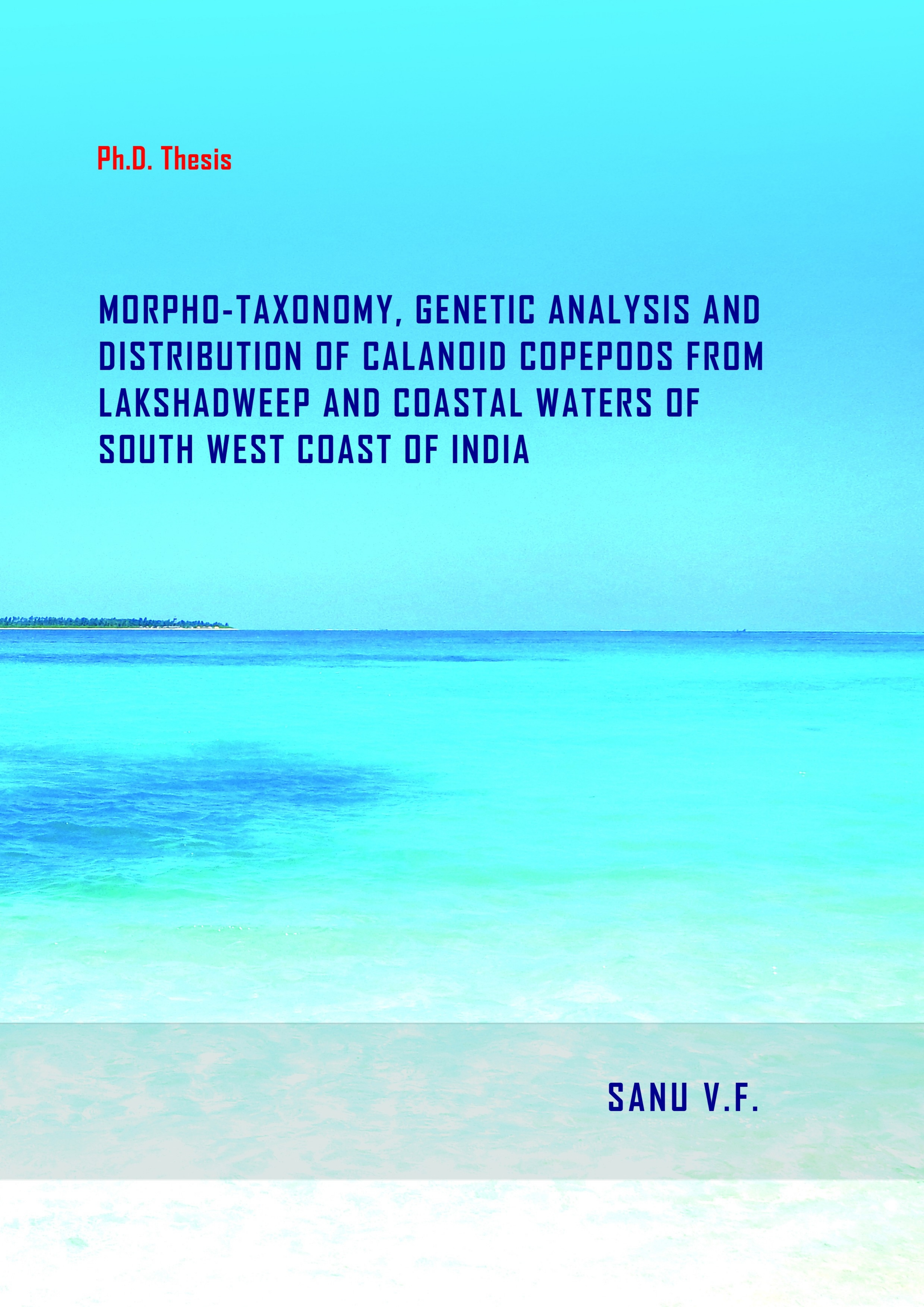

Ph.D. Thesis

MORPHO-TAXONOMY, GENETIC ANALYSIS AND DISTRIBUTION OF CALANOID COPEPODS FROM LAKSHADWEEP AND COASTAL WATERS OF SOUTH WEST COAST OF INDIA

SANU V.F.

Morpho-taxonomy, Genetic Analysis and Distribution of Calanoid Copepods from Lakshadweep and Coastal Waters of South West Coast of India

Thesis submitted to the

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Under the Faculty of Marine Sciences

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Certificate

This is to certify that the thesis "*Morpho-taxonomy, Genetic Analysis and Distribution of Calanoid Copepods from Lakshadweep and Coastal Waters of South West Coast of India*" is an authentic record of research work carried out by Mr. Sanu V.F. (Reg. No. 4892) under my supervision and guidance in the Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Marine Biology, Cochin University of Science and Technology under the faculty of Marine sciences. There is no plagiarism in the thesis and that, the work has not been submitted for the award of any degree/diploma of the same Institution where the work was carried out, or to any other Institution.

It is also certified that all the relevant corrections and modifications suggested by the audience during the pre-synopsis seminar and recommended by the doctoral committee has been incorporated in the thesis.

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Dr. S. Bijoy Nandan
(Supervising Guide)

Declaration

I hereby declare that the thesis entitled ***"Morpho-taxonomy, Genetic Analysis and Distribution of Calanoid Copepods from Lakshadweep and Coastal Waters of South West Coast of India"*** is an authentic record of research work carried out by me under the supervision and guidance of **Dr. S. Bijoy Nandan**, Professor, Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Marine Biology, Cochin University of Science and Technology under the faculty of Marine sciences and that no part of this has been presented before for the award of any other degree, diploma or associateship in any university.

Kochi - 682 016 **Sanu V. F.**

December 2018

This thesis is a devotion to the almighty
and dedication to my family…

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Chapter - 1

INTRODUCTION

1.1. GENERAL INTRODUCTION

The marine environment covers around 71% of the earth and provides diverse habitats that support and sustain a vast population of organisms, distributed in both pelagic and benthic realms. Almost 80% of the earth's primary production takes place in this environment. Among them, phytoplankton and zooplankton community constitutes the primary food source for most of the organisms in the ocean. The Oceans are conventionally classified into four central basins: the Pacific Ocean, the largest and the deepest; The Atlantic Ocean is a little larger than the Indian Ocean but similar in average depth. The Arctic is the smallest and shallowest. Marginal to the central ocean basins are many shallow seas, such as the Mediterranean Sea, the South China Sea and the Gulf of Mexico. Although the oceans are considered as four separate entities, they are interconnected (Castro and Huber, 2003). The Indian Ocean, one of the major oceans, is enormous, extending from the Tropic of Cancer to the shores of Antarctica, separated into northern and southern regions of the equator. The northern region includes the Arabian Sea, the Bay of Bengal and the Andaman and the Lakshadweep seas. Coastal waters of Southwest coast of India including the lagoon waters of Lakshadweep are known to be vital habitat to a wide variety of zooplankton groups. The composition, distribution, and abundance of zooplankton are a prerequisite in our understanding of the ecological status and productivity of any aquatic ecosystem.

Copepods are the most abundant crustaceans in the world oceans, usually contributing > 60% of the total zooplankton abundance (Ohtsuka and Nishida 2017, Jyothibabu et al. 2018). They act as a trophic link between phytoplankton and fishes in the food chain and thus, play a crucial role in ocean biogeochemical cycles (Campos et al., 2017). The Copepoda form a subclass of the phylum Crustacea that currently includes about 13,000 species of small planktonic, benthic, and symbiotic crustaceans (Ohtsuka and Nishida 2017). Calanoid copepods are the dominant groups in marine subtropical and tropical waters and exhibit great diversity in morphology and habitats they occupy. Previous studies in the Arabian Sea mainly focused on aspects related to ecology and diversity of calanoids, thus having severe lacunae on the taxonomic and phylogenic aspects. Pioneering studies since last three decades, interesting taxonomic information from the Arabian Sea have been documented during International Indian Ocean Expedition IIOE; 1962-65 and few notable works were by Silas and Pillai,1973, Pillai, 1975; Saraswathy, 1982; 1988, Rosamma, 1988; Saraswathy, 1986 and Jayalakshmi, 1991. However, the Lakshadweep coral islands and lagoons being a hotspot of marine biodiversity, occupying a significant part of the Northern Indan Ocean and coastal waters of the Arabian Sea has been least investigated especially on the taxonomy and community structure of copepods. Documenting the diversity needs accuracy on species identification, but in some cases, share morphometric and meristic characteristics that tend to confuse the identity of the species. Further, the co-occurrence of multiple closely related species also makes it difficult to determine their female-male correspondence by morphology (Nishida et al., 2015; Mulyadi et al., 2017). Hence, molecular techniques are now an essential supplementary tool for studies on population structure, phylogeography, and phylogeny of copepods. Therefore, this doctoral thesis discusses the taxonomic position of the pelagic calanoid copepods (Zooplankton: Crustacea) from the lagoon waters of Lakshadweep and coastal waters of the south-west coast of India based on morphological and molecular approaches.

1.2. COASTAL ECOSYSTEMS OF THE INDIAN PENINSULA

The Arabian Sea (AS) and the Bay of Bengal (BoB) (Fig. 1) are both tropical basins located in similar latitudes but separated by the landmass of the Indian peninsula. Both the basins are under the influence of seasonally reversing monsoon-south westerly from June to September and Northeasterly from November till February. The Arabian Sea on its northern, eastern and western sides is bordered by Asian and African landmass and is connected with the Persian Gulf through the Gulf of Oman by a deep sill called the Hormuz Straight. The total area of the Arabian Sea between latitudes 0°-25°N and longitude 50°-80°E is about $6.22\text{x}10^6$ Km^2. Annually, the AS loses freshwater through intense evaporation (~1 m yr^{-1}) and hence evaporation exceeds precipitation. The Bay of Bengal with the total is approximately $4.087 \text{ x } 10^6$ km^2, between latitudes 0°-23°N and longitudes 80°-100°E, where all the rivers of India, Bangladesh and Myanmar surrounded on three sides by landmass (Qasim,1998). In BoB, the precipitation exceeds evaporation as it receives large quantities of freshwater both from rain and river runoff (Sabu et al., 2015; Prasad, 1997; Rao and Sivakumar, 2003). Due to the suggested possible reasons like cloud cover, large sediment load, narrow shelf stable stratification and weak winter cooling, generally, the BoB is considered to endure the low biological production (Qasim 1977; Madhu et al., 2002; Radhakrishnan et al., 1978; Gomes et al., 2000; Madhupratap et al., 2003; Jyothibabu et al.,2004). Since the Indian Ocean is under the influence of annually occurring monsoons [the seasonally reversing wind systems that are propelled by a pair of low (high) and high (low) pressure zones over the land and the sea, respectively during winter or summer], the seasons are mainly classified as the following. The south-west monsoon (summer-monsoon; June to September), North-East monsoon (winter monsoon; December to March) and spring inter-monsoon period (transition period from winter to summer; March to May) and fall inter-monsoon period (transition period from summer ; March to may) and fall inter-monsoon period (transition period from summer to winter; September to October) (Madhupratap et al., 2001).

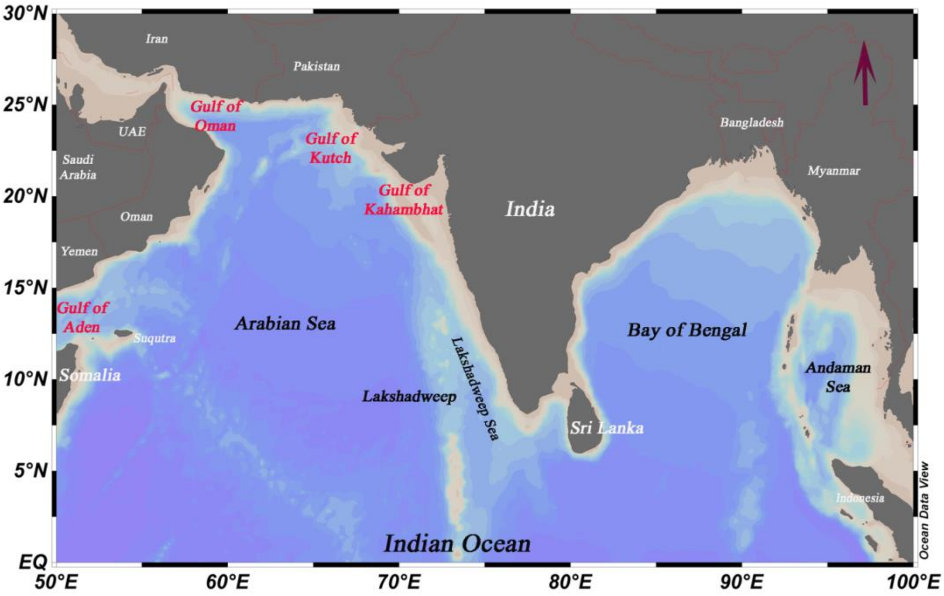

Figure 1. The map showing Arabian Sea and Bay of Bengal.

