E, mandible gnathobase; F, maxillule; G, maxilla; H, maxilliped.



**Fig. 6.3.** *Tortanus (Atortus) andamanensis*, n. sp., female (holotype), legs 1-4, anterior view. A, leg 1; B, leg 2; C, leg 3; D, leg 4.

Right antennule (Fig. 6.4D, E) geniculate; ancestral segments I-VIII, XXI-XXIII, XXIV-XXVIII totally or partially fused; segments XVI-XIX expanded. Armature as follows: I, 1; II-V, 5+ae; VI, 1; VII, 2+ae; VIII, 2; IX, 2; X, 2; XI, 2+ae; XII, 1; XIII, 1; XIV, 2; XV, 1; XVI, 2+ae; XVII, 2; XVIII, 2+ae; XIX, 1+p (process); XX, 1+p; XXI-XXIII, 2+ae+2p; XXIV-XXVIII, 9+2ae. Anteroproximal process on segment XIX slender, reaching distal end of segment; serrated ridge on segment XX produced proximally over one-third of segment XIX. Anterodistal seta on segment XX slightly curved near base.



**Fig. 6.4.** *Tortanus (Atortus) andamanensis*, n. sp., male (paratype). **A**, habitus, dorsal view; **B**, habitus, lateral view; **C**, urosome, right lateral view; **D**, **E**, antennule, segments XIX and XX (star) are indicated; **F**, leg 5, anterior view; **G**, right leg 5, posterior view; **H**, left leg 5, posterior view. Abbreviations: Cox, coxa; Bas, basis; Exp, exopod; Exp1, first exopod.

Right leg 5 (Fig. 6.4F, G) coxa semi-trapezoid with semispherical medial process with smooth surface; basis semicircular with seta on posterior surface and large medial process bearing 2 setae, the medial process being ocarina-shaped with depression on distomedial margin and with small rounded process at distal side of its base; exopod 1-segmented, slightly curved inwards, tapering distally into narrow tip,



and with 4 setae. Left leg 5 (Fig. 6.4F, H) coxa unarmed; basis elongate and straight, with lateral seta at distal third and medial seta midway; exopod 2-segmented, proximal segment with distorateral seta and proximomedial, large fingerlike process bearing seta, distal segment with patches of setules on anterior surface, 2 medial setae, 2 lateral minute setae, and blunt distal seta.

**Etymology:** The specific name *andamanensis* refers to the type locality of this species.

**Remarks:** Since three distinct forms, one represented by females and the others by males, were contained in the samples from the same sampling site of the present study, we referred to the following observations as rationale for the female-male correspondence of this species. (1) Females of the *tropicus* group (see below) have been reported to be larger than the males in all known species, with female/male TL ratios ranging from 1.05 to 1.48 according to the species (Table 6.1). *Tortanus digitalis*, the species most closely related to *T. andamanensis* (see below), has shown the largest values (1.48), and the ratio of the present *T. andamanensis* (1.22) is close to the mean ratio of 1.17, while the hypothetical ratio for the present female (= *T. andamanensis*) to the male of *T. sigmoides*, as described below, is 1.05, which is the lowest value for all species of the *tropicus* group. Accordingly, it is most unlikely that the female of *T. andamanensis* corresponds to the male of *T. sigmoides*. (2) The occurrence ratio of the female and male *T. andamanensis* and the male *T. sigmoides* was 77, 18, and 5% (all samples combined: authors' unpublished data), respectively. While the female *T. andamanensis* was much more abundant than the males, the male of *T. andamanensis* was three times more abundant than *T. sigmoides*, which supports the female-male correspondence of *T. andamanensis*, as described above.

The new species belongs to the *tropicus* species group proposed by Othman (1987) within the subgenus *Atortus* Ohtsuka, 1992 (see also Bowman, 1971; Ohtsuka and Kimoto, 1989). This species group is defined by the combination of the following characters: (1) the second urosomite of the male with a process on the right side, (2) the anterior end of the serrate margin of the ancestral segment XX of right antennule of the male produced proximally over the segment XIX, and (3) the distal segment of leg 5 of the female either slender and asymmetrical or subquadrate. The following 12 species are the current members of this group: *T. brevipes* A. Scott, 1909, *T. tropicus* Sewell, 1932, *T. longipes* Brodsky, 1950, *T. rubidus* Tanaka, 1965, *T. giesbrechti* Jones and Park 1968, *T. bowmani* Othman, 1987, *T. ryukyuensis* Ohtsuka and Kimoto, 1989, *T.*

*digitalis* Ohtsuka and Kimoto, 1989, *T. taiwanicus* Chen and Hwang, 1999, *T. vietnamicus* Nishida and Cho, 2005, and the present study two species, of which *T. brevipes* is known only from the female. While Ohtsuka and Kimoto (1989) proposed the name “*brevipes* species complex” for this assemblage of species, the name “*tropicus*” proposed by Othman (1987) is followed here, since the male of *T. brevipes* has not yet been described (see also Nishida and Cho, 2005).

The female of *T. andamanensis* is distinguished from the other members of the *tropicus* group by the following characters. (1) The posterior dorsolateral processes of fifth pediger in the female are of characteristic shape with the right process produced more posteriorly than the left (Figs. 6.1A-C). The fifth pediger in the other species is either symmetrical (*T. ryukyuensis*), asymmetrical with the left posterior process more produced than the right (*T. rubidus*, *T. giesbrechti*, *T. longipes*), asymmetrical with posterior extension of the both sides subequal (*T. bowmani*, *T. digitalis*, *T. taiwanicus*), or asymmetrical with the posterior processes produced posteriorly, rather than dorsolaterally (*T. vietnamicus*, *T. tropicus*, right process of *T. brevipes*), or laterally (left process of *T. brevipes*). (2) The caudal rami are asymmetrical with middle margin of the left ramus produced medially (Fig. 6.1A, D). The caudal rami of the other species are either symmetrical or asymmetrical without such a process on the left ramus. The male *T. andamanensis* is distinguished from the other species of the group by the presence of a semispherical process on the coxa of right leg 5. Such a process is lacking (*T. giesbrechti*, *T. longipes*, *T. ryukyuensis*, *T. tropicus*) or of different shape (*T. taiwanicus*, *T. digitalis*, *T. bowmani*, *T. rubidus*, *T. vietnamicus*) in the other species. The males of *T. andamanensis* most closely resemble to those of *T. digitalis*, although there are marked differences between their females in the structure of the fifth pediger, genital compound somite, and caudal rami. The slight differences between the male of the two species are in (1) the shape of the coxal process in right leg 5 (smooth semispherical in *T. andamanensis* (Fig. 6.4F, G), blunt papilla in *T. digitalis* (Fig. 6F, G of Ohtsuka and Kimoto, 1989)), and (2) the presence of semicircular process at the base of medial process on the basis in right leg 5 (Fig. 6.4F, G) (such a process is lacking in *T. digitalis* (Fig. 6F, G of Ohtsuka and Kimoto, 1989)).

**6.4. *Tortanus (Atortus) sigmoides* new species in this studies (Figs. 6.5)**

Material studied: Specimens were collected on 27 March 2012 at Burmanallah (11°33'N, 92°43'E), South Andaman Island, India. Holotype: male (ZSI-ANRC: 11072). Paratypes: 2 intact males (ZSI-ANRC: 11074). Specimens are preserved in vials in 2% formaldehyde/seawater with a drop of glycerol added.

Male (Figs. 6.5) Total length 1.96–2.08 mm ( $\bar{x} \pm SD = 2.01 \pm 0.06$ , n=5; holotype, 1.96 mm). Prosome length 1.40–1.52 mm, width 0.50–0.59 mm. Habitus (Fig. 6.5A, B). Prosome about 2.5 times as long as urosome. Posterior corners of fifth pediger rounded and asymmetrical with left side more produced posteriorly than right (Fig. 6.5A). Urosome 5-segmented. Proportional lengths of urosomites and caudal ramus 15: 16: 15: 14: 8: 32 (= 100); width to length ratios 1.5, 1.3, 1.3, 1.3, 2.1 and 0.23. First abdominal somite with posterolateral and posteroventral processes on right side (Figs. 6.5A-C), of which the latter smaller, each with minute seta on tip, and tip of the former reaching about middle of second somite in both dorsal and lateral view. Caudal rami symmetrical.

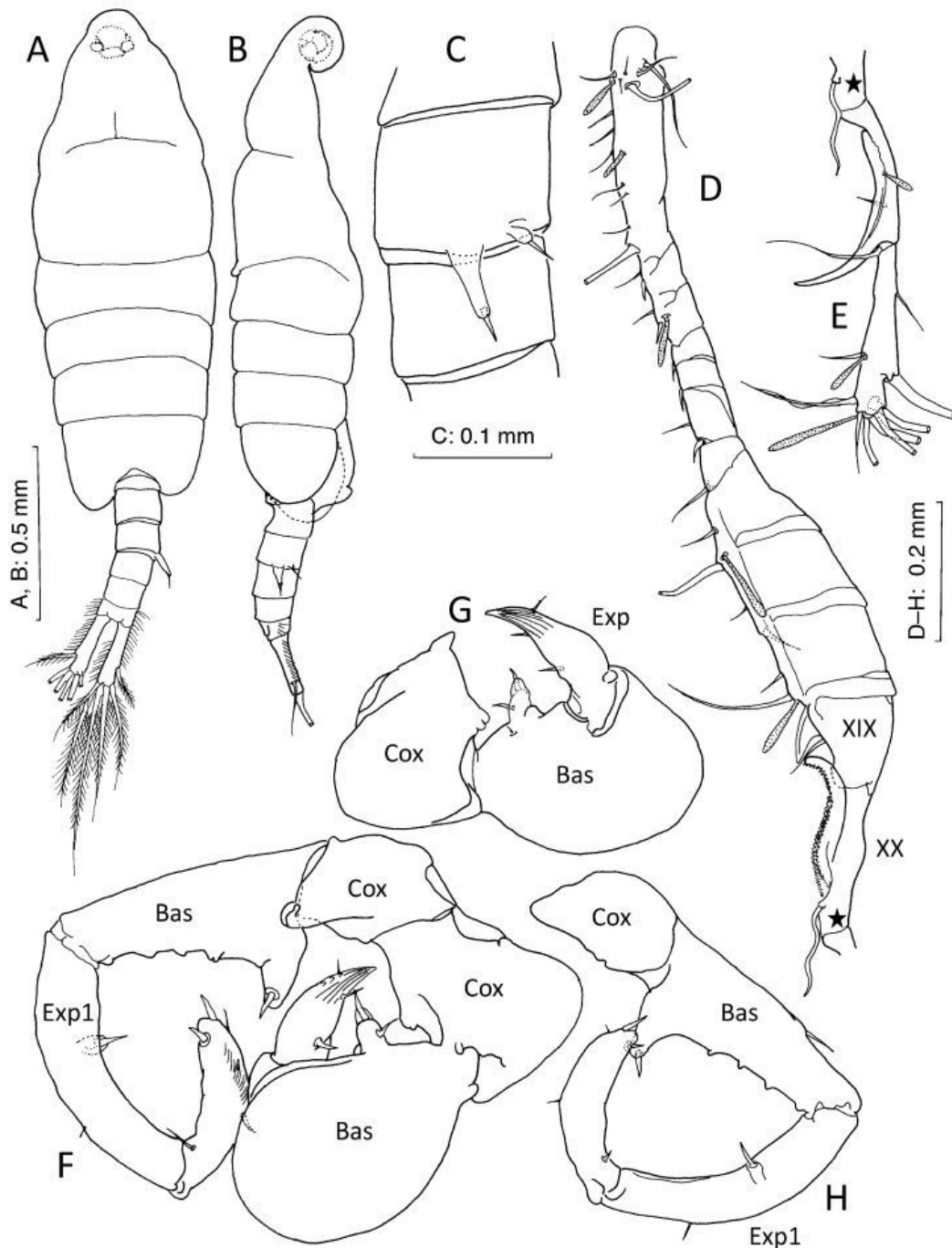
Appendages similar to those of male *Tortanus andamanensis* except the following characters in right antennule and leg 5.

Right antennule (Fig. 6.5D, E). Anteroproximal process on segment XIX triangular, reaching middle of segment; serrated ridge on segment XX curved sigmoid and produced proximally to middle of segment XIX, close to tip of triangular process; anterodistal seta on segment XX also curved sigmoid.

Right leg 5 (Fig. 6.5F, G). Coxa semicircular and expanded laterally with small bilobate medial process; basis semicircular and expanded laterally, with small finger-like medial process bearing 2 setae; exopod 1-segmented, slightly curved inwards, tapering distally into pointed tip, and with grooves on distal surface and 3 setae. Left leg 5 (Fig. 6.5F, H) coxa semi-trapezoid and unarmed; basis elongate and straight with lateral seta at distal third, medial margin strongly sinuate with large triangular proximal process with subdistal seta and much smaller four processes at regular intervals; exopod 2-segmented, proximal segment with midlateral seta and proximomedial process bearing seta, distal segment with tufts of setules on distolateral surface, 1 proximomedial-, 1 midlateral-, and three distal setae (Fig. 6.5F, H).

Female unknown.

Etymology. –The specific name *sigmoides* refers to the serrated ridge and the anterodistal seta on the right antennule segment XX, both are strongly curved sigmoid.



**Fig. 6.5.** *Tortanus (Atortus) sigmoides*, n. sp., male (holotype). A, habitus, dorsal view; B, habitus, lateral view; C, first abdominal somite, right lateral view; D, E, antennule, segments XIX and XX (star) are indicated; F, leg 5, posterior view; G, right leg 5, anterior view; H, left leg 5, anterior view. Abbreviations: Cox, coxa; Bas, basis; Exp, exopod; Exp1, first exopod.

Remarks: The male of *T. sigmoides* is distinguished from the other members of the *tropicus* group by the serrate ridge and the anterodistal seta on segment XX of the

right antennule, both of which are strongly curved sigmoid; these characteristics are autoapomorphies in the *tropicus* group. The males of *T. sigmoides* closely resemble those of the *longipes* group (*T. longipes* and *T. giesbrechti*) defined by Ohtsuka and Kimoto (1989), especially in the posterior process of prosome with left end produced more posteriorly than right, the triangular anteroproximal process on the segment XIX of right antennule, the expanded basis of right leg 5, and the prominent medial triangular process on the basis of left leg 5. In addition to the characteristics in the antennule as above, *T. sigmoides* is distinguished from *T. longipes* and *T. giesbrechti* by (1) the presence of medial process on the coxa (lacking in the latter two), (2) the smoothly curved exopod [acutely curved in *T. longipes* (Fig. 250K of Tanaka, 1965)], both of right leg 5, and (3) the medial processes at regular intervals on the basis of left leg 5 [arranged irregularly in *T. giesbrechti* (Fig. 22 of Jones and Park, 1968)]. Since *T. longipes* and *T. giesbrechti* have been recorded from the coasts of the island bordering the westernmost rim of the Pacific Ocean and an oceanic island in the Central Pacific, respectively (Ohtsuka and Kimoto, 1989), the present occurrence of *T. sigmoides* in this study extends the distribution of the *longipes* group to the Indian Ocean.

**Table 6.1: Literature records of female/male ratios of total length for the tropicus-species group of *Tortanus* (*Atortus*)**

Species	Total length(mm)		F/M ratio	Reference
	Female	Male		
<i>T. bowmani</i>	1.92	1.58	1.22	Othman (1987)
<i>T. digitalis</i>	2.79	1.89	1.48	Ohtsuka and Kimoto (1989)
<i>T. giesbrechti</i>	2.57	2.37	1.08	Jones and Park (1968)
<i>T. longipes</i>	2.55	2.40	1.06	Tanaka (1965)
<i>T. longipes</i>	2.39	2.10	1.14	Ohtsuka and Kimoto (1989)
<i>T. longipes</i>	2.59	2.46	1.05	Ohtsuka and Kimoto (1989)
<i>T. rubidus</i>	2.3	2.09	1.10	Tanaka (1965)
<i>T. rubidus</i>	2.35	1.99	1.18	Ohtsuka and Kimoto (1989)
<i>T. ryukyuensis</i>	2.15	1.78	1.21	Ohtsuka and Kimoto (1989)
<i>T. ryukyuensis</i>	2.14	1.78	1.20	Ohtsuka and Kimoto (1989)
<i>T. taiwanicus</i>	2.05	1.68	1.22	Chen and Hwang (1999)
<i>T. tropicus</i>	2.71	2.29	1.18	Sewell (1932)
<i>T. vietnamicus</i>	2.16	1.90	1.14	Nishida and Cho (2005)
Mean			1.17	
<i>T. andamanensis</i>	2.12	1.74	1.22	This study
<i>T. sigmoides</i>	–	2.01	–	This study

**6.5. *Tortanus (Atortus) murrayi* A. Scott, 1909**

*Tortanus murrayi* A. Scott, 1909, pp. 191-193, pl. 56, Fig. 1-8; Steuer, 1926, pp. 65-66, Fig. 7 (from Scott); Rose, 1956, p. 462. Not *Tortanus murrayi* A. Scott. Wilson, 1950 (= *T. scaphus*)

Material studied: Burmanallah (11°33'N, 92°43'E), South Andaman Island, India.

Female (Figs. 6.6) Total length 2.28-2.40 mm, mean length 2.34±0.06 ( $\bar{x}$ ±SD, n=3), prosome width (0.65-0.75 mm) and, prosome (1.55-1.90 mm) and urosome (0.58-0.63 mm) length in approximate proportion of 3:1; prosome length to width ratio 2.5:1.

Cephalosome and first pediger separated and narrowed considerably in front (Fig. 6.6A, B). Multilobed eye prominent at the anterior cephalic region (Fig. 6.6C); antennule symmetrical, extend beyond the caudal ramus; a small anterior process or triangular spine at the base of the antennule is visible from lateral side (Fig. 6.6C). Prosome about 3 times as long as urosome. Fourth and fifth pedigerous somites fused with posterior corners of fifth pediger rounded and symmetrical. Urosome 2 segmented and nearly symmetrical with short blunt process or tubercle on the left posterior corner of the genital segment (Fig. 6.6D). Anal segment fused with caudal rami and the left caudal ramus slightly enlarged with distal part of the left caudal ramus rectangular in shape. The setae are placed at the apex of each joint. The lateral margins are naked.

Leg 5: Proximal segments of right and left legs fused to form a common base; terminal segment of both legs bearing three prongs; proximal and central prongs being longer than the distal prong (Fig. 6.6E).

Male was not found in the present study.

Occurrence and distribution: The specimen has been found to be rare (may be due to conventional sampling method) and collected in the rainy season during rough weather condition. The species has been recorded from Malay Archipelago, Philippines and China Sea.

**6.6. *Tortanus (Tortanus) gracilis* (Brady, 1883)**

*Corynura gracilis* Brady, 1883: 71, pl. 33; *Corynura gracilis* Brady, 1893: 525.

*Tortanus gracilis*, Giesbrecht and Schmeil, 1898: 258; Cleve, 1901: 51, pl. 7; Thompson and Scott, 1903: 254; Cleve, 1903: 369; Wolfenden, 1905: 1026; A. Scott, 1909: 190; Sewell, 1912: 377; Sewell, 1914: 248.

New species and reports of *Tortanus* from South Andaman

Material studied: Chattam (11°41'11"N, 92°43'20"E) and Junglighat (11°39'27"N, 92°43'22"E), South Andaman Island, India. Total length 1.81-1.89 mm, mean length 2.34±0.06 mm ( $\bar{x}\pm SD$ , n=3), prosome width (0.65-0.75 mm) and, prosome (1.55-1.90 mm) and urosome (0.58-0.63 mm) length in approximate proportion of 3:1; prosome length to width ratio 2.5:1.

Female (Fig. 6.7A, C) Cephalosome and first pediger separate; fourth and fifth pediger separate, posterior of the fifth pediger rounded, knob like. A small protrusion present in the median part of the postero-dorsal margin of the cephalosome. Upper lip semicircular with a row of fine hairs. Urosome 3-segmented, asymmetrical; anal segment and long caudal rami fused. Caudal rami asymmetrical with right ramus larger and longer than left; anal segment narrow in dorsal and lateral view. Antennule symmetrical, reaching to mid-length of caudal ramus; Legs 1-4 biramous with 3-segmented exopod and 2-segmented endopod; outer seta on leg 1 basis minute. Seta (in Arabic numerals) and spine (in Roman numerals) formula as follows:

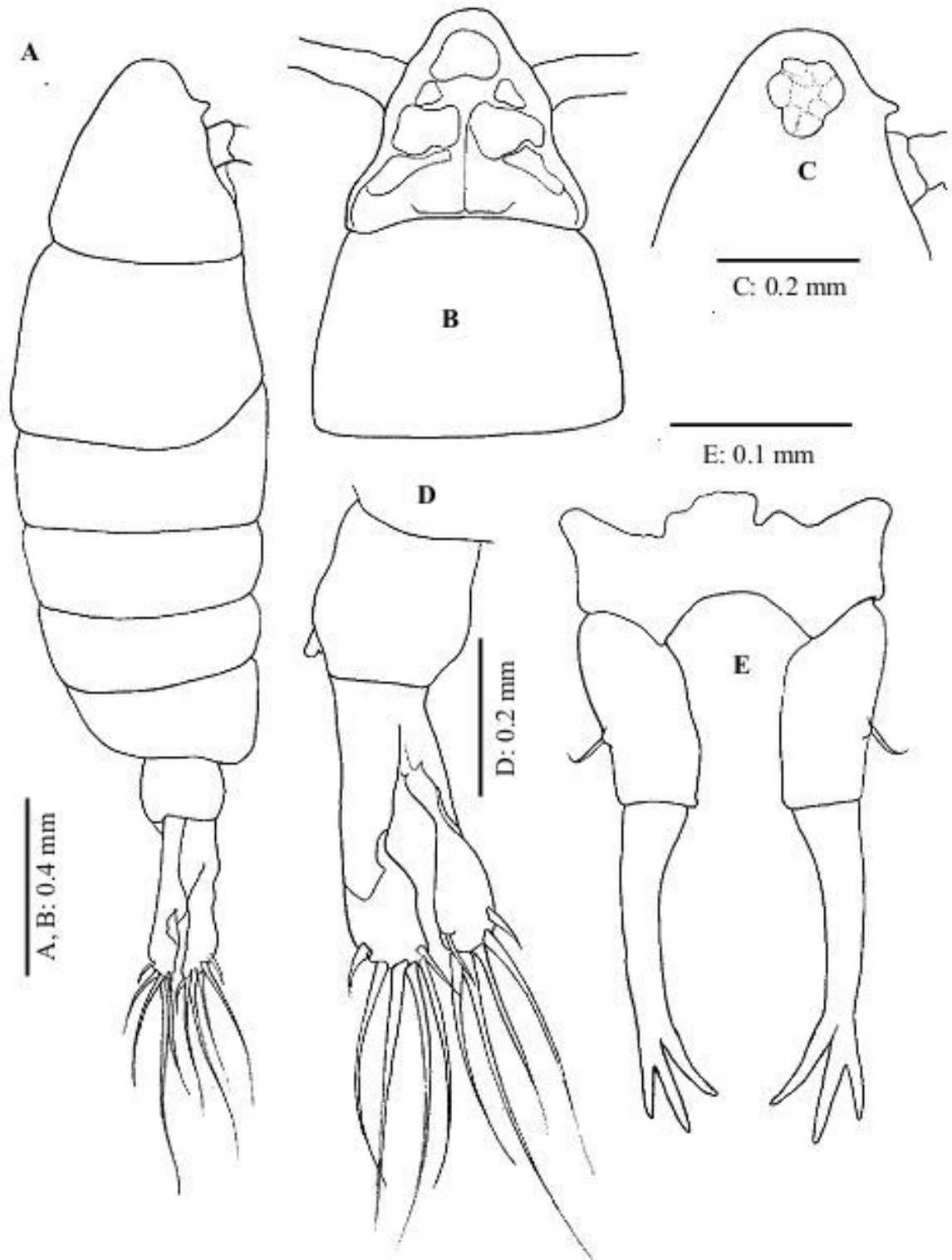
	Coxa	Basis	Exopod segment 1; 2; 3	Endopod segment 1; 2
Leg 1	0-1	1-0	0-1; 0-1; II, I, 4	0-3; 1, 2, 3
Leg 2	0-1	0-0	I-1; I-1; III, I, 5	0-3; 1, 2, 4
Leg 3	0-1	0-0	I-1; I-1; III, I, 5	0-3; 1, 2, 4
Leg 4	0-1	1-0	I-1; I-1; III, I, 5	0-3; 1, 2, 3

Leg 5 (Fig. 6.7C) slightly asymmetrical, longer on left, terminal segment with 2 small spines on distal outer margin. Steuer (1926) drew a seta on the outer middle margin of each basis.

Male (Fig. 6.7B, D) Cephalosome and first pediger separate; fourth and fifth pediger separate, posterior of the fifth pediger rounded, knob like. A small protrusion present in the median part of the postero-dorsal margin of the cephalosome. Urosome slightly asymmetrical. Appendages similar to those of female except right antennule and leg 5.

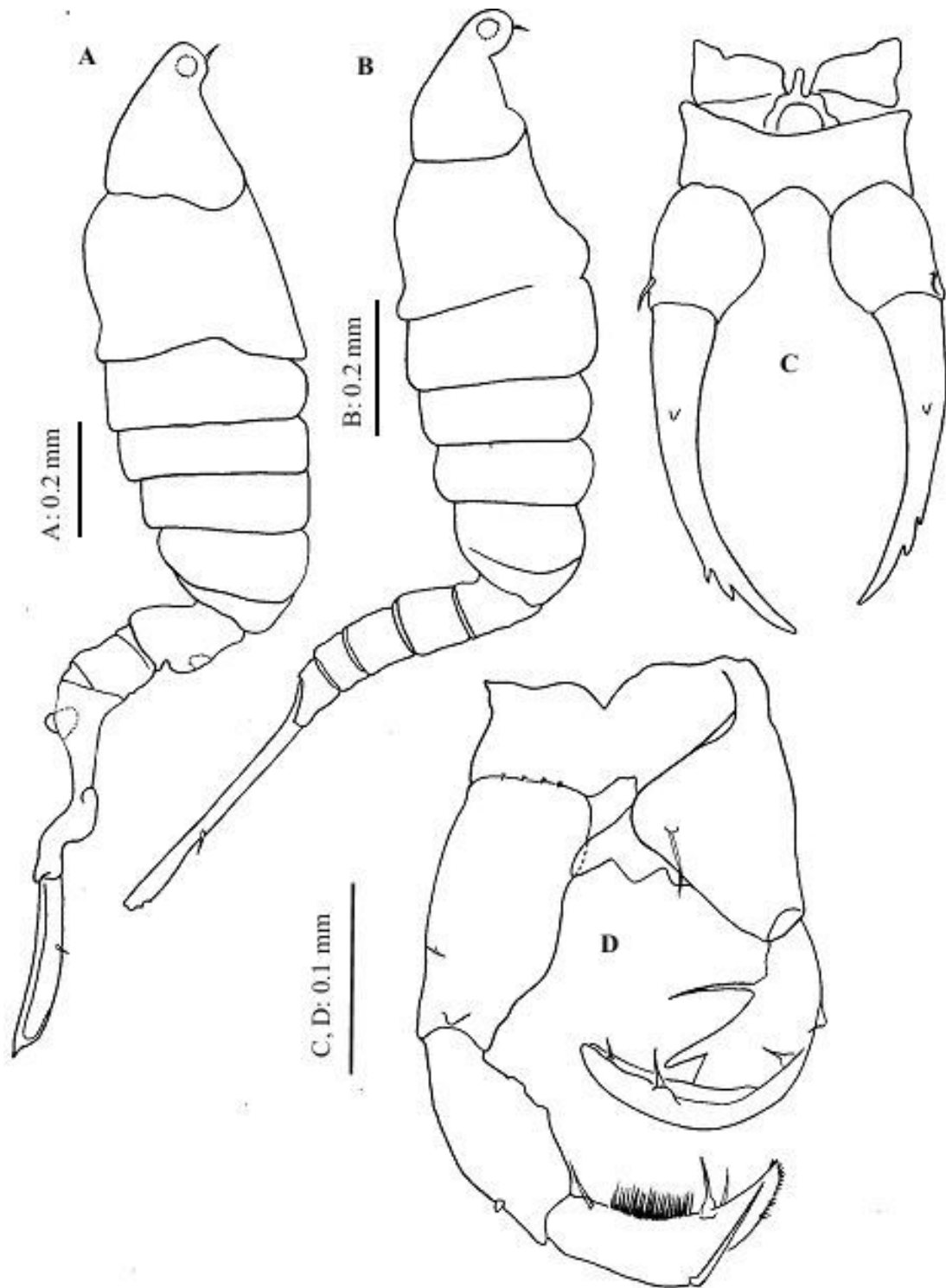
Leg 5 (Fig. 6.7D): Right P5 second segment with a pointed triangular projection with tooth just internal to the point; left P5 longer than right, terminal segment curved, inner margin with a fringe of fine hairs and 2 small spines.

Occurrence and distribution: The specimen has been found to be common and collected in the rainy season during rough weather condition. The species has been recorded from Malay Archipelago, Philippines and China Sea.



**Fig. 6.6.** *Tortanus (Atortus) murrayi*. A, habitus, lateral view; B, head, dorsal view; C, multilobed eye and triangular spine at the base of the antennule; D, urosome, dorsal view; E, leg 5.





**Fig. 6.7.** *Tortanus (Tortanus) gracilis*. A, female, lateral view; B, male, lateral view; C, female, leg 5; D, male, leg 5.

## 6.7. Discussion

The habitat segregation of the subgenera is well established and each species within the genus are restricted to a certain localities in the coastal waters of Indo-West Pacific region and Northwestern Atlantic, *Tortanus* (*T.*) *discaudatus*. The subgenus *Tortanus* occurs in the tropical-temperate eutrophic waters, whereas *Atortus* is distributed in oligotrophic waters of Indo-West Pacific (Ohtsuka and Kimoto, 1989; Ohtsuka, 1992; Ohtsuka and Reid, 1998). *Tortanus* (*Atortus*) *tropicus*, described as new by Sewell (1932), was collected by surface tow of a net at Nankauri Harbour, Nicobar Islands, which has been the only record of *Tortanus* (*Atortus*) species from the Andaman and Nicobar Islands. With the addition of the present two species, accordingly, now three species of the *tropicus* group are known to occur within this relatively narrow geographic area, suggesting that they have different niches in terms of microhabitats and/or behavior (e.g., swarming and feeding; see also Ohtsuka and Kimoto, 1989; Ohtsuka *et al.*, 2000). These species are relatively distinct with respect to several characters as follows. Size (total length) is largest in *T. tropicus* (female 2.71 mm; male 2.29 mm: Sewell, 1932), medial in *T. sigmoides* (male 1.96-2.08 mm) and smallest in *T. andamanensis* (female 2.00-2.23 mm; male 1.67-1.78 mm). In the male antennule, the serrated ridge on segment XX is straight and the anteroproximal process on segment XIX is slender in *T. andamanensis*, while the former is smoothly curved and the latter triangle in *T. tropicus*, and the former is curved sigmoid and the latter triangle in *T. sigmoides*. In the male leg 5, the medial margin of right coxa has a prominent process in *T. andamanensis*, while a smaller process in *T. sigmoides*, but no such process in *T. tropicus*; left basis has a prominent triangular process in *T. sigmoides*, but no such processes are present in the other two species.

The species of the *tropicus* group are unique among pelagic copepods with their highly limited geographic distribution (Ohtsuka and Kimoto, 1989; Nishida and Cho, 2005). According to Ohtsuka and Kimoto (1989), among the eight species that were known at that time, only *T. longipes* and *T. rubidus* had been recorded at multiple localities, while the other six species were known only from the type localities. This peculiarity has continued to date, and all four subsequently discovered species (*T. taiwanicus*, *T. vietnamicus*, *T. andamanensis*, *T. sigmoides*) are also from single localities, indicating high probability of discovering undescribed species at newly studied localities. This may be partly due to their patchy distribution associated with habitats of complicated topography such as coral reefs and sea-grass beds, wherein

conventional net-sampling may not be much effective (Ohtsuka and Kimoto, 1989; Ohtsuka and Reid, 1998; Ohtsuka *et al.*, 2000; Nishida and Cho, 2005), but also due to the presumed extensive speciation of this group through geological vicariance events in this particular region (Ohtsuka and Kimoto, 1989; Nishida and Cho, 2005).