The Arabian Sea is one of the most highly productive regions of the world ocean (Ryther et al.,1966; Qasim,1988) while the Bay of Bengal, the eastern counterpart is a basin of low productivity because of low phytoplankton biomass, low availability of nutrients, more massive cloud coverage and turbidity arising from sediment fluxes that limit effective penetration of solar radiation in the upper euphotic column (Radhakrishnan et al.,1978 a, b; Qasim,1977; Gomes et al., 2000; Prasannakumar et al., 2001; Madhupratap et al., 2003; Sabu et al., 2015). Qasim (1977) estimated total column primary production to be 4.42x1015 g C y-^{1}, secondary production to be 69x10^{12} g C y-^{1} and tertiary production or potential exploitable yield to be 15-17x10^{12} g C y-^{1} in the Indian Ocean. Annual total global ocean productivity averaged 67 Pg C Yr^{-1} (Behrenfeld et al., 2005) whereas the primary productivity of the Arabian Sea was 163-337 mg C m^{-2} d $^{-1}$, that of BoB was 32-512 mg C m^{-2} d $^{-1}$) (Gauns et al., 2005).

1.2.1. *The Arabian Sea coastline*

The Arabian Sea is divided into three subsystems: (i) The Western Arabian Sea along the African coast, (ii) the central Arabian Sea and (iii) the Eastern Arabian Sea bordering the shores of India, Srilanka and Pakistan (Dwivedi and Choubey 1998). Each subsystem differs in biodiversity, current patterns, and physio-chemical characteristics. Local topography, monsoon winds, backwaters, width, depth of the continental shelf and drainage of the coastal areas further created three coastal ecosystems; they are the central West Coast Ecosystem, the North West Coast Ecosystem and Islands. (Dwivedi and Choubey, 1998). The South West Coast Ecosystem extends off the Kerala and Karnataka coasts. The coastline extends 890km with many backwaters and mangrove swamps. The continental shelf area in the South West Coast is shallow with 65000 square kilometres. The Central West Coast Ecosystem covers Goa and Maharashtra with 783 square km of coastline. The continental shelf is narrow and encompasses 97000 square kilometres (www.fishbase.org).

1.2.2. *Island ecosystems (coral reef ecosystem)*

Island ecosystems (coral reef ecosystem) comprises 30% of the world's biodiversity hotspots, 50% of tropical marine diversity and consists of unusual and rare species (Zeitzschel, 1973). Many species remain unknown in this incredible ecosystem. Island ecosystem which primarily includes coastal ecosystems also fulfils many ecological roles, ranging from shoreline protection to buffer zones, from land-based activities and pollution to feeding, breeding and nursery grounds to many marine species. The coral reefs which form a specific ecosystem command the highest importance by their very high productivity, the maximum diversity of fauna representing all animal phyla, the complexity of the trophic organisation and finally the resources that are of direct economic importance to humanity (Qasim, 1998). Coral reefs provide support for marine fisheries, which provide the principal protein source for many island populations, coastal communities exploit coral reefs for the commercial purpose along with their livelihood. Such an over-dependence on reefs as a means of human sustenance have made coral reefs and island ecosystem more susceptible to destruction. According to the current records, the highest proportions of species extinctions are also taking place in islands despite its high biodiversity. A large number of coral ecosystems located all over the world are on the brink of extinction. Coral reefs of the Indian Ocean consist of Atolls, fringing reefs, patch reefs, elevated banks and submerged banks. Under the category of major oceanic coral reefs, three areas are described Lakshadweep islands, Andaman and

Nicobar Islands and the Maldive Islands. Besides these, coral reefs of the fringing and patch- types in the Indian ocean are found in Sri-Lanka, Chagos Archipelagos, Mauritius, Seychelles, Malagasy, African coast, Burma, Thailand, Malesia and Indonesia.

The major islands of the Indian Ocean are Lakshadweep islands, The Andaman and Nicobar Islands, the Maldives and the Great Barrier Reef. **Lakshadweep islands** are a group of 11 inhabited and 24 tiny uninhabited islands and geographically separated from the Malabar Coast along the west coast of India by a distance of about 200-400km comprising twelve atolls, three reefs and five submerged banks. The archipelago covers an area of 32sq.km. **The Andaman** and **Nicobar islands** are situated about 1150km east of the Indian subcontinent near Burma and Sumatra that constitutes 325 islands of which 38 are inhabited. The total land area of both groups of islands amounts to 8120 sq.km of which most of them are natural forests. These are of volcanic origin with elevated sedimentary mountain ranges. Fringing reefs border eastern side at depths ranging 5-7m and western side by barrier reefs with lagoons up to 40m deep. **The Maldives** include 1190 islands forming a double chain with a total land area of about 297.8sq.km. Three islands have an area of 4sq.km and nine islands with 2sq.km. Out of the entire islands, about 200 are inhabited, with Male as its capital. **The Great Barrier Reef** of northern Australia is the most extensive and a complicated system of more than 2500 small reefs, and cays, lagoons, channels and islands which runs more than 2000 km along the northeastern coast of Australia, varying width between about 15 and 350km and covering an area of over 2,25000 sq. km.

Coral reefs are treasure troves of the wold seas. No other ecosystem on Earth is as valued for their aesthetics and biodiversity as coral reefs. Reports on the status of world reefs show that the reefs have lost more than half of their coral cover over the last two decades due to direct and indirect anthropogenic activities, with the associated services taking a severe beating. In islands, outlined by coral lagoons, the population has increased when compared to previous years and is mounting day by day which in turn will have an impact on physicochemical and biological aspects. Changes occurring in the physicochemical factors of the reef habitats like variations in the water pH and nutrient loads elevated sea surface temperature corresponding to global warming and fluctuations in the weather conditions often threaten the functioning and biodiversity of the reef ecosystems. (Vineetha et al., 2018). In the reef ecosystem, zooplankton species can be demersal, epibenthic, pelagic reef residents and offshore migrants. These help them in the effective utilisation of the diverse food resources in the reef ecosystem and turn to make them a suitable diet choice for a wide range of consumers in the food web (Madhupratap, 1991). Currently, the marine food web is undergoing severe changes due to climate change, top down and bottom up processes which in turn has a strong bearing on various components of the trophic tie occupied at primary, secondary and tertiary levels. Since 1998, the least productive oceanic habitats in the three of the world's major oceans have been expanding at average rates between 0.8% - 4.3% per year. Studies on changes in ocean productivity during the post-1999 warming period have provided insight into how future climate change can alter marine food webs (Polovina et al., 2008). Variation in plankton production can have a massive impact on marine species as well as humans (Cowell,1996; Harvell et al.,1999). Since the Indian Ocean including its islands and associated lagoon systems remains under-sampled in both space and time, especially when compared to the Atlantic and Pacific oceans, understanding its ecological, physicochemical and biological process is still rudimentary (Second International Indian Ocean Expedition [IIOE-2] Scientific plan,2015).

1.3. ZOOPLANKTON IN THE MARINE ENVIRONMENT

Pelagic zone, circumscribe the entire ocean water column from the surface to the deepest depths, is home to a diverse community of organisms. Differences in their locomotive ability categorise the organisms inhabiting in the pelagic realm into two, ***plankton*** and ***nekton*** (Lalli and Parsons, 1997). ***Plankton*** consists of all organisms drifting in the water and are unable to swim against water currents whereas ***Nekton*** includes organisms having strong locomotive power. The extensive ecological studies on the plankton community, which form the base of the aquatic food chain, help in the better understanding of the dynamics and functioning of the marine ecosystem. The term ‘Plankton’ first coined by Victor Hensen (1887), the German founder of quantitative plankton and fishery research (Lalli and Parsons, 1997), Plankton, (Greek word: *planktos* meaning “passively drifting or wandering”) is defined as drifting or free-floating organisms that inhabit the pelagic zone of water. Based on their mode of nutrition planktonic organisms are categorised into phytoplankton (organisms having an autotrophic mode of nutrition) and zooplankton (organisms having a heterotrophic mode of nutrition). Zooplankton includes a taxonomically and morphologically diverse community of heterotrophic organisms that drift in the waters of the world's oceans. Qualitative and quantitative studies on zooplankton community is a prerequisite to delineate the ecological processes active in the marine ecosystem.

Zooplankton community plays a pivotal role in the pelagic food web as the primary consumers of phytoplankton and act as the food source for planktivorous organisms in the higher trophic levels, particularly the economically essential groups such as fish larvae and planktivorous fishes. They also function in the cycling of elements in the marine ecosystem. The dynamics of the zooplankton community, their reproduction, growth and survival rate are all significant factors determining the recruitment and abundance of fish stocks as they form an essential food for larval, juvenile and adult fishes (Rothschild, 1998; Beaugrand et al., 2003). Zooplankton grazing in the marine environment controls the primary production and helps in determining the pelagic ecosystem (Banse, 1995). Through grazing in surface waters and following the production of sinking faecal matters and also by the active transportation of dissolved and particulate matter to deeper waters via vertical migration, they help in the transport of organic carbon to deep ocean layers and thus act as key drivers of biological pump’ in the marine ecosystem. Zooplankton grazing and metabolism also, transform particulate organic matter into dissolved forms, promoting primary producer community,microbial demineralization, and particle export to the ocean’s interior (Fashametal., 1990; Blackford et al., 2004; Gauns et al., 2005; Buitenhuis et al., 2006; Everaert et al., 2018). A schematic representation of a marine epipelagic food web is illustrated in Figure 2. The large density, shorter lifespan, drifting nature, high group/species diversity and different tolerance to the stress of the zooplankton groups make them indicators of the physical, chemical and biological processes in the aquatic ecosystem (Gannon and Stemberger, 1978; Ghajbhiye, 2002; Rissik and Suthers, 2008). Through the continuous observation of species diversity, biomass and abundance of zooplankton community, any variation in the health of an ecosystem can readily be determined and thus long-term monitoring of marine zooplankton community becomes an indispensable tool in predicting the impact of climate changes on the pelagic ecosystem and has been receiving considerable research interest lately (Beaugrand and Ibanez,2004).

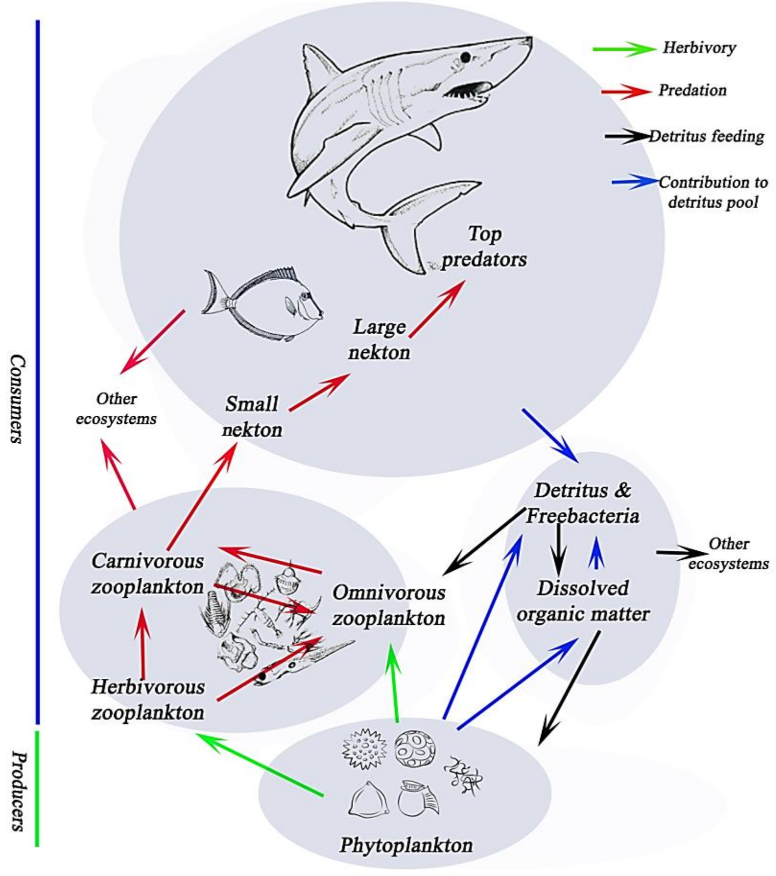

Figure 2. A simplified epipelagic food web.