The subgenus *Atortus* Ohtsuka, 1992 is regarded as the most advanced of the subgenera which includes two species complexes and four distinct species groups (Bowman, 1971; Ohtsuka and Kimoto, 1989; Ohtsuka and Reid, 1998; Soh *et al.*, 2001). In 1909, A. Scott recorded the occurrence of *Tortanus murrayi* in the Malay Archipelago, including the species *T. brevipes*. However, Sewell (1932) in the collection from Nankauri Harbor in the Nicobar Islands have described a further new species, *T. tropicus* and newly established the subgenus *Atortus* accommodating *T. recticauda* (Giesbrecht, 1889), *T. brevipes* A. Scott, 1909, *T. murrayi* A. Scott, 1909, *T. tropicus* Sewell, 1932. Although, Sewell (1932) had failed to designate any type species for the newly proposed subgenus, *T. murrayi* is one of the well-illustrated species and hence, it has been designated as type species of subgenus *Atortus* by Ohtsuka (1992).

*Tortanus* (A.) *murrayi* has been assigned to West Pacific *murrayi* species group, of the Indo-West Pacific *recticauda* species complex and, the species group comprised of seven species such as: *T. (A.) murrayi*, *T. (A.) lophus* Bowman, 1971, *T. (A.) scaphus* Bowman, 1971, *T. (A.) sinicus* Chen, 1983, *T. (A.) bonjol* Othman, 1987, *T. (A.) erabuensis* Ohtsuka *et al.*, 1987 and *T. (A.) tumidus* Chen *et al.*, 2004. Whereas, the Indian Ocean *recticauda* species group of the same species complex accommodates six species (Ohtsuka and Conway, 2005). These species of *murrayi* group have exclusively reported in the waters bordering western Pacific and South China Sea (A. Scott, 1909; Bowman, 1971; Chen and Hwang, 1999) and might have expanded their distribution in the neighboring waters of the Andaman Sea, Indian Ocean.

*T. (A.) murrayi* inhabits subtropical or tropical waters in the eastern sea of the Indo-Malayan region, western Pacific and South China Sea (Ohtsuka and Kimoto, 1989) however there are no recent records on these species from this area (Madhupratap and Haridas, 1986). This may be due to the difficulty in collecting the *Tortanus* species by conventional plankton tows since they are demersal during daytime (Ohtsuka and Kimoto, 1989). In the present study *Tortanus (T.) gracilis* was found in the sheltered coastal waters surrounded by islands, and exposed to pollution due to settlements and harbor activities. *Tortanus (T.) forcipatus* and *T. (T.) gracilis* are inclined to be similar

species (Cleve, 1901; Wolfenden, 1905; Sewell, 1912) due to the occurrence of two different forms of *T. (T.) gracilis* which later established by A. Scott (1909), one with symmetrical leg 5 (smaller form) whereas the other slightly asymmetrical in the length of the left and the right fifth leg. Owing to the distinctness between the female leg 5 of the two species (A. Scott, 1909) and the discovery of males of *T. (T.) forcipatus* by Sewell (1914) have confirmed them as distinct species. *T. (T.) gracilis* was reported from western and eastern Indian Ocean (Ganapathi and Santhakumari, 1961; Saraswathy, 1966; Patel, 1975; Madhupratap and Haridas, 1986; Ramaiah and Nair, 1997; Mishra and Panigrahy, 1999; Vareethiah, 1999; Tiwari and Nair, 2002; Conway *et al.*, 2003; Gaonkar *et al.*, 2010; Roy, 2010), Straits of Malacca (Rezail *et al.*, 2004), Gulf of Thailand (Maiphae and Sa-ardrit, 2011), yet unknown from Andaman waters have been recorded and described in the present study.

The Indian Ocean has been well explored for copepods (Rao and Griffiths, 1998), although the inshore waters of the oceanic islands and the coastal waters of many countries have remained unexplored (Conway, 2005). In addition to that the conventional net-sampling of copepods may not be much effective for numerous genera. Consequently, specific methods such as those by SCUBA diving (Ohtsuka and Kimoto, 1989) and night-time collection, with or without light (Jones and Park, 1968; Bowman, 1971) will undoubtedly improve the knowledge of distribution, diversity and speciation of this group of copepods in the Indian Ocean.

**A NEW SPECIES AND OTHER REPORTS OF  
*PSEUDODIAPTOMUS* (COPEPODA, CALANOIDA) FROM  
SOUTH ANDAMAN**

### **7.1. Introduction**

The calanoid family Pseudodiaptomidae Sars, 1902 is a group of demersal copepods that are known to have wide distribution in fresh, estuarine, coastal waters and near shore waters of oceanic islands along the tropics and temperate regions (Sewell, 1932; Pillai, 1980; Walter, 1987; Walter *et al.*, 2006). The restricted distribution and geographical isolation of *Pseudodiaptomus* species have been attributed due to their demersal disposition and the extensive archipelago system of the Indo-Pacific region (Walter, 1987). However, the report on the occurrence of *Pseudodiaptomus serricaudatus* (T. Scott, 1894) from the open oceanic waters of the Equatorial Indian Ocean suggest the successful existence of the species beyond the coastal waters under the influence of monsoonal currents (Rebello *et al.*, 2014). Extensive study on systematics and distribution of this genus has been carried out from the coastal waters of India (Sewell, 1919; Sewell, 1932; Roy, 1977; Pillai, 1980; Reddy and Radhakrishna, 1982; Walter, 1984; Madhupratap and Haridas, 1986; 1989; 1992) although a complete review of the genus from Indian Ocean is needed (Walter, 1994).

In the Indian waters, about 29 species of *Pseudodiaptomus* were so far been reported: *Pseudodiaptomus andamanensis* Pillai, 1980, *P. annandalei* Sewell, 1919, *P. ardjuna* Brehm, 1953, *P. aurivilli* Cleve, 1901, *P. batillipes* Brehm, 1954, *P. binghami* Sewell, 1912, *P. binghami malayalus* Wellershaus, 1969, *P. bowmani* Walter, 1984, *P. burckhardti* Sewell, 1932, *P. charteri* Grindley, 1963, *P. clevei* A. Scott, 1909, *P. compactus* Walter, 1984, *P. cornutus* Nicholls, 1944, *P. daughlihi* Sewell, 1932, *P. heterothix* Brehm, 1953, *P. hickmani* Sewell, 1912, *P. jonesi* Pillai, 1970, *P. lobipes* Gurney, 1907, *P. marinus* Sato, 1913, *P. masoni* Sewell, 1932, *P. mertonii* Früchtl, 1923, *P. nankauriensis* Roy, 1977, *P. pankajus* Madhupratap and Haridas, 1992, *P. pauliani* Brehm, 1951, *P. salinus* (Giesbrecht, 1896), *P. serricaudatus* (T. Scott, 1894), *P. sewelli* Walter, 1984, *P. stuhlmanni* (Poppe and Mrázek, 1895) and *P. tollingeriae* Sewell, 1919. However, the species record from the coastal waters of Andaman archipelago is scarce due to an insignificant sampling effort on the diverse ecological

region. In the present study on the community structure of zooplankton resulted in the discovery of one new species of *Pseudodiaptomus* from the coastal waters of Andaman Sea, is described herein, along with other species recorded from the coastal waters of South Andaman.

## 7.2. Systematic account

Subclass COPEPODA Milne Edwards, 1840  
Order CALANOIDA Sars, 1903  
Family PSEUDODIAPTOMIDAE Sars, 1902  
Genus *Pseudodiaptomus* Herrick, 1884

### 7.3. *Pseudodiaptomus* sp. new species (Figs. 7.1-7.5) (yet to be named).

Material examined: adult females and males, 16-March-2012, Carbyn's Cove, (11°38'N, 92°44'E), South Andaman Island, India. The type specimens will be deposited to Zoological Survey of India-Andaman and Nicobar Regional Centre (ZSI-ANRC) and Department of Ocean Studies and Marine Biology (DOSMB), Pondicherry University after conformation.

Female (Figs. 7.1-7.3) Total length 1.05-1.09 mm ( $\bar{x} \pm SD = 1.07 \pm 0.02$ , n=20). Prosome length 0.69-0.71 mm ( $\bar{x} \pm SD = 0.7 \pm 0.01$ , n=20) and urosome in approximate proportion 1.9:1.

Head rounded in dorsal view (Fig. 7.1A). Rostrum with paired filaments. Cephalosome and first pedigerous somite separate; pedigerous somites four and five fused completely. Fifth pedigerous somite produced posteriolaterally into symmetrical spiniform processes with fine hairs along the medial margin. Urosome 4-segmented. Proportional lengths of urosomites and caudal ramus 31:16:17:14:22 (=100). Genital double-somite (=urosomite 1) produced ventrally, asymmetrical in dorsal view; left proximolateral surface produced; with fine seta in the dorsolateral surface; anteriorlateral surface with spinule patch (Fig. 7.1B, C). Right anterior with dorsolateral row of coarse spines (9-10); clusters of spinules (Fig. 7.1D) and a dorsal seta; ventral surface with a pair of fine setae near posterior margin. Posterior margins of genital and second urosomite devoid of posterodorsal scale rows and third urosomite with scale rows. Caudal rami with hair on inner margin and symmetrical with 6 setae; setae 2 to 5 plumose, seta 1 with fine hair only along the inner margin and seta 6 located dorsally. Oviparous females bear single egg sac with 5-11 individual eggs attached ventrally in the genital region.

Antennules (Fig. 7.1E) symmetrical with 22 segments and reaches to the posterior margin of genital segment; each segment except 6, 15, 16, 18-20 segments with aesthetasc; segments 6-7 incompletely fused, the former with short spine; segment 20 having specialized seta with small teeth on medial margin.

Antenna (Fig. 7.2A) coxa with single seta; basis with 2 setae; endopod 2-segmented, first segment with 2 setae, second segment with 7 terminal and 8 subterminal setae, and with lateral fringe of fine hairs. Exopod 4-segmented; first segment with 1 seta, second segment with 1 proximal, 2 medial and 1 terminal setae; third segment with 3 setae; fourth segment with 1 medial and 3 terminal setae.

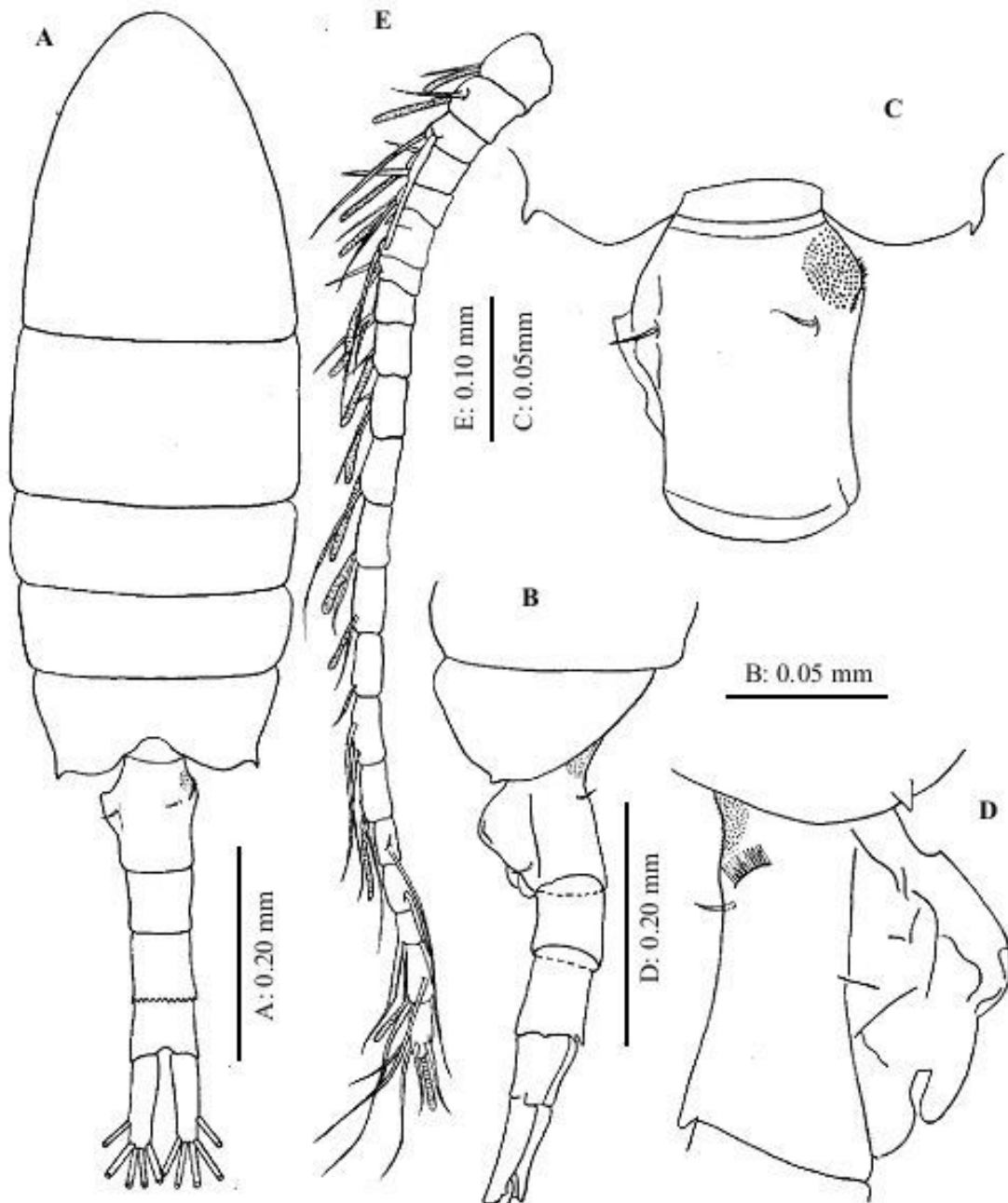
Mandible (Fig. 7.2B) basis with 4 setae along the inner margin; endopod 2-segmented, first segment with 4, second with 9 setae; endopod with 6 setae; segmentation incomplete. Gnathobase (coxa) with serrate dorsal seta and 3 cuspidate and 4 blunt teeth.

Maxillule (Fig. 7.2C) praecoxal arthrite with 9 strong and 6 finer setae; coxa with 4 setae on endite and 9 setae on epipodite; basis with 4 and 5 setae on proximal and distal endites, and with 1 seta on exite; endopod 3-segmented with 4, 4 and 6 setae from first to third segments; exopod with 10 setae. Maxilla (Fig. 7.2D) first praecoxal endite with 4 setae, second praecoxal and 2 coxal endites each with 3 setae; basis with 1 stout seta and 3 thinner setae; endopod with 9 setae.

Maxilliped (Fig. 7.2E) with praecoxa and coxa completely fused; endites with 0, 2, 3, 4 setae; basis with 3 setae; basis and first endopodal segment nearly fused; endopodal segment having 6 segments, first segment with 2 setae, second segment with 2 bifurcated setae and 1 seta, third and fourth segments with 1 bifurcated seta and 1 seta, fifth and sixth segments with 3 and 4 setae, respectively.