The categorisation of zooplankton into various ecological groups is based on several factors such as duration of planktonic life, size, food preferences and habitat. As they vary significantly in size from microscopic to metazoic forms, the classification of zooplankton based on size has paramount importance in the field of quantitative plankton research. Schütt (1892), first described three major size divisions among zooplankton, viz. micro, meso and macrozooplankton. Later, several scientists have revised and made amendments in size classifications (Omori and Ikeda, 1984; Redden et al., 2008) and among them, the widely accepted one is the classification by Seiberth (1978), given below.

A.	Femtoplankton	(0.02-0.2 μm)
B.	Picoplankton	(0.2-2.0 μm)
C.	Nanoplankton	(2-20 μm)
D.	Microplankton	(20-200 μm)
E.	Mesoplankton	(0.2-20mm)
F.	Macroplankton	(2-20 cm)
G.	Megaplankton	(20-200 cm)

Based on the duration of planktonic life, zooplankton are categorised into Holoplankton (organisms which complete their entire lifecycle as plankton) and Meroplankton (organisms which are planktonic during the early part of their lives such as the larval stages of benthic and nektonic organisms). Tychoplankton are organisms which live a brief planktonic life, such as the benthic crustaceans (cumaceans, mysids, isopods) which ascend to the water column at night for feeding and certain ectoparasitic copepods, they leave the host and spend their life as plankton during their breeding cycle.

Several ecological groups of zooplankton are based on the depth of the habitat they occupy (horizontal or vertical). According to the horizontal distribution pattern, they are categorized as Neritic (organism inhabiting shallow water column overlying continental shelves) and Oceanic (organisms inhabiting deep water column greater than 200 m). Vertical habitats among zooplankton vary greatly. Based on the depth range of their habitat they are grouped as Neustonic (organisms inhabiting the upper few centimetres of water column), Pleustonic (organisms living on the upper layer and part of the body is exposed), Epiplanktonic(Organisms inhabiting up to 200 m depth), Mesoplanktonic (Organisms inhabiting depth zone between 200 and 1000 m) and Bathyplanktonic(Organisms inhabiting depths greater than 1000 m in the water column). Based on their food preferences zooplankton are classified as Herbivores (organisms which primarily feed on phytoplankton), Carnivores(those feeding on other heterotrophic organisms), Omnivores (feeding on a mixed diet of phytoplankton and smaller zooplankton) and the Detritivores (organisms feeding on dead organic material).

1.4. COPEPODS, MOST NUMEROUS MULTICELLULAR ORGANISMS ON EARTH

Copepods constitute the most numerous multicellular organisms on earth (Ohtsuka and Nishida, 2017). Of all the marine zooplankton groups, copepods are probably the most familiar, since they are the dominant constituent of the plankton in all marine systems, comprising about 70% of the plankton fauna and ranked as the world's most abundant metazoans (Reymont, 1983). They outnumber the insects although the insects are more diverse, having more species than copepods. Being an aquatic animal, they are primarily marine but occur in a vast number of freshwater environments. The subclass Copepoda belongs to the phylum Crustacea. The name copepod originates from the Greek words *kope*, an oar and *podos*, a foot, and refers to the flat, laminar swimming legs on the animals. Copepoda currently includes about 13,000 species of small planktonic, benthic, and symbiotic crustaceans (Ohtsuka and Nishida, 2017). However, this species richness represents a fraction of the real diversity because of the low taxonomic resolution, especially in symbiotic taxa. There are ten orders of copepods containing different numbers of families, genera and species. Which regularly constitute up to 80% of total mesozooplankton (Jonasdottir, 1998). Because small-sized crustaceans are not directly related to human society as commodities, taxonomic information is largely restricted to two groups: planktonic copepods that are main prey items of commercially important fish, and parasitic copepods which are pests in aquaculture. Free-living copepods are a vital link between primary producers and higher trophic levels in aquatic ecosystems and are considered to be one of the most numerous organisms on Earth (Huys and Boxshall, 1991). They are the major metazoan consumer of both primary and microbial production and the main conduit through which such production reaches higher trophic levels such as fish larvae (Runge, 1988; Purcell and Grover, 1990).

The first marine copepod was described in 1770 by Gunnerus from the sea south of Hammerfest in Northern Norway in the name *Monoculus finmarchicus* and was assigned to insects. The generic name *Calanus* was given by Leach (1816) and established by Giesbrecht (1892). Till today *Calanus finmarchicus* remain as the best-studied marine copepod (Marshall and Orr, 1955). The work of Giesbrecht (1892) is the most significant contribution to the taxonomy of copepod, who divided subclass copepoda into two orders namely Brachyura and Eucopepoda. Later taxonomists had raised many defects in his system of classification. Sars (1905) gave the first natural and most comprehensive classification of copepod and divided order Eucopepoda into seven suborders namely Calanoida, Harpacticoida, Cyclopoida, Notodelphydida, Monstrilloida, Caligoida and Lernaeoida. A series of revision has been attempted in phylogeny by some taxonomists. Huys and Boxshall (1991) and Humes (1994) listed the various modifications attempted in the phylogeny of copepods. According to the recent and widely accepted classification of Huys and Boxshall (1991), the subclass Copepoda is divided into ten orders (Table 1).

Table 1. Classification of copepods after Huys and Boxshall (1991) and Humes (1994).

- Subclass: Copepoda Milne-Edwards,1840
  - Infraclass: Progymnoplea Lang,1948
    - Order: Platycopioida Fosshagen,1985
  - Infraclass: NeocopepodaHuys and Boxshall,1991
    - Superorder: Gymnoplea Giesbrecht,1882
      - Order: Calanoida Sars,1903
    - Superorder: Podoplea Giesbrect,1882
      - Order: Misophirioida Gurney,1933
      - Order: Cyclopoida Burmeister,1834
      - Order: Gelyelloida Huys,1988
      - Order: Mormonilloida Boxshall,1979
      - Order: Harpacticoida Sars,1903
      - Order: Poecilostomatoida Thorell, 1859
      - Order: Siphonostomatoida Thorell,1859
      - Order: Monstrilloida Sars,1903

The Platycopioids are marine, benthopelagic species, two living in anchialine caves in Bermuda. The calanoids are primarily pelagic, 75% are marine, 25% live in freshwater. The cyclopoida are divided between marine and fresh waters and can be pelagic, commensal or parasitic. The misophrioida are primarily benthopelagic, and inhabitants of anchialine caves-only two species are pelagic, and the Mormonilloida are pelagic marine species. The Gelyelloida occurs in karstic systems in France and Switzerland. The Harpacticoida are primarily marine species, 10% living in fresh waters. Most species are benthic, pelagic and commensal. The Poecilostomatoida and Siphonostomatoida are marine, commensal or parasitic species. The Mostrilloida are marine species that are pelagic as adults but parasitic when young.

1.4.1. *Importance of copepods in the marine ecosystems.*

Copepods, mainly calanoid copepods, of all the marine zooplankton, are the most dominant group in marine subtropical and tropical waters and exhibit great diversity in their morphology and habitats (Sanu et al., 2014). Being herbivorous, copepods have prime importance in the marine ecosystem, feeding on the phytoplankton, and forming a direct link between them and fish such as the herring, sardine and pilchard. They are also eaten by a vast variety of invertebrate species, both pelagic and epibenthic. Because copepods are a crucial link between primary producers and higher trophic levels, any changes in copepod populations may disseminate throughout entire marine ecosystems (Smith et al., 2017). The Arctic and Antartic Oceans and continental shelves in middle latitudes form the significant zones of calanoid copepods. Their numbers relative to other organisms vary seasonally in middle and high latitudes. Their body size is small, most species having a body length of 0.5 to 2.0mm. Copepods are being promoted as a food organism in some marine hatcheries. Marine copepods are natural feed, which can act as alternatives or supplements to Artemia nauplii, of doubtful nutritional stability. Nutrition wise, the copepods are found to be rich in highly unsaturated fatty acids (Watanbe et al., 1983).

Moreover, they provide a full-size range of food organisms for hatchery use (6 nauplii stages and six copepodid stages). The migration of copepods is essential for the Oceans CO_2 uptake. For example, the calanoid copepod *Calanus finmarchicus* Gunnerus, 1770swim down 1000 meters to hibernating in the cold, dark waters, which slows their metabolism and helps them, save energy until the next phytoplankton bloom. The vertical migration of the species into deeper waters to hibernate that it comes down into the water which is not in an exchange with the atmosphere. The CO_2 released at these depths by the copepods burning their carbon-containing lipids into the water will not be exchanged in the atmosphere. In this the way, the copepods indirectly remove CO_2 from the atmosphere. Different copepods species are showing association with different substrates and environments. They are associated with sand flats (Youngbluth,1982; Ohtsuka et al., 1996) Kelp beds (Hammer, 1981), Lagoons (Jacoby and Greenwood, 1988), Coral reefs (Emery, 1968; Sale et al., 1978; Mckinnon, 1991; Heidelberg et al., 2004; Fukuoka et al., 2015; Smith et al., 2017), and Seagrass beds (Walters and Bell,1994). The sheer dominance and importance of copepods to global ocean ecosystem makes understanding their responses to changes in the chemistry of seawater. In recent years, several studies initiated to understanding the ocean acidification impacts on copepods (Mayor et al., 2007; Kurihara, 2008; Fitzer et al., 2012; McConville et al., 2013; Hildebrandt et al., 2014 and Smith et al., 2017).

1.5. THE SCOPE OF THE STUDY

Understanding the composition, distribution and abundance of zooplankton is a prerequisite to assess the ecological status including the productivity of any aquatic ecosystem. However, in recent years, most of the studies on biotic communities in aquatic ecosystems have been mostly on general ecological aspects; its relation to the environment, the assessment of cultivable species, general biodiversity aspects and related information. So, the knowledge on the species character regarding its taxonomy and systematics in an ecosystem is very vital for evolving its biodiversity, about the trophic status. Moreover, biodiversity assessment is not valid, without having proper knowledge of the species characteristics; its morphology, the pattern of distribution and abundance, succession and related information. However, of late, most of the research is oriented to general ecological, microbiological and molecular aspects of organisms or probably even deriving bioactive compounds from organisms, grossly neglecting the science of taxonomy. Further, the information on the taxonomy of invertebrate planktonic groups is grossly neglected compared to higher groups organisms. In-depth knowledge of a particular species character of an organism regarding its taxonomy and systematics in an ecosystem is very vital for evolving its biodiversity, about the trophic status. The rapidly dwindling taxonomic expertise in plankton especially copepods in the ecosystem over the years has restricted local scientists in their ability to study changes in community structure in detail. Such knowledge is essential to understand and to predict the impact of environmental changes on fish stock fluctuations. Copepod taxonomic analysis will provide with practical applications to a range of issues such as climate change, biodiversity, the introduction of alien species, pollution and eutrophication in addition to fisheries.

Our existing taxonomic descriptions of many ecologically essential copepod species seem to be insufficient and incomplete. Moreover, previous studies in the Arabian Sea and Lagoon waters of Lakshadweep are focused on aspects related to ecology and diversity of planktonic copepods, thus having severe lacunae on the morpho-taxonomy and systematics. Copepod crustaceans living in the oceanic realm have received much attention from molecular biologists, as they are difficult to identify because of their similar morphological characteristics, especially in closely related species. Hence, molecular techniques are now an essential tool for studies on population structure, phylogeography, and phylogeny of copepods (Bijoy Nandan et al., 2014; Sanu et al., 2016). Molecular analysis can provide unambiguous taxonomic discrimination (Bucklin and Wiebe, 1998; Lee and Frost, 2002; Eyun et al., 2007; Soh et al., 2012; Sanu et al., 2016; Radhika et al., 2016; Santu et al., 2017; Francis and Nishida, 2018 and Sanu et al.,2018) and sequence analysis of mitochondrial genes can reveal intra specific and interspecific variations (Bucklin et al., 1995; Bucklin and Wiebe, 1998; Goetze, 2003). The morpho-genetic match would lead to a startup of barcode library of copepods from selected marine habitats of the south-west coast of India that would undoubtedly help to ascertain the taxonomic significance of intraspecific genetic separation discovering cryptic species especially sibling species that have been discriminated only with few or subtle morphological characters. The ability to accurately measure the diversity of species and to accurately identify individual species which are morphologically similar is also unique. Protection of coral reefs requires more emphasis on converting science into adequate policies for conservation. Recent studies indicated that the ocean acidification reduces demersal zooplankton that resides in tropical coral reefs (Smith et al., 2017). Ocean acidification changes coral community composition from branching to massive bouldering of coral species, which leads to losing the association between the corals and certain copepods species which resides in the lagoon ecosystem (Smith et al., 2017). By the effective monitoring of zooplankton, primarily the copepods from the different islands of Lakshadweep archipelago give the health status of the coral ecosystem.

Consequently, under these circumstances, Department of Biotechnology (DBT), Government of India, initiated a major research project on *Taxonomy and genetic characterisation of pelagic copepods from marine habitats of the south-west coast of India* from 2013 to 2016 under the project investigatorship of Prof. (Dr.) S. Bijoy Nandan in the Department of Marine Biology, Microbiology and Biochemistry. The study explored and documented the ecology and community structure of mesozooplankton with thrust on the morpho-taxonomy and systematics of pelagic copepods by classical and molecular methods. Thus, this PhD work records the specific studies on the ecology of the mesozooplankton focusing on the morpho-taxonomy and molecular systematics of the calanoid copepods from the Lakshadweep lagoon and coastal waters of the south-west coast of India. Objectives of the study are thus enumerated below. The study also fulfils the goals enshrined in UN convention in Biodiversity (CBD) where India is a signatory under the Aichi Biodiversity Targets (2011-2020) that stresses the need for reducing biodiversity loss, strengthen capacity building (taxonomists) and make available scientific data and knowledge on biodiversity and its application.

1.6. OBJECTIVES OF THE STUDY

1. Explore the composition, abundance and community structure of zooplankton from Lakshadweep lagoon and coastal waters of the Southwest coast of India.
2. Analyse the abundance and distribution pattern of calanoid copepods from the study area.
3. Document morpho-taxonomy and molecular systematics of calanoid copepods and also resolve the ambiguities in their species status.

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Chapter - 2

REVIEW OF LITERATURE

Contents

2.1. INTRODUCTION

Zooplankton plays an essential role in structuring and regulating the coastal marine food web and also in the functioning of the biological pump (Chiba et al., 2006). As their community structure and function are highly susceptible to changes in the environmental conditions regular monitoring of their distribution as well as their interactions with various physicochemical parameters is inevitable for the sustainable management of the ecosystem (Kusum et al., 2014). Of all the marine zooplankton groups, copepods mainly calanoid copepods are the dominant groups in marine subtropical and tropical waters and exhibit considerable diversity in morphology and habitats they occupy (Madhupratap, 1991; Cornils et al., 2005) and usually contributing > 60% of the total zooplankton abundance (Ohtsuka and Nishida, 2017, Jyothibabu et al., 2018). They act as a trophic link between phytoplankton and fishes in the food chain and thus, play a critical role in ocean biogeochemical cycles (Campos et al., 2017). It has been well established that potential of pelagic fishes viz. finfishes, crustaceans, molluscs and marine mammals either directly or indirectly depend on zooplankton. The herbivorous zooplankton are efficient grazers of the phytoplankton and are referred to as living machines transforming plant material into animal tissue. Hence they play an essential role as the intermediaries for nutrients/energy transfer between primary and tertiary trophic levels. Due to their large density, shorter lifespan, drifting nature, high group/species diversity and different tolerance to the stress, they used as the indicator organisms for the physical, chemical and biological processes in the aquatic ecosystem (Ghajbhiye, 2002).

The study of calanoid copepods is a complex and dynamic activity. Zoological Records remain the principal source of such information in the pre-CD ROM eras. Most of the studies from India have insufficient taxonomic descriptions rather than detailing the distribution, abundance and diversity pattern of calanoids in different marine ecosystems of India. This chapter discusses the reviews on the studies in zooplankton especially calanoid copepods, the taxonomy of calanoid copepods by classical as well as by molecular methods from Indian and international waters.

2.2. ZOOPLANKTON STUDIES

The zooplankton research in the world ocean can be traced back to the late 17th century when Leeuwenhoek identified his "little animals." After that much work was done dealing with the taxonomy, ecology, and biology of marine zooplankton as part of different cruise programme, notable the NOVARA expedition (1858-1859), was the first large-scale scientific around the world mission of the Austrian Imperial Navy under the direction of the Geologist Ferdinand von Hochstetter and the zoologist Georg von Frauenfeld. The commencement of modern scientific marine expedition in the Indian Ocean was initiated by Challenger Expedition (1872-76) by *HMS Challenger* visiting the region twice. Later VALDIVIA expedition (1898-1899), was led by the marine biologist Carl Chun with the purpose of exploring the depths of the Ocean below 500 fathoms. Substantial information on oceanographic features of Indian Ocean was brought about later by John Murray Expedition (September 1933 to May 1934). Galathea expedition II (1950-52), with its primary purpose deep sea oceanography. International Indian Ocean Expedition during the year 1962-1965 was one of the most significant interdisciplinary oceanographic research efforts to explore the Indian Ocean in which 40 research vessels were belonging to 13 countries surveyed in the Indian Ocean. In addition to these expeditions, several attempts also made by various investigators to understand the zooplankton ecology of different seas and estuaries at local and regional scales. Recently the second international Indian Ocean Expedition (IIOE-2) is a major global scientific programme initiated over the period 2015-2020 revealing new information on the Indian Ocean which is fundamental for future sustainable development and expansion of the Indian Ocean's blue economy. Studies on the role of zooplankton especially gelatinous zooplankton structuring food web and community assemblages in the Arabian Sea and Bay of Bengal has been initiated as part of the IIOE-2 by Dr. S. Bijoy Nandan, Professor, Cochin University of Science and Technology for the period of 2018 - 2020.

The zooplankton research in Indian waters began in the early parts of the 20th century by Sewell (1913), when he tried to enumerate the plankton fauna of the Chilka Lake. The observation of Sewell was carried forward by Annandale and Kemp (1915) in the same environment. After that, Sewell (1929) has prepared an inventory of copepods occurring in the Indian seas. Based on the cruise data of RMIC Investigator, a series of reports entitled as *Memoirs of Asiatic society of Bengal* were published by him in the 1920s and 1930s. The zooplankton research in this country was further intensified in the 1950s and afterwards. Simultaneously, some studies were made in shelf waters of the Bay of Bengal, off Visakhapatnam through short-term cruises as well as on a seasonal basis in the harbour area. Results obtained during this cruise were documented in the *Memoirs of Oceanography* of Andhra University (Rao and Ganapati, 1958; Rao, 1958). Zooplankton studies of the west coast of India have been described by Panikkar (1970); Rao (1979); Madhupratap and Haridas, (1990); Madhupratap et a1.,(1990); Padmavathy et al.,(1998); Madhupratap et al., (2001). The finding of a 'paradox' for the northern AS was about the mesozooplankton biomass remaining almost invariant despite seasonal variations in the primary productivity (Madhupratap et al., 1992, 1996a, b; Baars, 1999). These observations have resulted in the perception that the Arabian Sea shifts between a highly productive upwelling dominated situations during the southwest monsoon and an oligotrophic condition during the spring and fall-intermonsoon. While this characterisation may be generally accurate, much of the details are lacking concerning the magnitude of the seasonal shift in the abundance and biomass of mesozooplankton and their relation to various physicochemical processes. Taxonomically, zooplankton represents a very heterogeneous community with members from metazoans and protists. Among these groups, copepods had emerged as the most dominant group throughout the year comprising about 70% of the plankton fauna and ranked as the world's most abundant metazoans (Raymont, 1983). Later, Banse (1994) reviewed processes and issue related to the connection between hydrography, plankton and the flux of the organic carbon to great depth for the offshore Arabian Sea and compared with the observations in similar regimes of other seas. According to this study, for advancing the understanding of the generation of flux in the upper layers and the consumption at depth, very much needs to be learned about the biology of the principal species of zooplankton and nekton. Studies of Mathew and Solomon (1996) on the impact of the oil spill occurred in the Gulf waters during the Gulf war (January-February 1991) showed the zooplankton biomass was very rich in the area and there was no evidence to show that the zooplankton community up to 200m was adversely affected by the oil slick. They noticed a serious depletion of the zooplankton population in the Bombay high areas where the oil drilling operations are on. Plankton nets and trawls in the plankton studies lack sufficient spatial and temporal resolution to give a precise description of the spatial distribution of vertical migration velocity of zooplankton. Luo et al., (1998) used a comparatively crude acoustic alternative. They used a low frequency (kHz) hull-mounted acoustic system in conjunction with a high frequency (153kHz) Acoustic Doppler Current Profiler (ADCP) to separate the sound scattering layer of larger organisms from the zooplankton and assessed the diel vertical migration of zooplankton and mesopelagic fishes from the Arabian Sea. Fernandes and Ramaiah, (2009) addressed the spatial variability in zooplankton biomass and composition in the central and western Bay of Bengal during the summer monsoon season of 2001. Studies on the mesozooplankton distribution of the Arabian Sea and Bay of Bengal with special reference to planktonic ostracods was done by Jasime, (2009). Jyothibabu et al., (2010) re-evaluated the paradox of mesozooplankton in the eastern Arabian sea based on ship and satellite observations. Anjusha et al., (2013)assessed the trophic efficiency of the planktonic food web and the observations was from Gulf of Mannar and Palk Bay. Elevation in the concentration of atmospheric CO_2 will impact zooplankton community. An observation was made by Smith et al., (2016) on the reduction in the demersal zooplankton community that resides in a tropical coral reef. Studies on the seasonal variations in the community structure of the zooplankton in the Palk straight has been carried out by Lathasumathi et al., (2017). While Kusum et al., (2017) studied the diel vertical migrations of zooplankton groups especially chaetognaths from the Bay of Bengal and the physicochemical factors that influence as a barrier in the diel vertical migrations. McKinstry and Campbell (2018) observed that the seasonal variation of zooplankton abundance and community structure in Prince William Sound, Alaska related to a set of environmental variables including SST, mixed layer depth, location, depth of chlorophyll-a max, mixed layer average salinity, chlorophyll-a maximum, and bottom depth. Kodma et al., (2018) studied the spatial variations in the zooplankton community and their major controlling factors along the Japanese coast. A study on zooplankton abundance, biomass, and species composition was carried out from two local coastal water types off Gopalpur, north-western Bay of Bengal by Baliarsingh et al., (2018).

Comprehensive coverage of modern techniques in zooplankton ecology includes sampling, acoustic and optical methods, estimation of feeding, growth, reproduction, and metabolism, and up-to-date treatment of population genetics and modelling by Harris et al., (2000) is the key reference work for marine scientists throughout the world. Later, Skjoldal et al., (2013) discussed an inter-comparison study of current zooplankton sampling systems. Recently a review on traditional and new zooplankton sampling techniques, sample preservation, and sample analysis, and to provide the sources where an in-depth discussion of these topics is addressed by Wiebe et al., 2017.