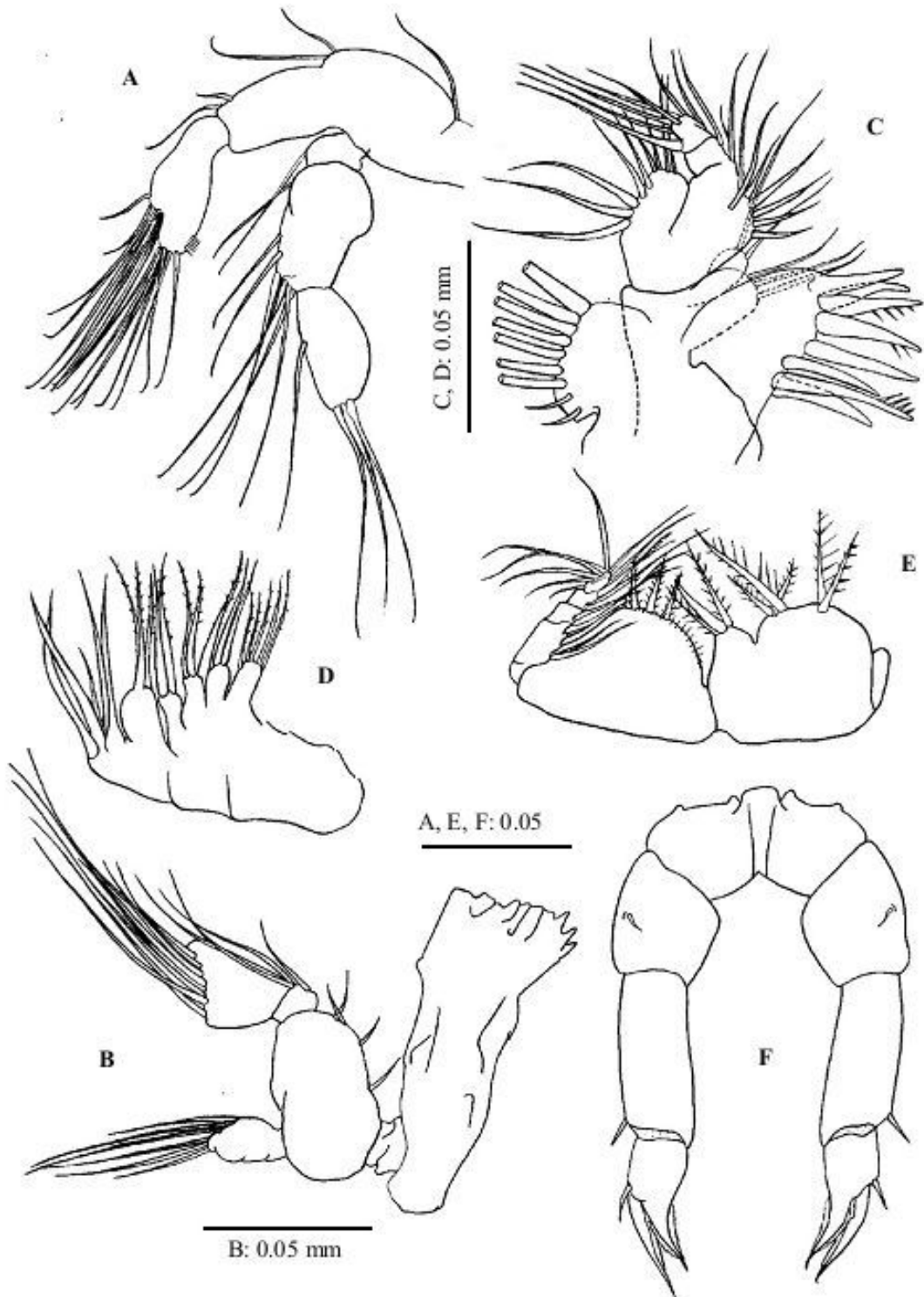
Legs 1-4 (Figs. 7.3A-D) biramous with 3-segmented rami; first and second segments of both rami of legs 1-3, except leg 1 endopod, with spinules on inner distal margin. Seta and spine formula as follows:

	Coxa	Basis	Exopod 1; 2; 3	Endopod 1; 2; 3
Leg 1	0-1	0-0	I-1; 0-1; II-4	0-1; 0-1; 1,2,3
Leg 2	0-1	0-0	I-1; I-1; II,I,5	0-1; 0-2; 2,2,4
Leg 3	0-1	0-0	I-1; I-1; II,I,5	0-1; 0-2; 2,2,4
Leg 4	0-1	1-0	I-1; I-1; II,I,5	0-1; 0-2; 2,2,3

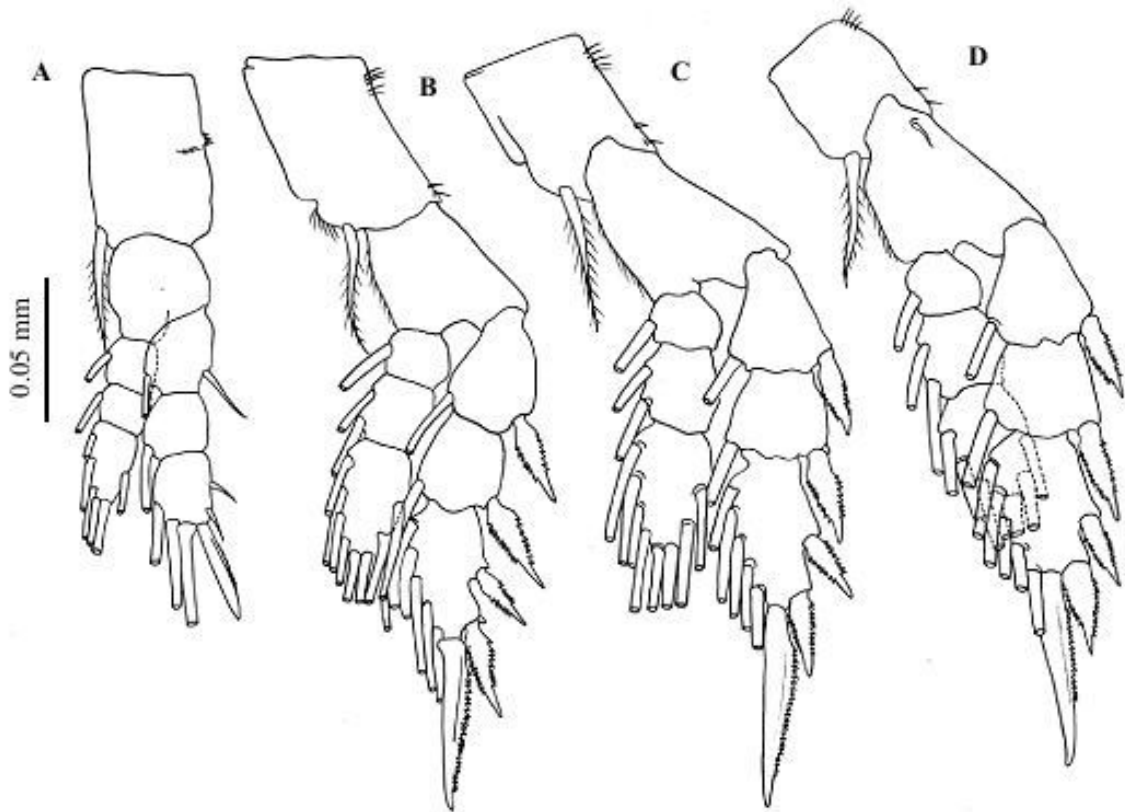


**Fig. 7.1.** *Pseudodiaptomus* sp. nov., female: (A) habitus dorsal view; (B) urosome left lateral view; (C) pediger 5 and genital complex dorsal view; (D) urosome 1 right lateral view; (E) left antennule.





**Fig. 7.2.** *Pseudodiaptomus* sp. nov., female: (A) antenna; (B) mandible; (C) maxillule; (D) maxilla; (E) maxilliped; (F) leg 5 anterior view.



**Fig. 7.3.** *Pseudodiaptomus* sp. nov., female: (A) leg 1; (B) leg 2; (C) leg 3; (D) leg 4.

Leg 5 (Fig. 7.2F) symmetrical and uniramous; basis with 1 seta, without spinules on distolateral margin. Exopod 3-segmented; first exopodal segment being longer with subterminal spine, second segment with distolateral spine and distomedial process with serrate membrane on both margins; third segment spine finely serrate along the inner margin.

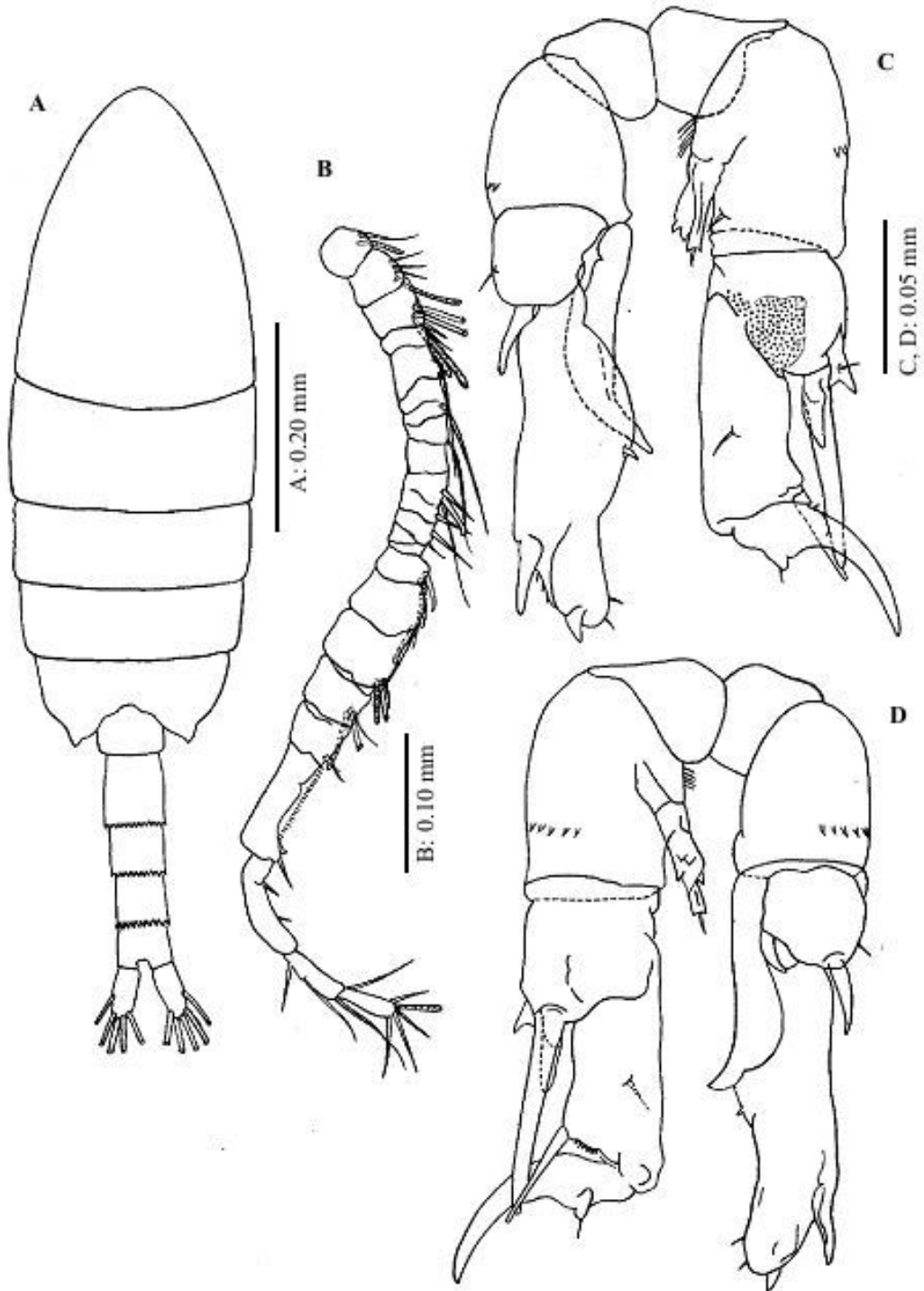
Male (Figs. 7.4-7.5) Total length 0.85-0.91 mm ( $\bar{x} \pm SD = 0.88 \pm 0.02$ , n=20). Prosome length 0.56-0.59 mm ( $\bar{x} \pm SD = 0.58 \pm 0.01$ , n=20) and urosome in approximate proportion 1.9:1.

Cephalosome and first pedigerous somite separate and pedigerous somite 4 and 5 fused completely. Urosome 5-segmented, posterior margins of urosomite 2 to 4 with posterodorsal scale rows; spines on urosome 4 relatively larger (Fig. 7.4A). Proportional lengths of urosomites and caudal ramus 16:23:18:14:11:17 (=100). Caudal rami and setae as in the female. Appendages similar to those of female except right antennule and leg 5. Right antennule (Fig. 7.4B) geniculate and 21-segmented; each segment except segments 5-8, 10, 12, 17-20 with aesthetasc; segments 6 and 7 incompletely fused; segment 10 with curved spine.

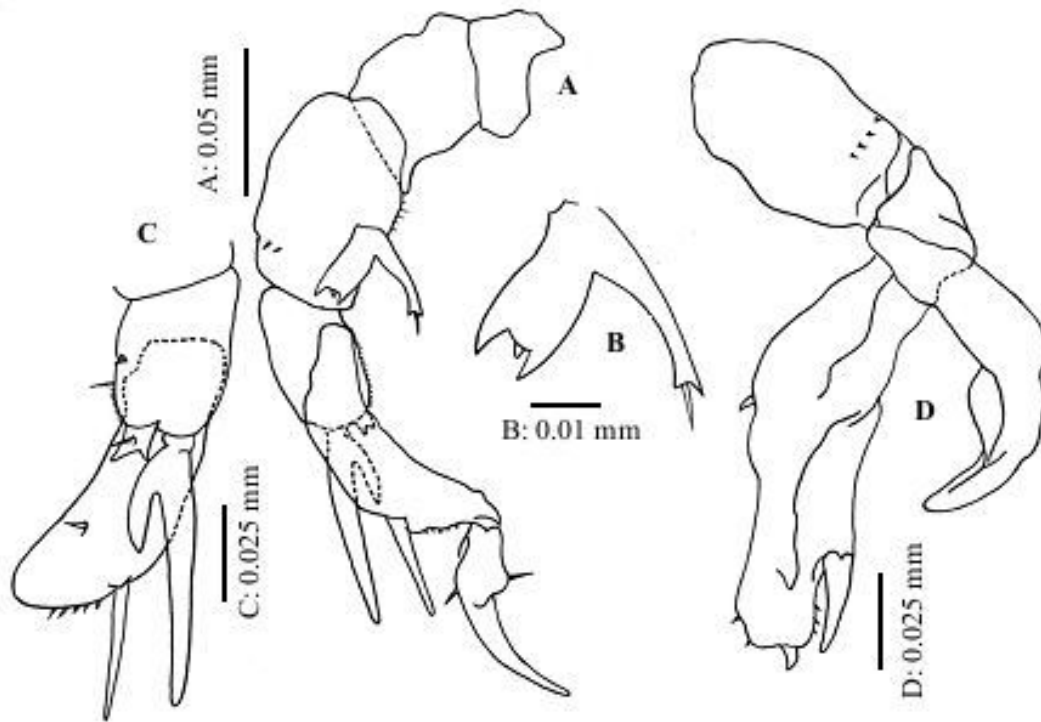
Leg 5 posterior view (Fig. 7.4C): right exopodite 1 with medial spinule patch and a bifid distolateral process with an inner short arm, and an outer long arm; a prominent small bifid spine with setae at midlength present at the base of distolateral process. Exopod 2 longer than broad with a smooth distolateral spine and a patch of spinules at the base of the spine. Exopod 3 sickle-shaped, a proximal knob with seta at the inner margin and with small lateral spines at the outer margin (Fig. 7.5A, C). Endopod bifid; medial lobe slender and longer than lateral, with fine distal seta; lateral branch thick with 4-5 blunt distal spinules (Fig. 7.4D and 7.5B). Left leg: basis produced at inner distal margin into a curved process which reaches middle of exopodite 2 (Fig. 7.5D). Exopodite 1 with mediolateral seta and a strong distolateral spine; exopodite 2 swollen medially with 1 medial and 2 anterior-surface setae, a strong distolateral and terminal spines and spinules between them, distomedial corner rounded. Leg 5 anterior view (Fig. 7.4D): coxa with fine hairs along the surface. Basis with single row of 7 spinules that extends to the posterior margin. Left leg: exopodite 2 with medial triangular spines.

Etymology: The article regarding the new species has been communicated (under review) in the name of *bharatii* refers to “Bharat”, an equally official name of India.

Remarks: The new species belongs to *Ramosus* species group and *hickmani* subgroup as established by Walter (1986). This species group is defined by the combination of the following characters: (i) male P5 with right endopod is conspicuous and branched, left endopod never fused, (ii) the female P5 with exopod 3 is less than the length of exopod 2, (iii) the male P5 with right exopod 1, distolateral spine bifid. There are nine species namely *Pseudodiaptomus ardjuna* Brehm, 1953, *P. australiensis* Walter, 1987, *P. hickmani* Sewell, 1912, *P. hypersalinus* Walter, 1987, *P. ishigakiensis* Nishida, 1985, *P. jonesi* Pillai, 1970, *P. marinus* Sato, 1913, *P. philippinensis* Walter, 1986, *P. sulawesiensis* Nishida and Rumengan, 2005 are the current members of the species group. The habitus most closely allied to *P. ishigakiensis* Nishida, 1985 and *P. sulawesiensis* Nishida and Rumengan, 2005.



**Fig. 7.4.** *Pseudodiaptomus* sp. nov., male: (A) habitus dorsal view; (B) right antennule; (C) leg 5 posterior view; (D) leg 5 anterior view.



**Fig. 7.5.** *Pseudodiaptomus* sp. nov., male: (A) right leg 5, anterior view; (B) right leg 5 endopod; (C) exopod 1 and 2, posterior view; (D) left leg 5 and endopod.