2.3. ZOOPLANKTON STUDIES DURING IIOE-I

The International Indian Ocean Expedition of 1960-65 was the first attempt to describe the quantitative geographic distribution and abundance of zooplankton in the Arabian sea. Ships from several countries collected 1548 plankton samples using the Indian Ocean Standard Net (Currie, 1963). Copepod distributions from the IIOE can be found in Kasturirangan et al., (1973), Fleminger and Hulsemann, (1973), Stephen et al., (1992), and Gopalakrishnan and Balachandran, (1992). Most of the available data covers the large calanoid copepods, due to the large mesh used during IIOE (>300µm). The samples also are typically limited to the 0-200 m strata and therefore underrepresent forms which have deeper distributions. Chaetognaths are studied by Nair and Rao, (1973). Brinton and Gopalakrishanan, (1973) reviewed the euphausid distributions. Other zooplankton groups are discussed by Zeitzschel, (1973). Various workers studied the distributions and abundance of various zooplankton groups. Ostracods were studied by George, 1968, euphausiid species (Goplakrishnan and Brinton,1969; Brinton and Gopalakrishanan, 1973), appendicularian species (Fenaux,1972), amphipods (Nair et al., 1973; Nair, 1977), total hydromedusae (Santhakumari,1978), and chaetognath species (Nair and Rao, 1973; Nair, 1976a) as well as other , less abundant zooplankton taxa, have been described from the plankton collections of the IIOE. Madhupratap and Haridas, (1986) provide a list of zooplankton species and show abundances of copepod taxa from a transect within the oceanic region of the western Indian Ocean. Unfortunately, their transect did not continue north into the central Arabian Sea. The cruise tracks of Soviet research vessels in the Arabian Sea show that Soviet oceanographers have collected many zooplankton samples throughout the northern and central Arabian Sea. Except for a few reports published (e.g., Vinogradov and Voronina, 1962a) or translated (papers in Oceanology) to English, the results are either unpublished or available only in Russian (e.g., Vinogradov and Voronina, 1962b; Voronina, 1962), and are generally unavailable. The species composition and distribution of zooplankton of the coastal waters off Arabia and of the oceanic central Arabian Sea are poorly known.

2.4. ZOOPLANKTON STUDIES FROM ISLAND ECOSYSTEMS

Recognition of the scientific importance of island ecosystems dates way back over a century to the observations of Charles Darwin in the Galapagos islands 1835. On reviewing through the available literature exposed the zooplankton studies carried out by several authors in different lagoons and islands of the Arabian Sea and Bay of Bengal. The composition and abundance of zooplankton have been studied Gerber, (1981) from Enewetak Atoll, Marshall Islands. Marichamy, (1983) reported on the zooplankton production in coastal waters of Andaman and Nicobar islands. Devi et al., (1996) documented Ichthyoplankton from Andaman and Nicobar seas. Doairaj et al., (1997) discussed studies on the marine fauna of the Mahatma Gandhi Marine National park. Ekblad, (2008) presented the effect of predatory chaetognaths on zooplankton assemblages at the start of the spring bloom in Glacier Bay, Alaska. Nair et al.,(2008) reported two new species of chaetognaths from the Andaman Sea. A comparative study on mesozooplankton abundance and diversity between a protected and unprotected coastal area of Andaman Islands was given by Honey et al., (2014).

As part of oceanographic cruises and various surveys, many researchers have recorded the biophysical aspects of Lakshadweep islands (James,1989; Koya, 2000; Vargis,2005). Documenting the account of the work carried on and collections made by an expedition during the years 1899 and 1900, Prof.J.Stanley Gardiner published two volumes of Fauna and Geography of the Maldives and Lakshadweep, its geographical features, land flora and fauna. Central Marine Fisheries Research Institute (CMFRI) established a research centre at Minicoy Island 1958. As a part of this, a monumental treatise on fishes of Lakshadweep archipelago was published by Jones and Kumaran, (1980)and a special issue on Lakshadweep incorporating series of articles with reviews of marine fisheries research up to 1986, where also published (Anon,1986), While James, (1987) described the pole line tuna fishery of Lakshadweep.

Tranter and Goeorge, (1972) have studied the zooplankton abundance at Kavaratti and Kalpeni atolls of Lakshadweep. Goswami, (1973) observed the total zooplankton biomass with diurnal species variations in the lagoon and of the surrounding sea of Kavaratti Attol. Wolfenden, (1906) studied the copepod contents of zooplankton of Lakshadweep. Comparative studies on the zooplankton abundance of Kavaratti, Agatti and Suhelipar lagoons were carried out by Madhupratap et al., (1977). Goswami and Usha, (1990) studied the diel variation in zooplankton in Minicoy lagoon and Kavaratti atoll. The densities and emergence rates of demersal zooplankton from Agatti atoll was reported by Madhupratap et al., (1991). He also studied the zooplankton from the lagoons of Minicoy, Agatti, Kadmat and Bitra. Jose et al., (2010) presented a hierarchical analysis of zooplankton assemblage over semidiel pattern in Kavaratti atoll. Robin et al., (2012) provided baseline information on the productivity, pigment concentration and plankton community structure and their trophic state concerning the marine food web. The zooplankton studies in the adjacent open sea of Minicoy lagoon was made by Mathew and Gopakumar, (1986). Achuthankutty et al. (1989) worked zooplankton of Kalpeni and Agatti atoll. Sanu et al., (2014) reported mesozooplankton distribution from Kavaratti atoll. Varghese et al., (2015) conducted a study on the zooplankton abundance in Amini and Kadamat islands of Lakshadweep. Recently Varghese et al., (2018) studied the plankton productivity in lagoons of Agatti and Bangaram atolls of Lakshadweep. Vineetha et al., (2018) addressed the impact of the El Niño 2015-16 on the zooplankton community in Kavaratti reef ecosystem.

2.5. COPEPODS FROM INTERNATIONAL WATERS

The copepod world took shape against the vast background of other invertebrates. There are several valuable contributions in the century observed after the establishment of Linnaeus's taxonomic system in 1758. Copepod research having started in 1770 with the description of *Monoculus finmarchicus* by Gunnerus. Gunnerus, made excellent contributions to the systematics of this group of small (up to 10 mm long), planktonic crustaceans, by a variety of distinguished authors, have followed, Wilhelm Giesbrecht (1892), George Ossian Sars, (1901-1921), and Willem Vervoort. In the years between 1946 and 1965, the level and amount of detail both in Vervoort's exact verbal descriptions (1941-1949) and in his highly accurate drawings remained unparalleled on the taxonomy of copepods (Bruggen, 1997). In retrospect, they even appear to constitute the individual match for Giesbrecht's original taxonomic work (Giesbrecht, 1892). Vervoort's impressing standards in meticulously accounting for anatomical details undoubtedly set the scene for new generations of copepodologists, and one of the actual impacts of his work indeed comprises a revival of the classical way of fully dismembering and next painstakingly describing all features observed on the organisms.

Vast oceanographic expeditions in the last quarter of the 19th century brought an unbelievable harvest of copepods for an expanding and exclusive copepod literature. The decade before and after 1900 was the Golden Age of Copepodology, with the beautiful and indispensable monographs of Wilhelm Giesbrecht, (1854-1913, Germany and Italy), and Georg Ossian Sars, (1837-1927, Norway). Mollman and Koster, (2002) studied the noticeable change in the population of calanoid copepods and the implications and predation by clupeid fish in the central Baltic Sea. In 2004, a new plankton database effort began, incorporating over ten years of plankton data management experience and user feedback into designing and building a new online data system explicitly intended for plankton data and plankton scientists. The **C**oastal & **O**ceanic **P**lankton **E**cology, **P**roduction & **O**bservation **D**atabase (**COPEPOD**) now contains the entire reprocessed plankton content of Brien et al., (2002), the significant amounts of new plankton data presented in COPEPOD-2005 (Brien, 2005) and new data added since 2005. The first report of two neustonic calanoid copepods *Pontella securifer* and *P.sinica* from the South Sea, Korea by Jeong et al., (2008). Later, Jeong et al., (2009) described four *Pontellopsis* species (*P. armata* Giesbrecht, *P. regalis* Dana, *P. villosa* Brady and *P. yamadae* Mori and redescribed the four species with SEM micrographs of female genitalia. COPEPOD also represents a new approach to providing data access and investigator acknowledgement in a global-scale database. In 2010, Cornils et al. studied the mesozooplankton distribution in the Spermonade Archipelago with particular reference to the calanoid copepods. Their results revealed that the composition of the mesozooplankton community changed from the coastal zone with a high abundance of meroplankton and neritic copepod species to an offshore community with a higher abundance of holoplanktonic organisms and oceanic copepod species. A new species of *Bestiolina* from the Yellow Sea has been described by Moon et al., (2010). While Hwang et al., (2010), and Beyrend-Dur (2013) studied the patterns of the zooplankton distribution from the Danshuei ecosystem in northern Taiwan. Mulyadi (2011) reported the species of *Pontella* Dana 1849 and *Ivellopsis* Claus 1893 and reexamined these genera from the Indonesian waters. In 2012, Prusova et al. illustrated and described sixty calanoid copepods from the Arabian Sea region. For each presented species a short description, detailed original line drawings and photographs of the female and male are given. Garcia et al., (2013) addressed the occurrence of sexual dimorphism in nine centropagid species and described the pattern of its trait from Patagonia (Argentina). They discussed the potential relevance of sexual dimorphism in *Boeckella spp.*moreover, *Parabroteas sarsi* as an adaptation to endure fluctuating environmental conditions, including resource limitation and predation, as well as other factors. Hirabayashi and Ohtsuka (2014) described a new species of *Labidocera* (Copepoda, Calanoida, Pontellidae) collected from Okinawa, southwestern Japan, with the establishment of five Indo-West Pacific species groups in the *L. detruncata* species complex. A new calanoid copepod *Peniculoides secundus* gen. et sp. nov. is described from a female specimen collected in the northern Atlantic from abyssal waters close to the seabed by Markhaseva and Renze, (2015). *Calanopia tulina* sp.nov. a new pontellid copepod described from the Red Sea by El-Sherbiny and Al-Aidaroos, (2017). The species is most similar to *Calanopia media* described from the Red Sea. Mulyadi et al., (2017) described seven new species of the planktonic copepod genus and subgenus *Tortanus* (*Atortus*) from North Sulawesi, Indonesia. Four of these species, *T. (A.) indonesiensis*, *T. (A.) omorii*, *T. (A.) processus* and *T. (A.) lukmani*, belong to the brevipes species complex sensu Ohtsuka and Kimoto, (1989). Two species, *T. (A.) sulawesiensis* and *T. (A.) manadoensis* placed in the recticauda species complex. The seventh species, *T. (A.) bilobus*, belongs to neither group. Ardania et al., (2017) reported the occurrence of a blue-pigmented calanoid copepod (*Acrocalanus sp.*) in Cendrawasih Bay, Papua - Indonesia as the first record. Copepod crustaceans of the genus *Gaussia* inhabit open ocean waters in epipelagic and bathypelagic zones from 0 to 5000 m. Alves et al., (2018) newly reported *Gaussia intermedia* Defaye,1998 (Calanoida, Metrinidae) from the Atlantic Ocean. This finding expands the global distribution of the species and is the first occurrence in the Atlantic Ocean, updating the checklist of meso-bathypelagic copepods for Brazilian waters. Maud et al., (2018) reported that the mortality of *Calanus helgolandicus* positively correlated to temperature and the abundance of predatory chaetognaths and siphonophores. Their study suggested that the gelatinous predator assemblage is the dominant agent for population control of the late stage copepodites of the species. Studies on the population structure of the non-indigenous calanoid copepod *Pseudodiaptomus marinus* Sato 1913 in the Belgium part of the North Sea for the first time by Deschutter et al., (2018). In their study, relevant environmental variables were analysed to identify the potential drivers explaining the population structure of the species. Studies on variability in copepod trophic levels and feeding selectivity based on stable isotope analysis in Gwangyang Bay of the southern coast of the Korean Peninsula by Chen et al., (2018).

2.6. COPEPODS FROM THE INDIAN WATERS

The scientific papers on distribution and taxonomy of the extent copepods occurring in the Indian Ocean have increased considerably, since the first work of Giesbrecht of 1889 on this group, particularly in the Arabian Sea, which is understood to possess many qualities that make it unique among the world ocean. Study on copepods from the Indian Ocean was announced with the work of Thompson, (1900) from the east coast of Africa to Ceylon and Bay of Bengal. Cleve, (1901) studied copepods from Aden to Java in the Malay Archipelago. Subsequently, Scott, (1902) and Thomson and Scott, (1903) studied copepod fauna from Suez to Colombo and around Pearl Banks of Ceylon. Wolfenden, (1906) and Scott, (1909) gave detailed information on copepods from the Maldives and the Malay Archipelago. Brady, (1910) and Wolfenden, (1911) presented a detailed account of copepods from the Southern part of the Indian Ocean. However, the most extensive study on the copepod fauna of Indian waters was done by Sewell in a series of publication. Sewell, (1912, 1914,) studied the copepods of the coastal regions Bay of Bengal, Arabian Sea, Chilka Lake, coastal region of South Burma, Andaman and Nicobar islands. Sewell, (1929 to 1932) described the copepods of the west coast of India and the Malay Archipelago. Copepod of John Murray Expedition was dealt with by Sewell, (1947 and 1948). Realising the need for a systematic survey of the Indian Ocean the International Indian Ocean Expedition (IIOE, 1960 to 1965) was organized and nine nations participated in the biological programme. The zooplankton samples collected during the expedition formed the basis for a series of papers dealing mainly with zoogeography, ecology, and systematics. The necessary information on copepods of the IIOE was given in the plankton atlas on copepods (IOBC, 1970). Copepoda being the most abundant group, the different families and genera were allotted to specialists, and some papers have been published. Kasturirangan et al., (1973) gave an overall picture of the distribution of calanoid copepods collected during the International Indian Ocean Expedition. Fleminger and Hulsemann, (1973) discussed the Centropagidae, Clausocalanidae, and Temoridae, especially on the distributional aspects. Systematics and zoogeography of family Scolecithricidae were studied by Gopalakrishnan and Saraladevi, (1998). An account of the genus Euchaeta was given by Tanaka, (1973). Stephen and Saraladevi, (1973), and Saraladevi et al., (1979) studied the genus Halopitlus; Pontellidae from the Indian Ocean by Silas and Pillai, (1973). Saraswathy, (1973 and 1986), Saraswathy and Iyer, (1986) studied the genera *Gaussia* and *Pleuromamma*. Canaciidae of the IIOE was dealt with by Lawson, (1977). The distribution of bathypelagic family Arietellidae and the epipelagic family Acartiidae were given by Stephen and Rao, (1980), and Stephen et al., (1992) gave the geographical distribution of various copepod taxa. These reports provide authentic information on the distributional range for different species of copepods from the entire Indian Ocean.

Among planktonic copepods, the calanoids rank highest in species diversity and numerical abundance. Detailed studies of only a few calanoid genera from the International Indian Ocean Expedition material were conducted; Frost and Fleminger (1968), Tanaka (1973), Lawson (1976), Stephen and Saraladevi, (1973) have studied different genera of calanoid copepods. After the International Indian Ocean Expedition, research on copepods became more elaborate and confined to distinct areas of the Indian Ocean. Stephen and Iyer, (1979) concentrated on calanoid copepods of the shelf and slope waters off Cochin. Madupratap et al., (1981) and Nair et al., (1981) discussed the diversity of copepods around the Andaman and Nicobar waters and the Bay of Bengal respectively. The distribution patterns of calanoid copepods in the Arabian Sea and Bay of Bengal were reported by Stephen, (1984). An account of the epipelagic calanoid copepods in the upper 1000m of the Arabian sea was studied by Madhupratap and Haridas, (1986). Madhupratap et al., (1990) dealt with the copepods of coastal upwelling in the eastern Arabian Sea. Stephen, (1992) studied copepods along the southwest and southeast coast of India. Goswami et al., (1992) examined the micro-distribution of copepods along the southwest coast of India. Madupratap et al., (1996) presented the trophic relations of copepods within the mesozooplankton community. Padmavathi et al., (1998) gave an account of the vertical distribution of copepods for the Central and eastern Arabian Sea. Stephen, (1998) traced the geographical distribution of calanoid species in the Indian Ocean. Madhupratap, (1999) gave an account of distribution, abundance and general feeding habitats of the free-living copepods from the Arabian Sea. Wishner et al., (2000) studied the ecology of copepods from the oxygen minimum zone of the Arabian sea. Later Wishner et al., (2008) provided the first comprehensive analysis of calanoid copepod vertical zonation and community structure at midwater depths (300–1000 m) through the lower oxygen gradient (oxycline) (0.02 to 0.3 ml/L) of the oxygen minimum zone of the Arabian sea. Yamani and Prusova, (2003) published an identification guide of thirty-seven copepod species occurring in the waters of Northwestern Arabian Sea. Copepod community structure and productivity were investigated by Satapoomin et al., (2004) from the deep oceanic waters of the Andaman Sea. Perumal et al., (2009) studied the percentage composition of protein, lipids, carbohydrates and amino acids of two calanoid copepods *Acartia spinicauda* and *Oithona similis*. The study supported the view that protein may function as a metabolic reserve in copepods. The community structure of the Harpacticoida (Crustacea: Copepoda) studied from the Chennai coast by Mantha et al., (2012). Two new species of calanoid copepods under the genus *Tortanus* from the Andaman Islands described by Nishida et al., (2015). Kavitha et al., (2018) studied the abundance and diversity of copepods from the offshore region of Tuticorin.

2.4.1. Studies from nearshore and estuarine waters

Studies on copepods along the west coast of India were mainly for the nearshore and estuarine zones of Cochin, Goa, Mumbai and South Gujarat. The Cochin backwater system had been intensively studied, and there are some publications on the copepods of the area. Taxonomy of copepods of the Cochin backwater was reported by Wallershaus, (1969). Kasthurirengan, (1963) has prepared a key for the more common planktonic copepods collected from Cochin, Calicut, Madras, and Mandapam. Tranter and Abraham, (1971) discussed the coexistence of species of the family Acartiidae. Pillai, (1971) and Pillai et al., (1973) also give an account of copepods on Cochin estuary. Later Madhupratap (1978, 1979 and 1987) studied in detail the various aspects on the distribution of copepods from Cochin backwaters. Haridas, (1982) studied copepods along with other zooplankton groups from the major estuaries of the Kerala coast.

Menon, (1931) and Menon, (1945) studied the copepods of Madras and Trivandrum coast. Saraswathi, (1967) examined the pelagic copepods from the inshore waters off Trivandrum coast. Subsequently, Bal and Pradhan, (1945), Jacob and Menon, (1947), Chacko, (1950), have also dealt with planktonic copepods of Indian waters. Krishnaswami, (1953 and 1954), studied the copepods of Madras coast. The distribution of copepods around Mandapam was described by Prasad, (1954 and 1956). Ganapathi and Santhakumari, (1962) have given an account of the planktonic copepod of Lawson bay. Ummerkutty, (1960, 1964, 1966,) has published a series of paper on the copepods of Indian water. The calanoid copepods family Pontellidae from the Indian ocean has been thoroughly discussed by Silas and Pillai, (1967 and 1973).

Copepods of Hooghly-Maltah estuarine system was taken up by Sarkar et al., (1986). Copepods of the Bahuda estuary, Orissa was studied by Mishra and Panigrahy, (1996). Goswami and Selvakumar, (1977) studied copepods along the inshore water of Goa. Padmavati and Goswami, (1996) studied the copepods of Mandovi and Zuari estuaries. Achuthankutty et al., (1998) elucidated the copepod assemblage in the estuarine and coastal waters of Goa. Zooplankton studies for the Mumbai coast were initiated with the work of Bal and Pradhan, (1945). Diurnal variation of zooplankton in the Malad Creek and Versova indicated the effect of pollution on the occurrence of different groups of zooplankton (Gajbhiye et al.,1984). Lodh, (1990), Gajbhiye et al., (1991), Tiwari and Nair, (1993) and Ramaiah and Nair, (1997) worked on copepods from the nearshore and creek environments of Mumbai including the species diversity of copepods from the harbour area (Nair and Ramaiah, 1998).

Zooplankton of Veraval was studied by Nair et al., (1987). Padmavati and Goswami, (1996) reported on the zooplankton and copepods from the nearshore waters between Goa to south Gujarat. A new species of Calanoid copepods *Pseudodiaptomus pankajus* (family Pseudodiaptoidae) is described from the salt pans of the state of Gujarat (West coast of India) by Madupratap and Haridas, (1992). Detailed studies on the distribution, abundance and composition of copepods from the Bay of Bengal, since 1936 (Aiyar et al., 1936; Rangarajan and Marichamy, 1972; Vijayalakshmi and Venugopalan, 1973; Elayaraja and Ramanibai, 2006; Mishra and Panigrahy, 1999) reported the distribution and abundance of Copepods from the east coast of the Bay of Bengal.

Kesarkar and Anil, (2010) studied the new species of copepod, *Paracalanus arabiensis* sp. nov. collected from Mandovi and Zuari estuaries, Goa, the central west coast of India. It differs from its congeners mainly in the structure of leg 5, with a row of six teeth along the edge of the inner terminal spine resulting in a serrated margin and two small, stiff spines of equal length protrude in between the terminal spines. Aggregation of mass swarming of the copepods from Ashtamudi and Cochin backwaters reported by Santu et al., (2016). Jagadeesan et al., (2017) measured the copepod grazing rate and its impact on the total and size-fractionated phytoplankton biomass in the coastal waters of off Kochi. Jyothibabu et al., (2018) studied the ecological indicators of copepods to oxygen deficient near-shore waters along the west coast of India.

2.4.2. Studies of copepods from island ecosystems

The coral islands and lagoons being a hotspot of marine biodiversity, occupying a significant part of the Arabian Sea and Bay of Bengal has been least investigated especially on the taxonomy and community structure of copepods. There are a few studies reported on the quantitative and qualitative distribution of copepods in Lakshadweep archipelago. Species composition of the zooplankton and status of copepods from the Andaman and Nicobar area is also little known. Since Gardiner's (1903-1906) classical studies on the fauna of the Maldive and Laccadive archipelago, there has been no other comprehensive work on this region. After, Tranter and George, (1969) described the nocturnal abundance of zooplankton at Kavaratti and Kalpeni.Observations on some planktonic copepods from Kavaratti atoll by Goswami, (1973). Silas and Pillai, (1973) studied the detailed description and distribution of calanoid copepod family Pontellidae from the Indian Ocean. In their studies, they covered the pontellid copepods from Lakshadweep and Andaman and Nicobar islands. A comparative study on the abundance of the copepods inside the lagoon and oceanic waters of Kavaratti, Agatti Suhelipar islands were made by Madhuratap et al., (1977). A new calanoid species *Acaria dweepi* from the lagoon waters of Agatti described by Haridas and Madhupratap, (1978). Madhupratap et al., (1981) covered the major crustacean groups and diversity around Andaman and Nicobar islands. A swarm of the copepods under the family Pontellidae in the Campbell Bay, Andaman were observed by Goswami and Rao, (1981). Latter observations on the distribution of copepods in and around lagoon waters of Agatti and Kalpeni islands has been made by Achuthankutty et al., (1989). Goswami and Usha, (1990) reported the families Candacidae, Calanidae, Pontellidae, Temoridae, Psuedodiaptomidae, Centropagidae Paracalanidae, Acartidae, Euchaetidae, Scolecithridae, and Pseudocalanidae from Lakshadweep waters. Satapoomin et al., (2004) studied spatiotemporal variations in biomass and production, and role in the pelagic food web of the copepods from Andaman. Santhanakumar et al., (2010) studied zooplankton biomass, composition and abundance including copepods of inshore region lined with mangroves and open sea areas close to few kilometres from the shore of Andaman and Nicobar islands. A study on the distribution and diversity of zooplankton especially copepods near the active volcano–Barren Island in the context of persistent volcanic signature and warm air pool by Pillai et al., (2011). Fifty-two calanoid species belonging to seventeen families were observed in their study. Abundance and species composition of harpacticoid copepods from a seagrass patch of South Andaman were studied by Jayabarati et al., (2012). In their study, a total of 47 species belonging to 34 genera distributed within 14 families of harpacticoid copepods were recorded.