The females of *Pseudodiaptomus* sp. is distinguished from the other members of the *Ramosus-hickmani* subgroup by the following characters: (i) the genital segment of the female with proximolateral projection in the left and the right anterior dorsolateral with a row of coarse spines. The anterior dorsolateral row of coarse spines in other species is either absent (*P. ishigakiensis*, *P. australiensis*, *P. hypersalinus*), or present at left side (*P. hickmani*, *P. marinus*), or on both the sides (*P. sulawesiensis*). The coarse spine and the proximolateral projection are in the alternate in *P. hickmani*. (ii) The posterodorsal margins of the female urosomites are devoid of triangular spine rows except urosomite 3 (as in *P. salinus* (Giesbrecht, 1896) from the *serricaudatus*-subgroup) whereas, the urosomites in other members are found with spine rows. (iii) The distolateral process of the right exopod 1 with two arms, the outer arm found to be thrice the length of the inner arm and outer arm tip not bifid, unlike *P. ardjuna*, the outer arm is bifid and twice the length of the inner arm, (iv) the prominent bifid spine with a medial seta at the base of the distolateral process of exopod 1 is an important character of the present species, whereas in other species that is either absent or simple (not bifid). (v) The size of *Pseudodiaptomus* sp. is comparatively smaller than other species in the members of the *hickmani*-subgroup (Table 7.1). However, the female to

male ratio of the total length is 1.22 mm and prosome to urosome ratio of both the sexes are 1.9 mm which is within the range of members of the subgroup. The mouthparts and swimming legs are almost identical in shape, segmentation and spinulation patterns with existing species of the genus.

**Table 7.1. Comparison of species in *Ramosus-hickmani* group: sex ratio of average total length and prosome (Pr) to urosome (Ur) ratios with respective references.**

Species	Total length (mm)			Pr/Ur ratio		References
	Female	Male	F/M	Female	Male	
			ratio			
<i>P. ardjuna</i>	1.20	1.07	1.12	1.8	2.0	Pillai (1970)
<i>P. australiensis</i>	1.25	1.05	1.19	1.9	2.0	Water (1987)
<i>P. hickmani</i>	1.36	1.16	1.17			Reddy and Radhakrishnan (1982)
<i>P. hypersalinus</i>	1.36	1.07	1.27	1.9	2.0	Water (1987)
<i>P. iskigakiensis</i>	1.25	1.03	1.21	1.6	1.8	Nishida (1985)
<i>P. jonesi</i>	1.16	0.97	1.20			Pillai (1970)
	1.12	0.91	1.23	1.8	1.9	Madhupratap and Haridas (1989)
<i>P. marinus</i>	1.23	1.02	1.21	1.8	1.8	Pillai (1970)
<i>P. philippiensis</i>	1.22	0.98	1.24	2.0	2.0	Water (1986)
<i>P. sulawesiensis</i>	1.26	1.02	1.24	1.8	2.1	Nishida and Rumengan (2005)
Mean	1.24	1.03	1.21	1.8	2.0	
<i>Pseudodiptomus</i>						
sp.	1.07	0.88	1.22	1.9	1.9	This study

**7.4. *Pseudodiptomus annandalei* Sewell, 1919** (Figs. 7.6–7.7)

*Pseudodiptomus annandalei* Sewell, 1919: 5-7, pl. 10, fig. 9; 1924: 787, pl. 44, figs. 2a-c; Brehm, 1934: 88-92, figs. 3-4; 1953: 306-308, figs. 68-71; Kasturirangan, 1963: 39, figs. 35a-d; Wellershaus, 1969: 263, figs. 25-26; Pillai, 1980: 248-250, figs. 1g-j; Grigg, 1972: 84-86, figs. 34a-b, 36a-e; Bayly, 1975: table 1; Reddy and Radhakrishna, 1982: 268-270, pl. 6, figs. 1-12; Goswami, 1983: 254-257; Walter 1986b: 159-162, figs. 14A-I.

*Pseudodiptomus nostradamus* Brehm, 1933: 137-142, figs.8-12; 1934: 84-91, figs.5-6; Kiefer, 1938: 81-91, figs.9-17.

*Pseudodiptomus dubius* Kiefer, 1936: 231-235, figs.9-12; 1938: 86-91, figs.18-24.

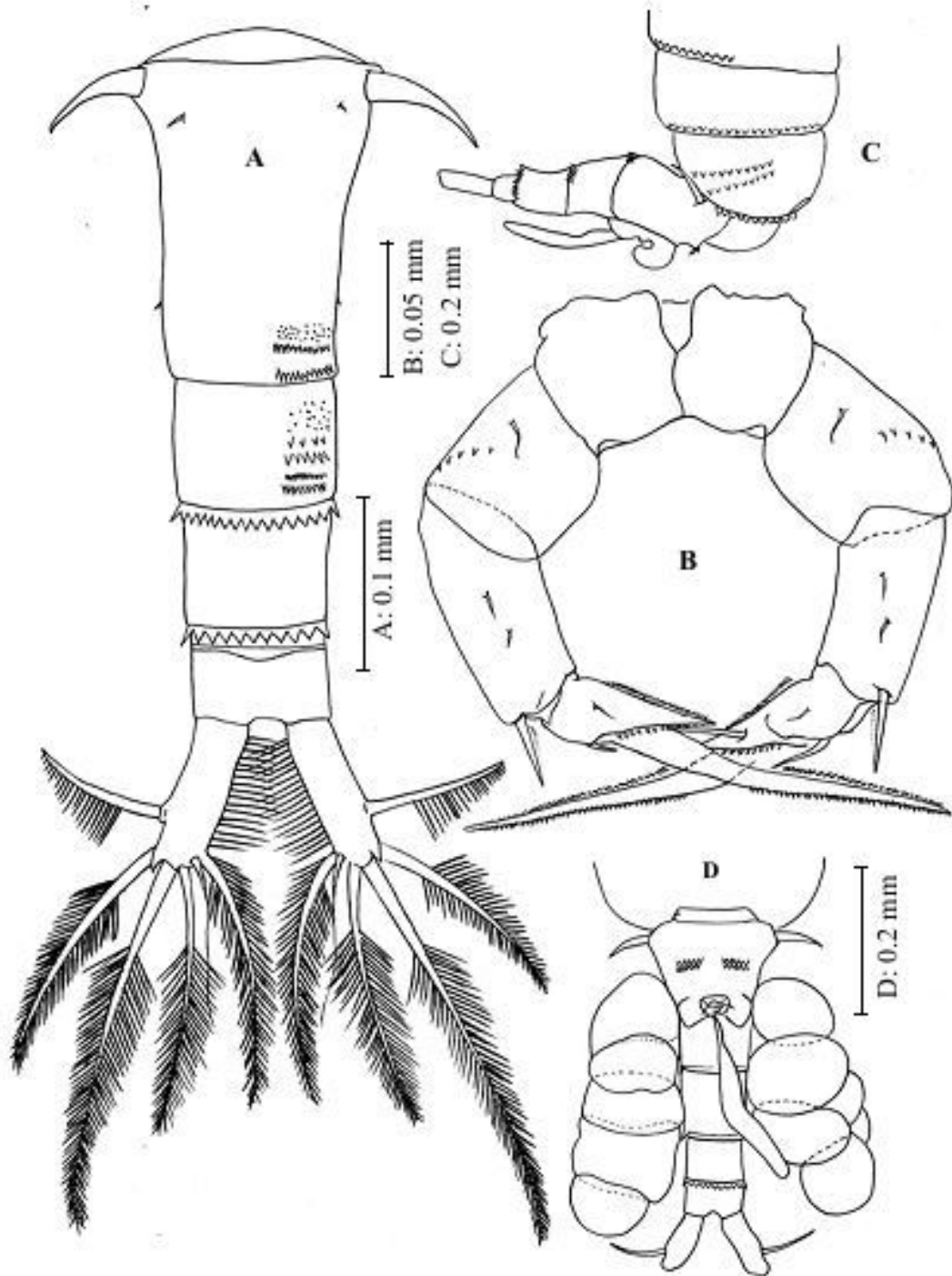
*Schmackeria annandalei* (Sewell) Marsh, 1933: 42-43, pl. 20, fig. 8, pl. 21, fig.1.

*Schmackeria dubius* (Kiefer) Shen, 1979: 77-78, fig. 34a-e; Chen and Zhang, 1965: 23, pl. 32, figs. 1-6.

Material examined: Carbyn's Cove (11°38'N, 92°44'E), South Andaman Island, India. This species was re-described and illustrated by Reddy and Radhakrishna (1982) and Walter (1986) and can be identified from other species by the characteristic morphology of leg 5 and the female genital segment. The following are additional morphological details noted from the specimens from this locality.

Female (Fig. 7.6): Total length 1.33-1.38 mm, mean length  $1.35 \pm 0.02$  ( $\bar{x} \pm SD$ ,  $n=7$ ), prosome (0.86-0.87 mm) and urosome (0.47-0.51 mm) in approximate proportion of 1.8:1. Pedigerous somites 2 and 3 with posterior spine row along dorsal and lateral margins (see Walter 1986). Genital double-somite with a pair of long curved lateral spines, posterodorsal margin with spinules incomplete and restricted to right side; a spinule patch and a spinule row in parallel to the posterior spinule row (Fig. 7.6A). Urosomite 2 with spinules along the posterodorsal margin and right dorsal with four spinule rows of varying size. The proportional length of urosomites and caudal ramus are 44: 17: 14: 8: 18= 100. Caudal rami symmetrical with setules on inner margin and bear 6 setae, the outermost caudal setae is separate and spiniform with setules along its inner margin, third caudal seta longer and sixth located on dorsal side (Fig. 7.6A).

Leg 5 perfectly matched with descriptions and illustrations in the original description and successive re-descriptions (Fig. 7.6B, see also Reddy and Radhakrishna, 1982; Walter, 1986; 1987). Basis 2 with spinule row extends to distolateral corner and a seta on posterior face. Exopodite 1 with distal spine serrate along the inner margin. Exopodite 3 almost 4 times longer than exopodite 2 and serrated on its outer side and lined with a thin hyaline membrane on its inner margin. The anterior face of leg 5 is smooth, devoid of spine rows and setae. The ovigerous females bear a pair of egg sacs and a spermarophore attached to the genital pore (Fig. 7.6C, D).



**Fig. 7.6.** *Pseudodiaptomus annandalei* Sewell. Female: a, dorsal view of urosome and caudal rami; b, posterior view of leg5; c, lateral view of pedigerous segment 2-5 and urosome; d, ventral view of urosome with spermatophore and egg sac.

Male (Fig. 7.7): Total length 1.10-1.19 mm, mean length  $1.14 \pm 0.03$  ( $\bar{x} \pm SD$ ,  $n=7$ ), prosome (0.71-0.75 mm) and urosome (0.39-0.44 mm) in approximate proportion 1.8:1. Pedigerous somites 2 and 3 with posterior spine row along dorsal and lateral



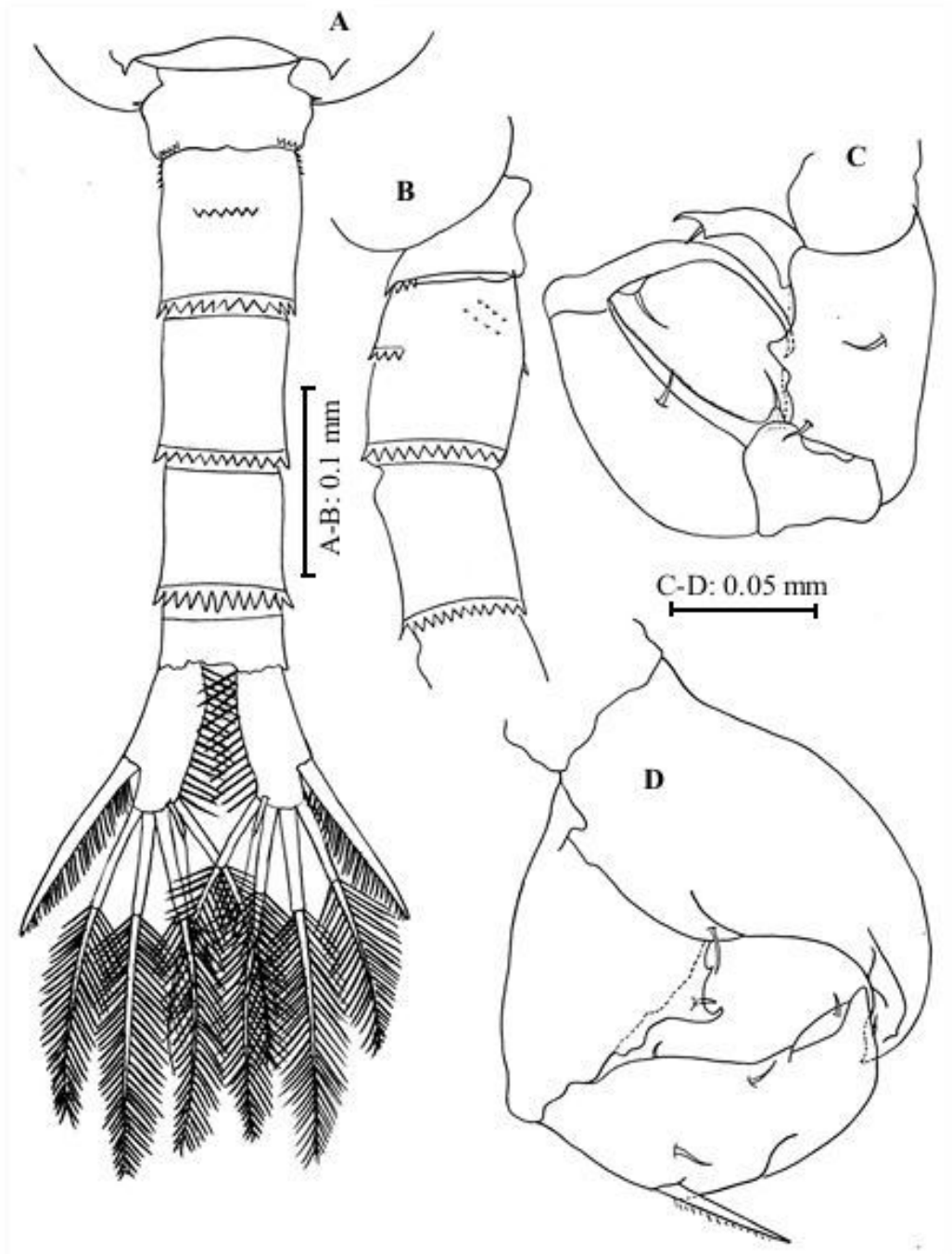
margin. Pedigerous somites 4-5 with pair of dorsal spines and rounded pedigerous somite 5 corners. Urosomite 1 with 3-4 small lateral spines and incomplete posterior margin spine row that restrict to the dorsolateral surface (Fig. 7.7A). Urosomite 2 with short spinule row on the dorsal and ventral surface and two rows of small lateral spinules on both sides. Caudal rami symmetrical with setules on inner margin and bear 6 setae, the outermost caudal setae is separate and spiniform with setules along its inner margin, third caudal seta longer and sixth seta located on dorsal. The proportional length of urosomites and caudal ramus are 14: 19: 21: 20: 8: 19= 100.

Leg 5: Right leg (Fig. 7.7C): Basis 2 with inner distal and outer distomedial setae; endopodite bifurcate with unequal arms; further, a spine arise from the fork near the shorter outer arm. Exopodite 3 elongate with small proximal swelling and spine. Exopodite 1 with medial seta and large stout spine, bifurcate with a large arm as long as Exopodite 2 and a blunt short arm. Exopodite 2 with medial seta. Exopodite 3 elongate and sickle-shaped with small proximal swelling and spine. Left leg (Fig. 7.7D): Basis 2 large medially produced with medial seta and laterally curved pointed apex. Exopodite 1 medially produced with two points. Exopod 2 distal tip medially curved, with five seta and large proximal outer spine plumose at one side.

Remarks: The size ranges of the present specimens are larger than earlier reports (Table 7.2) and comparable to the specimens reported from Panay Islands, Philippines (Walter *et al.*, 2006) and India though vary slightly (Reddy and Radhakrishna, 1982; Wellershaus, 1969).

The following are the additional morphological details that are noted from the present specimens: (1) female genital double somite with posterodorsal scale row incomplete and restricted to right half; a spinule patch and a spine row in parallel to the posterior scales (Fig. 7.6A); (2) urosomite 2 with 4 rows of spinules in varying size and spinule patch along the right dorsal surface; (3) male leg 5 right exopodite 1 with large stout spine, bifurcate with a large arm as long as exopodite 2 and a blunt short arm (Fig. 7.7C, see also Wellershaus, 1969), relatively a separate spine (Fig. 7.7C, see also Reddy and Radhakrishna, 1982); (4) male urosomite 1 with a pair of small lateral spines and fine hairs on both sides and posterodorsal spine row restricted to dorsolateral surface; (5) Urosomite 2 with short dorsomedial row of spine, rather than circular spinule patch (see Walter, 1986; 1987) or short double row of spines (Fig. 7.7A, see also, Reddy and Radhakrishna, 1982); (6) outermost caudal setae separate and spiniform with setules along its inner margin and third caudal seta being the longest, however, not enlarged as

described in the previous illustrations (Reddy and Radhakrishna, 1982; Walter, 1986; 1987).