Robin et al., (2012) made a study on planktonic communities and trophic interactions in the Kavaratti atoll. They observed 14 species of copepoda from Kavaratti atoll. Radhika et al., (2014 a) redescribed the female species of

Corycaeus crassiuculus and *C. catus* from Kavaratti atoll, Lakshadweep archipelago. Later Radhika et al., (2014b) studied the species assemblage and community patterns of cyclopoid copepods in the same area. Pillai et al., (2014) covered a comparative study on mesozooplankton abundance and diversity between a protected and an unprotected coastal area of Andaman Islands. Jayabarati et al., (2015) studied the relative aspect of composition, abundance and correlation of benthic copepods from Andaman. Nashad et al., (2018) reported four parasitic copepods from Andaman and Nicobar waters.

2.5. Molecular taxonomy and systematics of copepods

Copepods are proving to be an essential group in which to study the evolutionary processes of population divergence and speciation. Despite the dramatic examples of morphological diversity found between specific different copepod groups, at a closer level of relationships morphological statics is a commonly found pattern (Lee and Frost, 2002; Thum and Harrison, 2009) making genetic techniques crucial for the identification of divergent lineages and cryptic species. Interestingly, for some groups that had been previously relatively well-studied from an ecological perspective, genetic analyses of populations have revealed remarkably different copepod lineages (Burton, 1998) or clear cases of sympatric cryptic species (Lee, 2000; Goetze, 2003; Caudill and Bucklin, 2004; Chen and Hare, 2008). The further development of genomic resources will aid the study of the physiological differences that are likely to be essential drivers of divergence between such cryptic species. Although some species of copepods show these unusual patterns of dramatic genetic divergence over short geographic distances, other species have worldwide distributions with an apparent genetic exchange between ocean basins (Goetze, 2003; Eberl et al., 2007) highlighting the diversity patterns of population diversity found within the copepods as a group. DNA barcodes are being widely used recently for species identification and discovery particularly for copepods because these organisms are small, fragile and scattered throughout the aquatic ecosystems. Barcoding analysis is also used to identify species, population and trace their transport in ocean currents (Bucklin et al., 2007). Manwell et al., (1967) were the first to demonstrate the value of molecular techniques by showing that they could clearly distinguish the three common north-eastern Atlantic species *Calanus finmarchicus*, *C. helgolandicus* and *C. hyperboreus* from one another. Bucklin et al., (1995) have studied six Calanus and three Metridia species, determining the intra- and interspecific patterns in DNA sequences. Savolainen et al., (2005) emphasised that DNA sequences have become a routine technique to confirm species identifications for taxonomic, ecological and evolutionary purposes. Bucklin and Frost, (2003) established that mtCOI sequence variation proved to be a reliable marker in molecular systematics and phylogenetic assessment for families of calanidae and clausocalanidae. Bucklin et al., (2007) have reported DNA barcodes would provide rapid, automatable protocols for zooplankton species identification in the future.

The mitochondrial cytochrome oxidase I (mtCOI) is a 650 bp region (Folmer et al., 1994) has been used for species identification and classification of diverse taxa (Hebert et al., 2003). It is one of the most frequently used genes for the study of ecological and evolutionary patterns of species. The application of the mtCOI gene sequence for the DNA barcodes has proved to be a useful marker particularly for copepods (Hill et al., 2001; Bucklin and Frost, 2003). mtCOI has also been used to distinguish closely related genera in species identification (Paine et al., 2007). Several advantages including accelerated substitution rates, (almost) unambiguous orthology and being genome-level information have allowed the mitochondrial genome to be extensively used in population studies phylogeography and phylogenetic relationships at various taxonomic levels across animal taxa, particularly for arthropods (Minxiao et al., 2011). The nuclear ribosomal DNA and the mitochondrial gene cytochrome oxidase subunit I (mtCOI) are appropriate markers for species-level studies since they contain sufficient diversity to address intra and inter-specific phylogenetic relationships found among invertebrates (Sakaguchi and Ueda, 2011, Radhika et al., 2016 and Santu et al. 2017).

Mitochondrial marker genes COI (cytochrome c oxidase subunit I) and Cyt b (cytochrome b) are applied to investigate the genetic diversity of *Paracalanus parvus* species complex (Cornils and Held, 2014). They provided evidence of cryptic or pseudo-cryptic speciation in the *Paracalanus parvus* complex and showed that *Paracalanus parvus* is not panmictic, but may be restricted in its distribution to the northeastern Atlantic. 18S rRNA is used to examine relationships about the taxonomic levels of the calanoids (Blanco-Bercial et al., 2011). They also confirmed that multiple-gene analyses yielded consistent and well-supported phylogenetic results as obtained for superfamilies and families of the copepod order Calanoida. Hebert et al., (2003) reported the adequately trained taxonomists for the identification of DNA barcoding of species is insufficient. A comprehensive study on the DNA barcode database for the 300 described species of Arctic holoplankton for species identification done by Bucklin et al., (2009). Brone et al., (2011) proposed that the genomics research on copepods be needed to extend our exploitation and characterisation of their fundamental biological traits. Multiple gene analysis of caligid copepods by Freeman et al., (2013) indicates that the reduction of the thoracic appendage in Pseudocaligus represents convergent evolution. Blanco-Bercial, (2013) emphasised that the integrative morphological-molecular taxonomic analysis is needed to produce a taxonomically comprehensive database of barcode sequences for all species of marine copepods. Shiganova et al., (2015) used molecular genetic techniques along with the traditional characteristics to clarify the identification of non-native species of *Oithona davisae* Ferrari and Orsi, 1984 from the Black Sea. Baek et al., (2016) examined sequence variation of a partial mitochondrial cytochrome c oxidase I gene from 133 copepod individuals from the Korean peninsula. Young et al., (2016) provided insight into marine planktonic crustaceans such as copepoda and thecostraca genetic divergence patterns and species boundaries and species definitions. While Albaina et al., (2016) gave an insight into the invasion source of the copepod species, they colonised in Basque estuaries based on mitochondrial DNA sequences. Khodami et al., (2017) analysed for the first time, the phylogenetic status of 205 species belonging to all ten orders of copepods using the sequences of 28S,18S,mtCOI and H3 protein. The calanoid copepods *Calanus glacials* and *Calanus finmarchicus* are considered as the indicator species for Arctic and Atlantic waters respectively. Choquet et al., (2018) compared the identity of the two species by using morphological and molecular identification, and they proposed that the systematic use of the molecular tool is essential for the species identification in the field of copepod taxonomy. Kasapidis et al., (2018) revised the taxonomic status and distribution of the *Paracalanus parvus* species complex in the Medditeranianand Black sea through the morphological and molecular analysis.

2.5.1. Molecular taxonomy of copepods from Indian waters

In India, molecular studies in copepods are found to be scarce. Jagadeesan et al., (2009) distinguished the *Paracalanus parvus* from the other morphologically similar copepods with EcoRI and Hind III restriction enzymes using RFLP analysis. Rajthilak et al., (2010) studied the molecular variation in nuclear DNA isolated from *Euterpina acutifrons* and *Acrocalanus gracilis* using RFLP analysis. Sivakumar et al., (2013) have followed the molecular approach to identify *Thermocyclops decipiens* by using amplification of 18S rDNA and found the relationship of *T. decipiens* with other freshwater cyclopoid copepods. Mitochondrial COI sequences used for copepod taxonomy in India for the first time by Bijoy Nandan et al., (2014). In this study, barcode developed for the calanoid species *Labidocera acuta* Dana, 1849 collected from Lakshadweep waters and analysed genetic divergence with other related species. A point of significant confusion concerning *Labidocera madurae* and *Labidocera sp.* from the Hawaiian region was resolved based on the morphology and mtCOI gene sequence analysis developed by Sanu et al., (2016) from Lakshadweep waters. Studies on the morphological and molecular identification of marine copepod *Dioithona rigida* Giesbrecht, 1896 (Crustacea: Cyclopoida) based on mitochondrial COI gene sequences, from Lakshadweep sea by Radhika et al., (2016). The study presented the first molecular barcode of the species *D. rigida* based on mitochondrial COI sequence, along with its morphological description. Santu et al., (2017) resolved the taxonomic ambiguity exist of the calanoid species *Acartiella gravelyi* from the Vembanad backwaters using mtCOI sequences. Jeyam and Ramanibai, (2017) developed mtCOI sequences for the freshwater cyclopoid species *Mesocyclops leukarti* from Retteri lake. Santu et al., (2017) reassessed the status of the species *Pseudoddiaptomus malayalus* Wallershaus, 1969 and *P. binghami* Sewell, 1912 from the Cochin estuary based on morphology and mtCOI gene sequences. Francis and Nishida, (2018) collected *Pontella sinica* Chen and

Zhang, 1965 for the first time from the eastern Indian Ocean, and revised the synonymy of the species with *P. sewelli* Heinrich, 1987 as a Junior synonym of *P. sinica* based on morphological and mtCOI sequence analysis. Later specimens of *Pontella spinipes* and *P. diagonalis* collected from the Arabian Sea and morpho-molecular analysis carried out by Sanu et al. (2018) revealed that female *Pontella spinipes* Giesbrecht, 1889, and male *P. diagonalis* sensu Silas and Pillai, (1973) are genetically identical, providing evidence that the latter is *P. spinipes.*

Copepods by their sheer dominance in the zooplankton community have attracted the attention of taxonomist leading to extensive studies on the ecology and systematics of the group. Survey of copepods is also crucial because of the great diversity, numerical abundance especially in the euphotic zone and their primary position in energy transfer at the secondary level. In tropical seas, copepods exhibit great variety. There are about 13000 species of copepods described (Ohtsuka and Nishida, 2017), and the number is still steadily increasing with the description of new species.

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Chapter - 3

MATERIALS AND METHODS

Contents

3.1 STUDY AREA AND SAMPLING STRATEGIES

Field Sampling was conducted from different Lakshadweep islands from 2013 to 2016 on a seasonal scale and also from Leeward and windward side of Minicoy Island during spring intermonsoon 2015 (Cruise No.338 *FORV Sagar Sampada*). The Sampling was conducted along the coastal waters of the south-west coast of India during spring intermonsoon and fall intermonsoon 2015 (Cruise No. 338 and 345 FORV *Sagar Sampada*), and the sampling stations are represented in Fig.1 and Tables 1, 2 and 3.