**Fig. 7.7.** *Pseudodiaptomus annandalei* Sewell. Male: a, dorsal view of urosome and caudal rami; b, lateral view of urosomites 1-3 with spines on urosomite 2; c, posterior view of right leg 5; d, posterior view of left leg 5.

**Table 7.2. Comparison of size ranges of *Pseudodiaptomus annandalei* in the present study.**

Locality	Sex	Number	Length (mm)	Mean (mm)	Reference
Chilka Lake, Kolcutta	F	1		1.18	Sewell (1919)
	M	1		1.09	
Cochin Backwater and Gulf of Mannar	F	40	1.20 - 1.38	1.26	Pillai (1980)
	M	29	1.02 - 1.09	1.04	
Lake Kolleru, Kolletikota	F	20	1.21 - 1.31	1.25	Reddy and Radhakrishnan (1982)
	M	15	1.04 - 1.15	1.09	
Calatgan, Philippines	F	13	1.22 - 1.26	1.24	Walter (1986a; 1987)
	M	20	1.05 - 1.13	1.07	
Panay Islands, Philippines	F	4	1.13 - 1.46	1.33	Walter <i>et al.</i> (2006)
	M	4	1.05 - 1.11	1.08	
Southern coast of Sri Lanka	F	20	1.12 - 1.17	1.14	Deepananda <i>et al.</i> (2007)
	M	20	1.02 - 1.06	1.05	
Carbyn's Cove, South Andaman	F	7	1.33 - 1.38	1.35	Present study
	M	7	1.10 - 1.19	1.14	

**7.5. *Pseudodiaptomus compactus* Walter, 1984** (Figures 2-6)

*Pseudodiaptomus compactus* Walter, 1984: 375–378, figs. 3B–C.

*Pseudodiaptomus aurivilli*: Kasturirangan, 1963: 36, figs. 31a–d, 32a–c; Pillai, 1980: 247–249, figs. 1c–d.

*Pseudodiaptomus metrtoni*. –Wellershaus, 1969: 254–258, figs. 23.

Material examined from the study area Chattam (11°41'11"N, 92°43'20"E) and Junglighat (11°39'27"N, 92°43'22"E), South Andaman, Andaman Sea.

Female (Figure) Total length 1.08–1.12 mm, mean length 1.10±0.02 ( $\bar{x}$ ±SD, n=15), prosome (0.63–0.66 mm) and urosome (0.45–0.46 mm) in approximate proportion of 1.5:1. Head with dorsal hump. Cephalosome and first pedigerous somite completely fused; first pedigerous posterodorsal margin thickened; pedigerous somites four and five incompletely fused. Prosome with 3 pair of pigment spots. Urosome 4-segmented. Genital base swollen ventrally, with 1 pair of stout spines. Urosomites with posterodorsal scale rows; urosomite 3 with 1 pair of pigment spot. Proportional lengths of urosomites and caudal ramus 28:15:17:12:28 (=100). Caudal rami with hair on inner margin and symmetrical with 6 setae; setae 2 to 5 plumose, seta 1 with fine hair only along inner margin and seta 6 located dorsally. P5 posterior view: B1 with distomedial triangular corners. B2 proximomedial corners rounded. Re1 outer margin lined with fine hairs and a distal short Se.

Male (Figure) Total length 0.90-0.92 mm, mean length  $0.91 \pm 0.01$  ( $\bar{x} \pm SD$ ,  $n=15$ ), prosome (0.55-0.52 mm) and urosome (0.36-0.38 mm) in approximate proportion of 1.5:1. Cephalosome and first pedigerous somite completely fused; pedigerous somites four and five incompletely fused. Prosome with 3 pair of pigment spots. Urosome 5-segmented. Urosomite 4 with 1 pair of pigment spot. P5 male, posterior view: Right leg, B1 with distomedial corner bifid, inner process longer and bluntly pointed, outer process triangular. Se of B2 short, stout with recurved apex and 1 medial seta. Re1 long (reaching distal end of Re3), divided near distal tip with a straight elongate hyaline plate along posterolateral margin, giving the appearance of the spatulate Se. Re2 with long thin plumose Se. Re3 with 2 setae. Left leg, B1 distomedial corner simple. B2 meadial margin lined with small spinules along groove. Re1 with shoulder-like knob at distel cornet at base of Se. Re2 narrow with s setae along meadial edge, proximal ear-shaped protrusion, stout proximolateral spine and large ovoid hyaline process with patch of fine spinules distolaterally. P5 male, anterior: Right leg, B1 with fine subapical spinules. Ri compact, longer branch bifid, with 1 seta between the 2 small blunt points. Re1 with pointed basal process. Left leg, B1 with spinule row along distal suture.

Remarks: *Pseudodiaptomus aurivilli* Cleve, 1901 reported by Sewell (1932) corresponds to the *P. sewelli* Walter, 1984 and *P. mertoni* Fruchtl, 1923 were reported from Andaman and Nicobar waters. However, the later species reported by Pillai (1980) and Sewell (1932) were corresponds to *P. sewelli* Walter, 1984, *P. compactus* Walter, 1984 respectively (Walter, 1984). *P. sewelli* Walter, 1984 collected from Andaman and Nicobar waters were identified as *P. aurivilli* by Sewell (1932), and as *P. mertoni* by Pillai (1980). Further *P. compactus* noticed from Cochin Backwaters was confused as *P. mertoni* by Wellershas (1969) and Andaman Sea was confused as *P. aurivilli* by Pillai (1980).

## 7.6. Discussion

The pioneer studies of R.B.S. Sewell has contributed an extensive knowledge on the systematics and biogeography of Copepoda of Indian seas (Kasturirangan, 1963; Silas, 1972) has described seven species of *Pseudodiaptomus* Herrick (1884) from Indian Ocean (Sewell, 1912; 1919; 1932). Further information on the spatial distribution and taxonomic remarks on the family are specified by Pillai (1980) and

Reddy and Radhakrishna (1982) in the Indian waters. The members of the genus have been divided into seven different species groups, eight subgroups and one unassigned species group (Walter, 1987; Walter *et al.*, 2006).

The Andaman and Nicobar Islands comprises 10 species of *Pseudodiaptomus* Herrick (1884), namely, *Pseudodiaptomus burckhardti* Sewell, 1932, *P. masoni* Sewell, 1932, *P. andamanensis* Pillai, 1980, *P. nankauriensis* Roy, 1977, *P. clevei* A. Scott, 1909, *P. marinus* Sato, 1913, *P. sewelli* Walter, 1984, *P. compactus* Walter, 1984, *P. aurivilli* Cleve, 1901 and *P. mertoni* Fruchtl, 1924, however, the occurrence of last two species are doubtful (Walter, 1984). Since, these two species reported by Pillai (1980) and Sewell (1932) correspond to *P. sewelli* Walter, 1984 and *P. compactus* Walter, 1984 respectively (Walter, 1984). There are four species namely *Pseudodiaptomus burckhardti* Sewell, 1932, *P. masoni* Sewell, 1932, *P. andamanensis* Pillai, 1980 and *P. nankauriensis* Roy, 1977 have so far been originally described and other species were reported from Andaman and Nicobar waters.

The present new species belongs to Ramosus species group and *hickmani* subgroup as established by Walter (1986). This species group is defined by the characteristic morphology of male and female P5 and genital double-somites. There are nine species namely *Pseudodiaptomus ardjuna* Brehm, 1953, *P. australiensis* Walter, 1987, *P. hickmani* Sewell, 1912, *P. hypersalinus* Walter, 1987, *P. ishigakiensis* Nishida, 1985, *P. jonesi* Pillai, 1970, *P. marinus* Sato, 1913, *P. philippinensis* Walter, 1986, *P. sulawesensis* Nishida and Rumengan, 2005 are the current members of the species group. The new species *Pseudodiaptomus* nov. sp. is established based on the morphological variation in the male P5, spinule patterns of female urosomites and the relative size of the animal from the existing species in the Ramosus species group, *hickmani* subgroup (Walter, 1986, Walter *et al.*, 2006, Table 7.1). The distolateral process of the right P5 exopod 1 and the prominent bifid spine at the base of the distolateral process are the distinctive characters of the present species. Ovigerous female of *Pseudodiaptomus* nov. sp. appeared in all the seasons, suggesting that they breed irrespective of seasons, however, active during the inter monsoon period. The present new species has been distributed at a wide range of salinity (8 - 33 psu) from the mouth of the tidal creek to the coastal waters. In the coastal waters, the temperature and salinity range between 25-29°C, may be the optimal condition for the proliferation of this species. It has been the dominating calanoid copepod next to the cyclopoid species (*Oithona brevicornis* Giesbrecht, 1892 and *O. oculata* Farran, 1913) along the

vicinity and other co-occurred species include: *Acartia bispinosa* Carl, 1907, *Paracalanus parvus* Giesbrecht, 1892, *Centropages orsinii* Giesbrecht, 1892, *A. erythraea* Giesbrecht, 1889 and *Euterpina acutifrons* (Dana, 1849) respectively in the order of the abundance.

The *Pseudodiaptomus marinus* Sato (1913), belonging to the Ramosus group (Walter, 1986), was first described from the west coast of Hokkaido, Japan (Sato, 1913). It has subsequently been recorded from other areas of Japan (Brodsky, 1956; Tanaka, 1965; Nishida, 1985) considered to be native to the Northwestern Pacific Ocean (Walter, 1987). *Pseudodiaptomus marinus* was also reported in Indian Ocean, Mauritius (Grindley and Grice, 1969) and Andaman Sea (Pillai, 1980) and China (Jiang *et al.*, 2008), Russia (Brodsky, 1950), South Korea (Soh *et al.*, 2001) and Hawaii (Jones, 1966), as well as along the western coast of North America (Washington; Lawrence and Cordell, 2010), California (Fleminger and Kramer, 1988, Orsi and Walter, 1991; Jiménez-Pérez and Longoria, 2006) and from Adriatic Sea (Mediterranean Sea; Olazabal and Tirelli, 2011) (Razouls *et al.*, 2005-2016). The species has been reported as introduced in different waters mainly due to ballast water release and other human activity linked to vessel traffic or aquaculture (Carlton and Geller, 1993; Galil, 2009).

The Lobus species group is comprised of 19 species under two subgroups (*forbesi*-subgroups and *poppei*-subgroups) being the second largest group next to Ramosus species group (Srinui *et al.*, 2013). *Pseudodiaptomus annandalei* Sewell, 1919 is a member of Lobus species group and *forbesi*-subgroup and completely described by Reddy and Radhakrishna (1982) and Walter (1986). This species has been reported as a tropical species (CMFRI, 2003; Dur *et al.*, 2012) endemic to the low salinity condition (Reddy and Radhakrishna, 1982; Madhupratap *et al.*, 1979; Madhupratap and Haridas, 1986; Achuthankutty *et al.*, 1995; Nair and Ramaiah, 1995; Dhanker *et al.*, 2013). This species constitutes a major fraction of the diet of numerous estuarine fish larvae and in the transfer of microbial carbon to the classical food chain in estuarine and brackish water ecosystems has been well recognized (Dhanker *et al.*, 2013). *Pseudodiaptomus annandalei* has a wide distribution in the coastal waters around India, and this is the first report from Andaman and Nicobar Islands.

Until now, *Pseudodiaptomus annandalei* was unknown from Andaman and Nicobar Islands while it has been reported from Chilka lake (Sewell, 1919), Cochin backwaters (Madhupratap *et al.*, 1979; Wellershaus, 1969), Kolleru lake in Andhra

Pradesh (Reddy and Radhakrishna, 1982), the coastal ecosystem off Bombay (Nair and Ramaiah, 1995), estuaries of Goa (Achuthankutty *et al.*, 1995), Bahuda estuary of Orissa (Mishra and Panigrahy, 1999), and Muttukadu backwater, Chennai (Devi and Ramanibai, 2012), and from other regions such as estuaries and offshore regions of Gulf of Thailand (Srinui *et al.*, 2013; Suvapepun *et al.*, 1979; Pinkaew, 2003; Maiphae and Sa-ardrit, 2011), coastal waters off Panay Island, Philippines (Walter *et al.*, 2006), coastal brackish water pond of Taiwan (Dhanker *et al.*, 2013), south to Indonesia (Mulyadi, 2001) and Australia. In the present study, we have reported *P. annandalei* for the first time from the south Andaman Island with additional note on the morphological details that show minor variation (Reddy and Radhakrishna, 1982; Walter, 1986; 1987). This species was collected from a shallow tidal creek of south Andaman has been found to be restricted with salinity of 20 psu and maximum abundance at salinity 16 psu during December 2013 collection.

*Pseudodiaptomus aurivilli* Cleve, 1901 reported by Sewell (1932) corresponds to the *P. sewelli* Walter, 1984 and *P. mertoni* Fruchtl, 1923 were reported from Andaman and Nicobar waters. However, the later species reported by Pillai (1980) and Sewell (1932) were corresponds to *P. sewelli* Walter, 1984, *P. compactus* Walter, 1984 respectively (Walter, 1984). *P. sewelli* Walter, 1984 collected from Andaman and Nicobar waters were identified as *P. aurivilli* by Sewell (1932), and as *P. mertoni* by Pillai (1980). Further *P. compactus* noticed from Cochin Backwaters was confused as *P. mertoni* by Wellershas (1969) and Andaman Sea was confused as *P. aurivilli* by Pillai (1980). There have been few studies about zooplankton composition (Goswami and Rao, 1981; Madhupratap *et al.*, 1981a, b; Nair *et al.*, 1981; Nair and Gireesh, 2010; Antony *et al.*, 1997), focused particularly in the coastal waters around Andaman and Nicobar Islands. The study on the biodiversity and community structure of zooplankton in the coastal waters of the Andaman Sea revealed two new species of *Tortanus* (*Atortus*) copepods (Nishida *et al.*, 2015) indicating that there is need for more extensive exploration of these Islands, particularly around mangroves and coral reefs. Furthermore, the study revealed an existence of new species of genus *Pseudodiaptomus* and studies on copepods pertain to ecological habitats, such as, mangrove tidal creek and coral reef have been lacking from this Island ecosystem. Suggesting the need for effective sampling effort to be focused exclusively on the diverse geographical system which will provide a greater opportunity for future discovery of new copepod species.

## CHAPTER 8

### SUMMARY AND CONCLUSION

The present study was conducted in the coastal waters of Andaman Sea during January 2012 to April 2014. Samplings of plankton was done on monthly basis along the coastal waters of South Andaman Island at five locations namely Burmanallah, Carbyn's Cove, Chattam, Junglighat and Chidiyatapu. During the study, water temperature and salinity were ranged from 25°C to 33°C and 25psu to 34psu respectively. Seasonal variation of temperature was found to be higher in the southwest monsoon period (May to September) followed by northeast monsoon and SST was recorded lowest during the inter monsoon period and ranged from 27.29°C to 27.83°C. Whereas, the average surface salinity invariably higher during inter monsoon period followed by southwest monsoon. Additionally, salinity at all the stations was high during inter monsoon (non-rainy) and low during the monsoon season. Hence, the higher values during summer season could be attributed to the low amount of rainfall, higher rate of evaporation at Andaman Sea.

The average value of pH ranged between 7.6 and 7.8, the surface coastal waters showed slightly acidic during the months between August and October 2013 that ranged between 6.8 and 7.1 which in turn recovered in the succeeding periods. The average pH values were generally higher during the inter monsoon (January to April) followed by north-east monsoon period. The average value of dissolved oxygen (DO) ranged from 6.1 mgL<sup>-1</sup> to 6.7 mgL<sup>-1</sup> with the maximum of 9.6 mgL<sup>-1</sup> at Burmanallah and minimum of 3.6 mgL<sup>-1</sup> at Junglighat. In general DO was higher during northeast monsoon at all study locations. Overall, the variation in environmental parameters did not show statistical significance ( $p>0.05$ ) between the stations studied during the period.

The nutrients such as nitrate, nitrite and phosphate in the study area ranged from 0.08 to 4.12  $\mu\text{mol.L}^{-1}$ , 0.4 to 1.21  $\mu\text{mol.L}^{-1}$  and 0.60 to 2.25  $\mu\text{mol.L}^{-1}$  respectively during the study period with higher average concentration of nitrate and phosphate in Carbyn's Cove followed by Burmanallah while the lowest nitrate and phosphate was detected in Junglighat and Chattam respectively. The average concentration of silicate were higher during the north-east monsoon season that varied from 23.74±10.07  $\mu\text{mol.L}^{-1}$ , 39.42±7.28  $\mu\text{mol.L}^{-1}$ , 32.75±4.73  $\mu\text{mol.L}^{-1}$ , 27.27±11.60  $\mu\text{mol.L}^{-1}$  and



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$39.27 \pm 19.88 \mu\text{mol.L}^{-1}$  at Burmanallah, Carbyn's Cove, Chattam, Chidiyatapu and Junglighat respectively.

The Chlorophyll *a* was moderately correlated with SST ( $r= 0.558$ ;  $n=12$ ) and SSS ( $r= 0.413$ ;  $n=12$ ) at Burmanallah and Carbyn's Cove respectively and negatively correlated with pH ( $r= -0.416$ ) in Carbyn's Cove. While in Chattam moderate with pH ( $r= -0.471$ ;  $n=12$ ) and DO ( $r= 0.453$ ;  $n=12$ ) and significantly correlated with salinity ( $r= 0.603$ ,  $p < 0.05$ ;  $n=12$ ) at Junglighat, whereas very weak correlation was found in Chidiyatapu. The Chlorophyll *a* was strongly correlated with nitrate ( $r=0.821$ ;  $p < 0.01$ ;  $n=12$ ) in Chattam and with silicate ( $r=0.643$ ;  $p < 0.05$ ;  $n=12$ ) in Junglighat. In all other stations, the correlation of water nutrients with Chlorophyll *a* was very weak except in Carbyn's Cove where moderately correlated with phosphate ( $r= 0.488$ ). Analysis of variance (One-way ANOVA) suggests that the water nutrients and Chl *a* values were not significantly varied between the stations. In Burmanallah and Chidiyatapu, the pigment values were not significantly correlated with any nutrients.

Spatial and temporal distribution of copepods and other mesozooplankton taxa were studied from 5 coastal stations in the South Andaman and the ecology and community structure of the mesozooplankton are highlighted and discussed. The mesozooplankton taxa comprised 29 taxa under 10 phyla namely *Cnidaria*, *Chordata*, *Echinodermata*, *Chaetognatha*, *Arthropoda*, *Bryozoa*, *Annelida*, *Mollusca*, *Platyhelminthes* and *Retaria*. A large proportion of mesozooplankton abundance was contributed by copepods (66.0%) followed by crustacean nauplius (7.7%), gastropod veliger larva (6.0%), bivalve veliger larvae (4.6%), appendicularians (4.3%), other decapods larvae (2.9%) and chaetognaths (1.6%). In all the study stations mesozooplankton were dominated by copepods with high relative abundance of 74.4% at Carbyn's Cove followed by 67.9% at Chidiyatapu. The mesozooplankton community showed significant variation among the stations in terms of assemblage structure. All stations differed significantly in the assemblage of zooplankton except Burmanallah and Chidiyatapu.

Although, the zooplankton density varied between monthly collection, statistically no significant or clear pattern of seasonal variation was found neither with copepods nor mesozooplankton groups ( $p > 0.05$ ). Overall, the zooplankton groups namely chaetognaths, ostracods, isopods and fish eggs and larvae were relatively abundant during southwest monsoon whereas, foraminifera, amphipods, cumaceans,

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polychaete larva, bipinnaria larva and flat worm were higher during inter monsoon period.

The zooplankton biomass in terms of displacement volume and wet weight was found to be higher at Chattam followed by Junglighat while the dry weight biomass was recorded maximum at Carbyn's Cove. The elemental composition of zooplankton was analyzed for the first time from coastal waters of Andaman. The carbon content varied from 35-62% of DW and maximum Carbon was recorded during September 2013 could be due to the abundance of copepods. Hydrogen content varied from 1.8-3.1% of DW. Nitrogen content varied from 3.5-6.5% of DW. It showed similar trend to that of Carbon content in this study.

The copepod community in the coastal waters of South Andaman was comprised of 97 copepod taxa and 29 families, of which 73 were Calanoida, 14 were Cyclopoida, and 9 were Harpacticoida. The calanoids were belonged to 73 species, dominated with families such as Paracalanidae and Pseudodiaptomidae. However, the family with highest diversity was Pontellidae with 16 species followed by Paracalanidae with 13 species. Cyclopoids were belonged to 14 species, represented over 7 genera and 5 families, dominated by families such as Oithonidae, Corycaeidae and Oncaeidae and well represented by Oithonidae and Sapphirinidae with 7 and 3 species respectively. The harpacticoids were composed of 6 families, of which the families such as Miraciidae, Ectinosomatidae, Euterpinidae and Clytemnestridae were represented by 3, 2, 1 and 1 species respectively. The bulk of the individuals belonged to the species *Parvocalanus* sp. and *Bestiolina similis* followed by *Corycaeus* spp., *Oncaea* spp., *Oithona oculata*, *O. brevicornis*, *Pseudodiaptomus* nov. sp., *Euterpina acutifrons*, *Paracalanus parvus*, *Farranula gibbula*, *O. rigida*, *Acrocalanus gibber*, *O. plumifera* and *Calocalanus pavo*.

Overall, 30 species of copepods were found to be common in the all stations namely, *Acartia erythraea*, *Metacalanus aurivilli*, *Canthocalanus pauper*, *Mesocalanus tenuicornis*, *Centropages furcatus*, *C. orsinii*, *Subeucalanus subcrassus*, *Acrocalanus gibber*, *A. longicornis*, *Bestiolina similis*, *Calocalanus pavo*, *Paracalanus parvus*, *P. aculiatu*s, *Parvocalanus* sp., *Calanopia elliptica*, *Labidocera madurae*, *Temora discaudata*, *Corycaeus* spp., *Farranula gibbula*, *Oithona oculata*, *O. rigida*, *O. spinirostris*, *O. plumifera*, *Oncaea* spp., *Hemicyclops* sp., *Microsetella norvegica*, *M. rosea*, *Euterpina acutifrons*, *Macrosetella gracilis* and *Clytemnestra scutellata*.

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Overall, the Burmanallah and Chidiyatapu were rich in copepod species with higher diversity and evenness indices. While, Carbyn's Cove and Junglighat were found with higher dominance and lower values of evenness. Shannon diversity indices indicate poor diversity among the stations in the coastal waters of South Andaman. The number of species and all the diversity indices were significantly varied between the station ( $p < 0.01$ ) however, the number of individuals between the stations did not vary significantly ( $p = 0.265$ ). The inflow of effluents, sewage and domestic waste discharged through tidal creeks and human settlements and other anthropogenic activities linked with fisheries could be reasons for the low diversity at Junglighat and Carbyn's Cove compared to other stations. In addition, higher temperature and highest abundance of gelatinous zooplankton such as appendicularians, hydrozoans and siphonophores were also found in Junglighat which feed the zooplankton including copepods. Moreover, Chidiyatapu and Burmanallah were far distance from the urban region with least exposure to the major anthropogenic activities and also this region has been endowed with key ecosystems like corals, seagrass and mangroves which further improve the diversity of the copepods species in these area.

The species namely, *Acrocalanus gibber*, *Bestiolina similis*, *Calocalanus pavo*, *Paracalanus parvus*, *Parvocalanus* sp., *Pseudodiaptomus* nov. sp., *Corycaeus* spp., *Farranula gibbula*, *Oithona oculata*, *O. rigida*, *O. brevicornis*, *O. plumifera*, *Oncaea* spp. and *Euterpina acutifrons* were found to be maximum contributor to the total copepod abundance were accessed to find any variation in abundance among the seasons. The maximum production of copepod was found during inter monsoon period with average abundance of  $2119.4 \pm 443.7 \text{ ind.m}^{-3}$ , however, the seasonal variation was not statistically significant ( $p > 0.05$ ).

The list of species that showed seasonal variation is presented in the table 5.8. Most of the species were rarely occurred in the present study namely, *Acartia spinicauda*, *Cosmocalanus darwini*, *Paracalanus denudatus*, *Calanopia aurivilli*, *C. thompsoni*, *Labidocera detruncata*, *L. bataviae*, *L. acutifrons*, *Pontella fera*, *P. denticauda*, *Pseudodiaptomus marinus*, *Tortanus (Atortus) sigmoides*, *T. (A.) murrayi* and *Peltidium* sp. Among them, *C. darwini*, *P. denudatus*, *C. aurivilli*, *L. detruncata*, *L. bataviae*, *P. fera*, *P. denticauda*, *P. marinus* and *T. (A.) murrayii* were found only in the inter monsoon period, whereas *A. spinicauda* and *Candacia bradyi* were recorded only during southwest monsoon while *Temora stylifera* was noticed during northeast monsoon. However the variation was confirmed for statistical significance by using

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One-way ANOSIM which confirmed that population structure were not significantly varied between seasons (Global  $R = -0.005$ ;  $p = 0.47$ ). Multiple pairwise tests also revealed that population structures was not significantly different between among seasons during the study period. A significant simple correlation was found among 9 species that has been influenced by the environmental parameters measured during the study period.

In the present study, four species of *Tortanus* were collected and found to be new records for the locality. The calanoid species, *Tortanus (Atortus) murrayi* A. Scott, 1909 is new to Indian Ocean, *Tortanus (Tortanus) gracilis* (Brady, 1883) is first report to Andaman Sea and two species *T. (A.) andamanensis* Nishida *et al.*, 2015 and *T. (A.) sigmoides* Nishida *et al.*, 2015 are new to science were reported in this study. The new species were distinguished from the other members of the group by the characteristic morphology of the pair of posterior dorsolateral processes on the fifth pedigerous somite in the female and the antennule and leg 5 in the male. With the addition of the present report, seven species of *Tortanus* are known to occur in the coastal waters around the Andaman and Nicobar Islands.

The present study on the community structure of zooplankton resulted in the discovery of one new species of *Pseudodiaptomus* from the coastal waters of Andaman Sea, is described herein, along with other species *Pseudodiaptomus annandalei* and *P. compactus* recorded from the coastal waters of South Andaman. The new species was assigned to the Ramosus species group, *hickmani* subgroup based on the presence of the left endopod and the right exopod 1 outer spine is bifid in the male. The species is distinct from the other members of the subgroup by the presence of rigid bifid spine at the base of distolateral process of the right exopod 1 of the male leg 5 and the characteristic morphology of the genital segment in the female. The present study have reported *P. annandalei* from South Andaman Island with additional note on the morphological details that are minor variation not seen in the earlier reports. In addition, *P. compactus* was recorded from Andaman Sea was confused as *P. aurivilli* was reported and described in the present study collected from South Andaman.

The Indian Ocean has been well explored for copepods, although the inshore waters of the oceanic islands and many regions of coastal waters have remained unexplored. Furthermore, the studies on copepods pertain to ecological habitats, such as, mangrove tidal creek and coral reef have been lacking from this Island ecosystem. In addition to that, conventional net-sampling of copepods may not be much effective for

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numerous genera like *Tortanus*. Consequently, specific methods such as those by SCUBA diving and night-time collection, with or without light will undoubtedly improve the knowledge of distribution, diversity and speciation of this group of copepods in the Indian Ocean. The report of new species and first report of copepod species in this study indicate that there is a need for more extensive exploration of these Islands, particularly around mangroves and coral reefs. The results of the present study suggest the need for significant sampling effort focused exclusively on the diverse geographical system that will provide a greater opportunity for future discovery of copepod species.

The present research has extensively enhanced our knowledge on the status of zooplankton biodiversity in the coastal waters South Andaman to certain extent. The discovery of three new species of planktonic copepods only from South Andaman coast have increased the conviction that many new species could occur in this island ecosystem which indicates high potential biodiversity of the long stretch of Andaman and Nicobar Archipelago, necessitating continued research are essential. The present findings serve as a preliminary baseline thus important in enhancing this field for future studies and initiate further research on pelagic biodiversity in coastal region of Andaman and Nicobar Islands through integrated morphological, genetic, and biogeographic studies.

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## LIST OF PUBLICATIONS

1. Jayabarathi R, Padmavati G, **Anandavelu I** (2012) Abundance and Species composition of harpacticoid copepods from a seagrass patch of South Andaman, India. *Current Research Journal of Biological Sciences* 4(6): 717-724.
2. Baskaran R, **Anandavelu I**, Karpoorasundarapandian N, Mohan PM, Padmavati G (2013) First record of *Herviella mietta* from the Andaman Islands, Indian Ocean (Nudibranchia: Aeolidina: Glaucidae). *Marine Biodiversity Records* 6: e64.
3. Jayabarathi R, **Anandavelu I**, Padmavati G (2013) First report of the Green Mantis Shrimp *Gonodactylellus viridis* (Serène, 1954) (Crustacea: Stomatopoda) from seagrass habitat of the South Andaman coast, India. *Journal of Threatened Taxa* 5(10): 4517-4520.
4. **Anandavelu I**, Jayabarathi R, Padmavati G, Jayaraj KA (2013) Epifaunal assemblage on morphologically distinct intertidal seaweeds of Kodiyaghat (South Andaman), India. *Proceedings of the International Academy of Ecology and Environmental Sciences* 3(3): 229-237.
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## Abundance and Species Composition of Harpacticoid Copepods from a Sea Grass Patch of South Andaman, India

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**Abstract:** Abundance and species composition of Harpacticoida (Copepoda) inhabiting blades of *Thalassia hemprichii* and their canopy sediments were examined during the study period. Eleven different meiofaunal taxa were recorded from the study site, among which the blades comprised nine taxa and the canopy sediment constituted all eleven taxa. Harpacticoid Copepods were the dominating meiofaunal component in blades (86%) as well as in canopy sediments (57%) of *T. hemprichii*. A total of 47 species belonging to 34 genera distributed within 14 families of harpacticoid copepods were recorded. Harpacticoids on canopy sediments were significantly higher (t-test,  $p < 0.05$ ) compared to the seagrass blades. *Canuellina nicobaris* was the most abundant species followed by *Scottolana longipes* and *Harpacticus spinulosus* in both habitats. Higher diversity ( $H'$ ) and equitability ( $J$ ) of harpacticoid species were found in blade. Bray Curtis similarity shows that two distinct clusters of species in the habitats.

**Keywords:** Andaman, canopy sediment, meiofauna, seagrass blades, *Thalassia hemprichii*

### INTRODUCTION

Copepods inhabit all available benthic habitats and show considerable species diversity in the sea (Wells, 1976). Harpacticoids are permanent members of meiofauna that always remain within the meiofaunal size range 63-500  $\mu\text{m}$  (Gray and Elliott, 2009). They are highly mobile crustaceans (Hicks and Coull, 1983) which represents second most abundant meiofaunal group in marine sediment, while nematodes were dominant (Olafsson, 1995). In the coastal environment, harpacticoids have been associated with seagrass (De Troch *et al.*, 2003; Hicks, 1986; Walters and Bell, 1986, 1994) and form a large part of the phytal meiobenthos (Wells, 1976). They function as a key taxon among the seagrass-associated fauna, which is due to their habitat specificity (Bell *et al.*, 1988; Bell and Hicks, 1991; De Troch *et al.*, 2001; Hicks, 1977, 1980, 1986). And feed on sediment microbes (Hicks and Coull, 1983) and benthic diatoms (Montagna, 1984). Seagrass patches generally have rich assemblage of fauna compared to adjacent unvegetated sediment (Orth *et al.*, 1984). Seagrass patches have key ecological functions in the intertidal region such as, it stabilize sediments, reduce particle resuspension (Terrados and Duarte, 2000), provide substrate for epiphytes and epizoan to attach and nursery grounds for fishes, shrimps and a variety of invertebrate taxa. The knowledge on harpacticoid copepods is limited from coastal waters of Andaman (Wells and Rao, 1987). Further, the studies on marine

Harpacticoida associated with macrophytes are lacking. In view of the importance and scarcity of reports from this area, an investigation was carried out in the coastal waters of South Andaman, East Coast of India, to assess the relationship between copepod abundance on blades and sediments of *T. hemprichii*.

### MATERIALS AND METHODS

**Study site:** The present study was conducted at intertidal region of Kodyaghat (11°31.719'N, 092°43.409'E) in South Andaman (Fig. 1). This area is a rocky coast with medium to coarse sand with very little detritus supporting patches of seagrass, *T. hemprichii*. Numerous tidal pools, dead corals and the area are mostly invaded by different seaweeds. The intertidal region is submerged during high tide and exposed during lowest low tide when tidal level is less than 0.30 m. Sampling was carried out during lowest low tide.

**Environmental parameters:** Physico-chemical parameters such as temperature, salinity and pH were measured from seagrass patches during months of December 2010, January and February 2011 using thermometer, refractometer and pH meter respectively. The water samples were collected simultaneously for the estimation of Dissolved Oxygen by following standard procedure of Winkler's method (Grasshoff *et al.*, 1983).

# First record of *Herviella mietta* from the Andaman Islands, Indian Ocean (Nudibranchia: Aeolidina: Glaucidae)

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*The present study reports the first record of *Herviella mietta* from the Andaman Sea, Indian Ocean, more precisely from the Andaman and Nicobar Islands, India. The species is identified by colour pattern, morphological characters and microscopic investigation of the radula and the lateral denticles. The important diagnostic characters are the carrot-shaped cerata that are predominantly black in colour, black pigment on the body, and 8–9 denticles on each side of the small central cusp of each tooth.*

**Keywords:** Andaman Sea, Mollusca, Nudibranchia, new record

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## INTRODUCTION

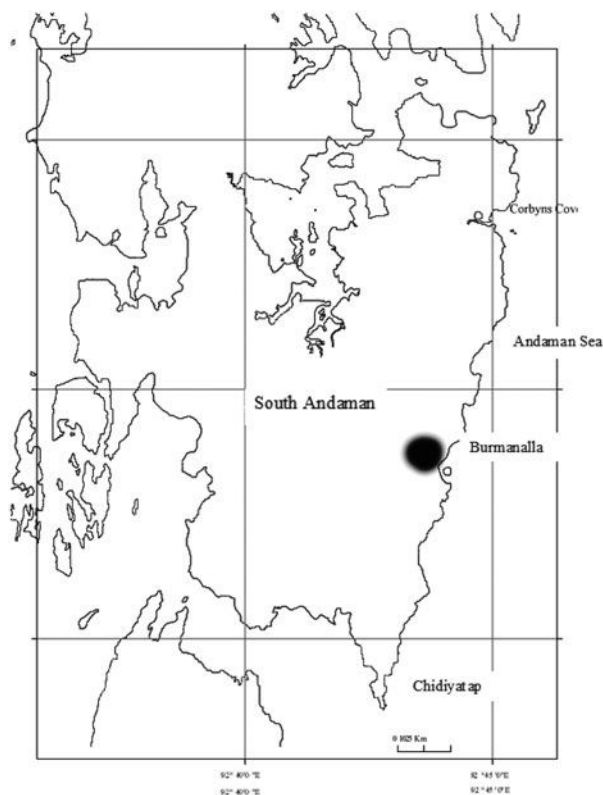
The Andaman and Nicobar Islands are endowed with invaluable diversity of marine fauna. Geographically, the islands are the summits of a submarine range extending from the Arakan Yomas of Burma in the north to the Sumatra in the south (Tikadar & Das, 1985). The groups include 572 islands, islets, reefs and isolated rocks and are situated within the latitude 6°45'N to 14°N and longitude 92°E to 94°E.

Sea slugs are the least studied fauna from Indian waters (Apte, 2009) and this is also the case in the Andaman and Nicobar Islands. However, the taxonomy and ecology of opisthobranchs from these islands have recently received some attention (Ramakrishna *et al.*, 2010; Sreeraj *et al.*, 2010, 2012a, b). To date, a total of 162 species was reported from the Andaman Islands (Sreeraj *et al.*, 2011, 2012a); 52 opisthobranch species were recorded from the Nicobar group, of which 11 were new records for Indian waters (Sreeraj *et al.*, 2012b). Current studies on nudibranchs reveal that the Andaman and Nicobar Islands manifest biodiversity of extraordinary range within a limited geographical area. These islands are a virtual bioserve and represent a rich repository, unique both in terms of biodiversity and abundance.

The following characteristics are diagnostic for the genus *Herviella*: a single row of cerata in the right liver; anterior of foot expanded and rounded; rhinophores simple; jaws high anteriorly and narrow posteriorly, masticatory edge with a single row of denticles; penial stylet present; and female ducts serial with the spermatheca (i.e. it is formed by a swelling of the oviduct or vagina) (Baba, 1966b).

## MATERIALS AND METHODS

Field observation of an intertidal rock pool was carried out on 21 October 2012. A pair of specimens was collected from the



**Fig. 1.** Black round with spot showing the species collected from the Andaman Sea.

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**FIRST REPORT OF THE GREEN MANTIS SHRIMP  
*GONODACTYLELLUS VIRIDIS* (SERÈNE, 1954)  
(CRUSTACEA: STOMATOPODA) FROM SEAGRASS  
HABITAT OF THE SOUTH ANDAMAN COAST, INDIA**

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The Andaman and Nicobar archipelago is known to host a high diversity of marine flora and fauna. While the biodiversity of this region has been under exploration relatively few studies have focused on seagrass (Das 1996; Kannan et al. 1999; Thangaradjou et al. 2010). Seagrass bed structure is an important component of tropical and temperate marine ecosystems. They have a key ecological function in the intertidal region (Terrados & Duarte 2000), and are known to support a rich assemblage of associated fauna (Orth et al. 1984). Recently, Jayabarathi et al. (2012) documented the seagrass associated meiofauna from South Andaman. In addition, a contradicting hypothesis states that predation intensity is greater near seagrass beds, in which potential predators are more abundant (Virnsten et al. 1983; Summerson & Peterson 1984).

The present report deals with a stomatopod species *Gonodactylellus viridis* found on seagrass patches of *Thalassia hemprichii* during the study of seagrass habitats of South Andaman. Stomatopod crustaceans are benthic marine predators (Cheroske et al. 2009) and raptorial carnivores found in shallow tropical or subtropical marine environment. In recent decades

this species has been reported from Vietnam, western Andaman Sea of Malaysia, Indonesia, New Caledonia, Japan, the Philippines and Australia (Ahyong 2001). The bibliographic sources emphasize that gonodactyloids appear to be quite abundant on coral reef habitats (Moosa & Erdmann 1994; Moosa 2000) and collected by plankton net (Ahyong 2001). The present finding is of a Green Mantis Shrimp from seagrass habitat.



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**Materials and Methods**

Sampling on seagrass patches of *Thalassia hemprichii* in the intertidal region of Burmanallah (11°33'N & 92°43'E), South Andaman (Image 1) during low tide on 14 November 2012 revealed the presence of one species of stomatopod crustacea. The specimen was collected using forceps and immediately transferred into a polythene bag and carried to a laboratory for identification. The species was distinctive for its striking green coloration (Image 2A) identified by studying the morphological characteristics and also compared with the previous reports of Erdmann & Manning (1998), Manning (1998), Ahyong (2001) and Ahyong & Moosa (2004). After confirmation, the reference specimen was deposited in the National Zoological Collections of the Zoological Survey of India (ZSI/ANRC 8134), Port Blair.

Abbreviations for morphological terminology used follows Manning (1998) and Ahyong (2001). It includes: Total length (TL) in millimeters (mm) measured along the midline from the tip of the rostrum to the apices of the submedian teeth, abdominal somite (AS), thoracic somite (TS), median (MD), submedian (SM), intermediate (IM), lateral (LT); and marginal (MG). The photographs

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Article

## Epifaunal assemblage on morphologically distinct intertidal seaweeds of Kodiya ghat (South Andaman), India

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### Abstract

Benthic macroalgae termed seaweed occupy coastal environments primarily on rocky intertidal areas. However, it has significant role by adding spatial complexity to the substratum and alter accessibility to other faunal and floral community. The studies of potential benefits of seaweeds have encouraged extensively yielding industrial, medicinal, pharmaceutical and cosmetic products. The present study deals with the quantitative distribution of epifaunal community associated with seaweeds of South Andaman and the influence of conspicuous morphology of seaweed on the assemblage of epifauna were compared. *Galaxura* sp. and *Halimeda tuna* supported higher faunal density than other seaweeds, with the respective mean density of 139.2 and 104.5 nos. per 100g of algal wet weight. *Sargassum duplicatum* held the lowest epifaunal density. *Arthropoda* was the major group found in this study, dominated by the *Amphipoda* (35.1%), *Mysida* (19.4%) and *Isopoda* (2.8%) followed by *Annelida* (20.1%) and *Mollusca* (12%). The result indicated that the distribution and abundance of epifauna differ based on the structural morphology among macroalgal species which forms suitable habitat for these organisms. The present study suggests that the sediment retention capacity of weeds might play an important role on the assemblage of epifaunal community.

**Keywords** Andaman Islands; epifauna; seaweed; *Galaxura* sp.; *Halimeda tuna*; sedimentation; India.

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### 1 Introduction

Algae are the primary producers of ocean and form the base of marine food chain (Sridhar et al., 2006; Saravanakumar et al., 2008). They include unicellular phytoplankton (Folkowski and Knoll, 2007; Paerl and Justić, 2011) to the giant multicellular macrophytes (Castro and Huber, 2003). Seaweed as a benthic primary producer (Kaladharan and Kandan, 1997; Charpy-Roubaud and Sournia, 1990; Howarth and Marino, 2006; van Dam et al., 2008) occupy significant role in many coastal environment particularly on rocky intertidal areas. Since they need a substratum for attachment, the rocky intertidal areas are more favorable for seaweed

Article

## Biochemical composition and calorific value of zooplankton from the coastal waters of South Andaman

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### Abstract

Estimation of biochemical composition of zooplankton is important in understanding their metabolism, nutritive value and energy transfer which are relevant to the marine ecosystem. Zooplankton biomass and their biochemical composition were estimated from the coastal waters of South Andaman during October 2011 to September 2012. The dry weight biomass and chlorophyll *a* discerned a positive correlation ( $p < 0.05$ ; one-way ANOVA) in two stations. Protein formed the major fraction of the organic constituents. Seasonal variation in the protein content of zooplankton was observed. Carbohydrate was the minor component and ranged from 1.1-12.2% ( $\bar{x} = 3.4 \pm 1.1$ ) in terms of dry weight. Neither lipid nor carbohydrate appeared to be significant source of energy for these organisms. Caloric value obtained in this study ranged from 1.35 to 2.72 kcal/g dry weight ( $\bar{x} = 1.8 \pm 0.2$ ). Relatively higher values were attributed to the dominance of calanoid copepods in the zooplankton population almost throughout the year. Zooplankton did not show an extensive lipid storage suggesting that protein may serve as metabolic reserve. It is therefore evident that zooplankton can be utilized as nutritional live feed for the cultivable species of fish and prawn in aquaculture farms. The variations in biochemical composition of zooplankton are influenced by species composition and feeding activities of zooplankton, which is in accordance with the previous studies. This study is the first report on Biochemical Composition and Calorific Value of Zooplankton from the coastal waters of Port Blair, South Andaman.

**Keywords** Andaman; biochemical composition; biomass; calorific content; zooplankton.

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### 1 Introduction

Zooplankton are considered to be “nutritionally superior live feeds” for commercially important cultivable species, as they are valuable source of proteins, lipids, carbohydrates and enzymes, all of which play an important role in digestion and the metamorphosis of larvae (Støttrup, 2000; Molejon and Alvarez-Lajonchere, 2003; Rajkumar and Vasagam, 2006; Rajkumar et al., 2008). Estimation of biochemical composition of



TWO NEW SPECIES OF *TORTANUS* (*ATORTUS*) (COPEPODA,  
CALANOIDA, TORTANIDAE) FROM THE ANDAMAN ISLANDS

BY

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ABSTRACT

Two new species of the planktonic copepod genus *Tortanus*, subgenus *Atortus*, are described from inter- to sub-tidal water of South Andaman Island, India. The new species are assigned to the *tropicus* group sensu Othman (1987) and distinguished from the other members of the group by the characteristic morphology of the pair of posterior dorsolateral processes on the fifth pedigerous somite in the female and the antennule and leg 5 in the male. An analysis of previous records of the *tropicus* species group indicates their sporadic occurrence combined with high species richness in Southeast Asia, suggesting future discovery of even more species by sampling with finer geographic and habitat coverage.

Key words. — *Tortanus* (*Atortus*), Copepoda, new species, Andaman Islands

RÉSUMÉ

Deux nouvelles espèces du genre de copépode planctonique *Tortanus*, sous-genre *Atortus*, sont décrites des eaux inter- à sub-tidales de l'île Andaman du Sud, Inde. Les nouvelles espèces sont assignées au groupe *tropicus* sensu Othman (1987) et se distinguent des autres membres du groupe par la morphologie caractéristique de la paire de processus dorsolatéraux postérieurs situés sur le cinquième somite pédigère chez la femelle et par l'antennule ainsi que la patte 5 chez le mâle. Une analyse des mentions antérieures des espèces du groupe *tropicus* indique leur présence sporadique combinée avec une richesse en espèces élevée en Asie du Sud-Est, suggérant la découverte future d'encore plus d'espèces par un échantillonnage utilisant une couverture plus fine au niveau géographique et de l'habitat.

Mots clés. — *Tortanus* (*Atortus*), Copepoda, espèce nouvelle, îles Andaman

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RESEARCH

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# Spatial heterogeneity of benthic copepods: a comparative aspect on composition, abundance, and correlation

R Jayabarathi\*, G Padmavati and I Anandavelu

## Abstract

**Background:** Comparing meiofaunal assemblages in the seagrass zone with bare sediment will provide information on the structuring factors and phytal preferences of meiobenthic invertebrates since differences in density and diversity of meiofauna are to be expected between vegetated and bare zones.

**Results:** A total of 11 groups of meiofauna, with harpacticoids dominating (51 %) and comprising 48 species within 14 families, have been identified. At all localities, the following harpacticoids were found to be relatively abundant, contributing 30.9 % of all harpacticoids: *Longipedia weberi*, *Canuellina nicobaris*, *Scottolana longipes*, and *Parastenhelia hornelli*. A highly significant correlation ( $r = 0.987$ ,  $r^2 = 0.974$ ,  $F_{(1,9)} = 337.3$ ,  $P < 0.001$ ) of meiofaunal assemblage was found between seagrass leaf blades and the canopy sediment compared to bare sediment which was found to have a moderate correlation ( $r = 0.543$ ,  $r^2 = 0.294$ ,  $F_{(1,9)} = 3.756$ ,  $P = 0.085$ ). In addition, the abundance of harpacticoids was significantly higher (ANOVA,  $F_{(2,144)} = 19.53$ ,  $P < 0.001$ ) in seagrass sediments and differed markedly from blades and bare sediments, and the composition was unique in the different zones of the present study.

**Conclusions:** Productive seagrass ecosystems are as yet inadequately studied in the Andaman Islands. This study provides a first step to characterize a faunal group from the seagrass community.

**Keywords:** Andaman; Harpacticoids; Meiofauna; Seagrass; Sediment

## Background

Meiofauna has been considered as a dynamic element of the marine environment and an integral part of the benthic trophic food chain (Watzin 1983; Higgins and Thiel 1988; Mascart 2010). They inhabit a wide diversity of habitats from the littoral zone to great depths, as associates or parasites of several multicellular animals and plants, and also in sea ice (Coull et al. 1982; Grainger 1991). The patchiness of meiobenthos has been influenced by availability of food and oxygen and other environmental factors (Hicks and Coull 1983; Mantha et al. 2012a) and even by macrofaunal bioturbation (Ólafsson and Moore 1992; Ólafsson 2003). Although sediment granulometry is a major structuring factor of meiofaunal population (Ólafsson 1995; Boucher 1997; Ndaro and Ólafsson 1999; Semprucci et al. 2010), benthic

primary producers such as micro- and macroalgae and higher plants have great influence on the assemblages of benthic fauna which continue to live an epifaunal transition mode of life (Jayabarathi et al. 2012; Anandavelu et al. 2013). The physical and biological characteristics of macrophytes form a dynamic community of animals which subsist as epifauna on them. Seagrass beds are some of the most productive parts of coastal ecosystems with estimated annual primary production comparable to that of tropical rain forests (Duarte and Chiscano 1999; Hemminga and Duarte 2000). They provide energy through detritus decomposition and direct herbivory pathways. The rhizomal root system stabilizes the sediment, while densely growing leaves reduce current velocity and encourage the settling of further particles from suspension.

Shallow water vegetation of seagrass patches is also widespread and has an important role in the coastal ecosystem of the Andaman archipelago (Jagtap 1991; Thangaradjou et al. 2010). The coastal waters of

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