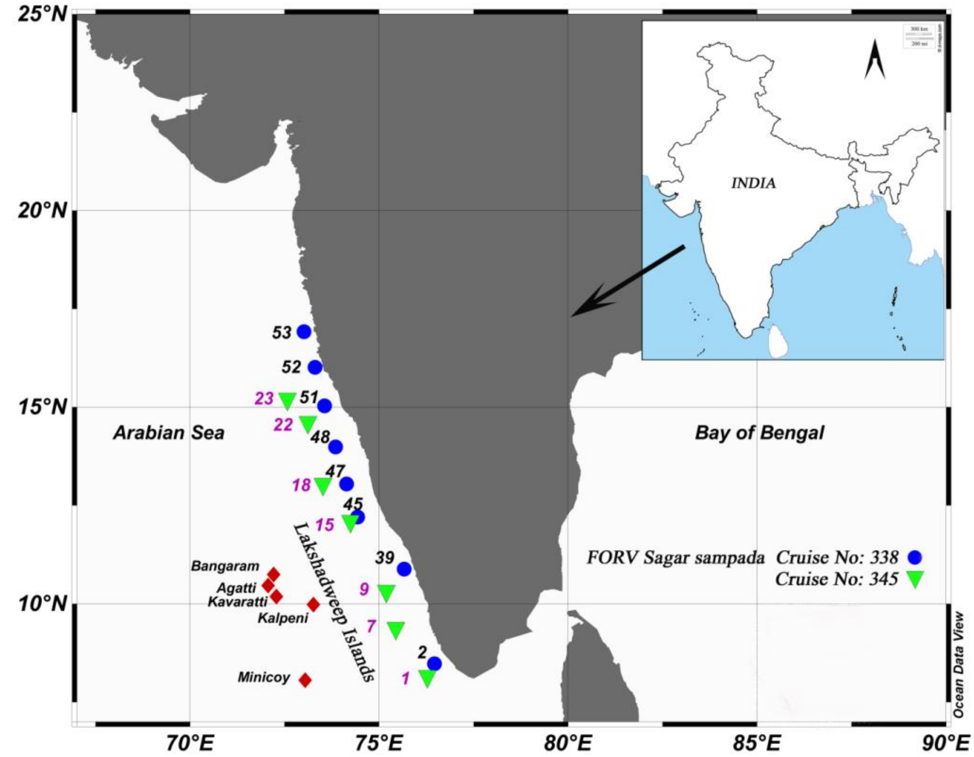

Figure 1. Sampling locations in Lakshadweep islands and coastal waters of Southwest coast of India during 2013-2016.

Study area describes the details of the study location based on its importance and characteristics. The stations selected along the coastal waters are based on the depth that ranged from 50 to 100 meters. The lagoon stations were shallow, and it ranged from 3 to 10 meters inside the lagoon. Lakshadweep is the only coral island that exists in India (Fig. 2). Lakshadweep is an archipelago consisting of 12 atolls, 3 reefs and 5 submerged banks scattered in the Arabian Sea around 200-500 km of the west coast of Kerala. Lakshadweep islands comprise of ten inhabited islands, seventeen uninhabited islands, four newly formed islets, five submerged reefs. Lakshadweep islands are grouped into clusters like 1. Aminidive group consisting of five inhabited islands, 2. Laccadive group composed of four inhabited and twelve uninhabited islands, three submerged reefs and five submerged banks. The origin of these islands can be traced to gradual submergence of some of the volcanic ridges into the Indian Ocean followed by accumulation of coralline deposits on the peaks and craters of these mountains. (Anon, 2008)

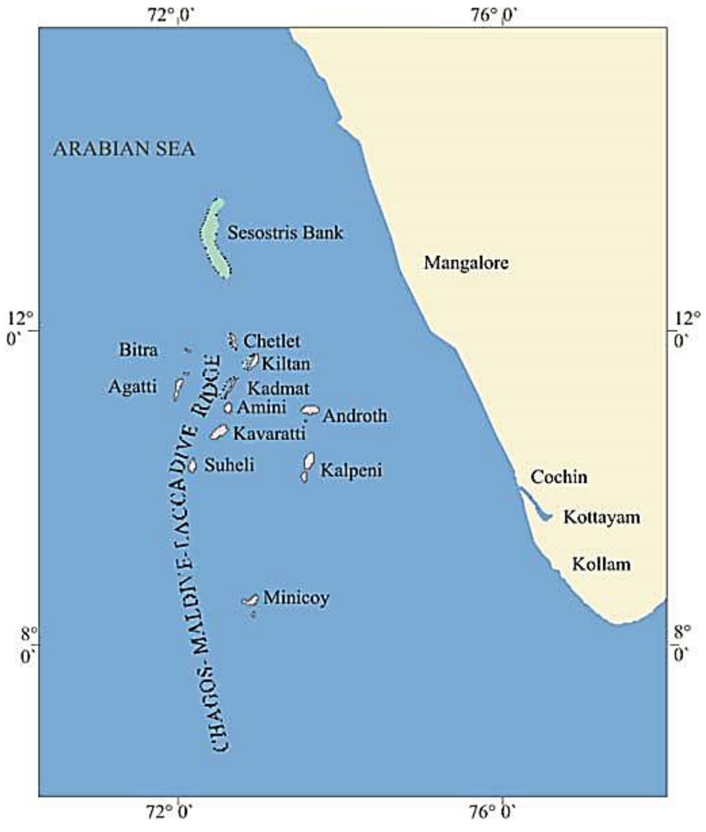

Figure 2. Map showing different islands of Lakshadweep archipelago (Source: Anon, 2008).

Sampling conducted in lagoon waters of Agatti (10°50'N 72°09'E), Bangaram (10°56'N 72°17'E), Kavaratti (10°33'N 72°37'E), Kalpeni (10°06'N 73°38'E) and Minicoy (8°17'N 73°02'E) islands of Lakshadweep archipelago from spring intermonsoon 2013 to spring intermonsoon 2016. Samples collected by using mechanised fishing boats (Fig. 3), the traditional country crafts a fitted with outboard motors (OBM) are also widely used for fishing in Lakshadweep. Zooplankton samples were collected inside the lagoon waters by using Simple plankton net (mesh size: 200 µm; mouth area: 0.28 m2; Length 1.5 m) attached with a calibrated flowmeter (General Oceanics 2030-R). The subsurface water samples were collected using Niskin water sampler (General Oceanics-1.7L). Temperature, salinity was measured using probes (Eutech model number PCD 650). The number of stations in each lagoon and details of five islands selected for sampling is described as following.

Figure 3. Traditional country craft fitted with outboard motor used for sampling.

3.1.1. Agatti

Agatti is located at the western limit of the Lakshadweep archipelago with geographic coordinates of, 10° 50' N 72°09'E and is located west of Kavaratti Island (Fig. 4). The island lies on a north-south axis, to the north-west of the submarine Lakshadweep–Chagos Ridge. A 200-meter narrow channel separates the southern tip of the island from the small uninhabited islet of Kalpitti and 7 km to the southwest side of Bangaram, the nearest island. The land generally rises from 3-6 m in elevation above the mean sea level at most of the places on the island. Agatti is located at a distance of 363 km from Mangalore, 383 km from Calicut (Kozhikode) and 459 km from Kochi. The lagoon area is 24.84 km2. Sampling conducted inside the lagoon from three stations during winter monsoon 2015 and spring intermonsoon 2016.

3.1.2. Bangaram

Bangaram atoll is 8.1 km in length with a maximum width of 4.2 km (Fig. 5). Moreover, with a lagoon area of 36 km^2 and is located over 400 km off Kochi. It is situated about 7 km northeast of the island of Agatti and 25 km to the southeast of Perumal Par, in the western Lakshadweep archipelago at 10°56′N 72°17′E. Bangaram atoll connected to the reef of Agatti through a shallow submarine ridge. Sampling was conducted inside the atoll from three stations during winter monsoon 2015.

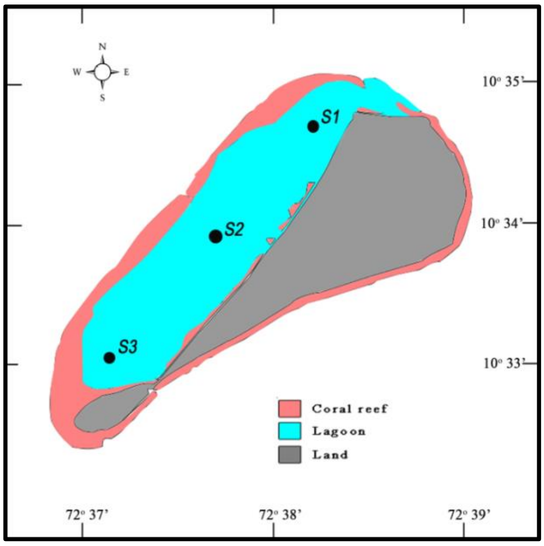

Figure 6. Sampling stations in Kavaratti atoll

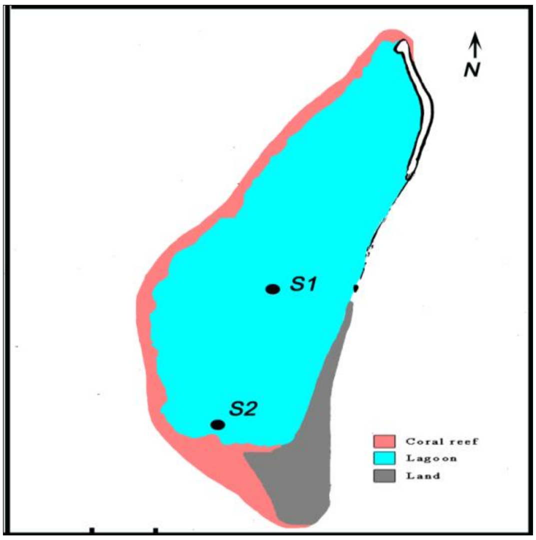

Figure 7. Sampling stations in Kalpeni atoll

Figure 4. Sampling stations in Agatti lagoon

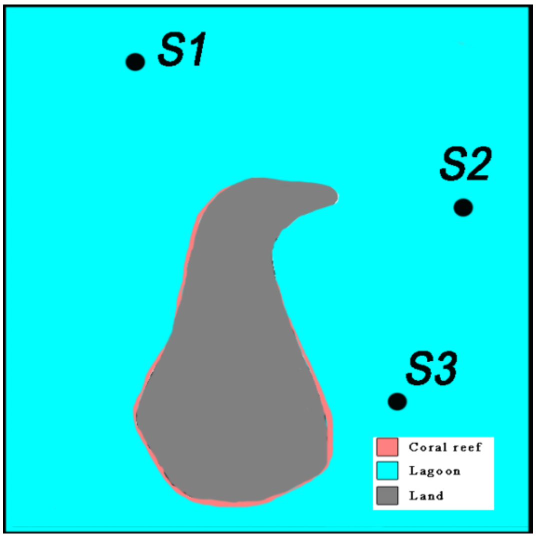

Figure 5. Sampling stations in Bangaram atoll

3.1.3. *Kavaratti*

Kavaratti island is the capital of the Union Territory of Lakshadweep. The island of Kavaratti lies 404 km off the Kochi at 10.57°N 72.64°E (Fig.6). The closest island is uninhabited Pitti islet, located 24 km north of Kavaratti. The inhabited island of Agatti lies 54 km to the NW and Suheli Par 53 km to the SW. It has a lagoon area of 8.96 km2. Sampling was conducted inside the Kavaratti atoll from three stations during spring intermonsoon 2013 &2016, fall intermonsoon 2013 and winter monsoon 2014 & 2015.

3.1.4. Kalpeni

Kalpeni island is situated 218 kilometres west from the port of Kochi at 10.076°N 73.646°E (Fig.7) and lies 71 kilometres south of Andrott and 201 kilometres to the NNE Minicoy, with the broad Nine Degree Channel between them. Suheli Par situated 139 kilometres to the west of Kalpeni. Kalpeni forms a single coral atoll along with the uninhabited islands of Cheriyam, Tilakkam, Kodithala and Pitti islet. Coral debris accumulated in the eastern and southern shorelines of the island due to the massive storm that hit the area in 1847. It has a lagoon area of 25.6 km^2. Sampling was conducted inside the lagoon waters from two stations during fall intermonsoon 2013 and winter monsoon 2014.

3.1.5. Minicoy

Minicoy, locally known as Maliku is an island in Lakshadweep, India (Fig.8). Along with Viringili, it is on *Maliku atoll*, the southernmost atoll of Lakshadweep archipelago. It is the second largest island and the southernmost among the islands of the Lakshadweep. The island located 201 km to the SSW of Kalpeni island, at the southern end of the Nine Degree Channel and 125 km to the north of Thuraakunu, Maldives. The atoll has 10 km length and breadth of about 6 km. The closest geographic feature is the Investigator Bank, a submerged shoal located 31 km to the northeast. The Minicoy lagoon with two entrances on its northern side. Its western side with a narrow reef and coral rocks. The lagoon interior area is sandy and of moderate depth and has some coral patches. Sampling conducted inside the Minicoy lagoon from two stations during fall intermonsoon 2013 and winter monsoon and summer monsoon 2014.

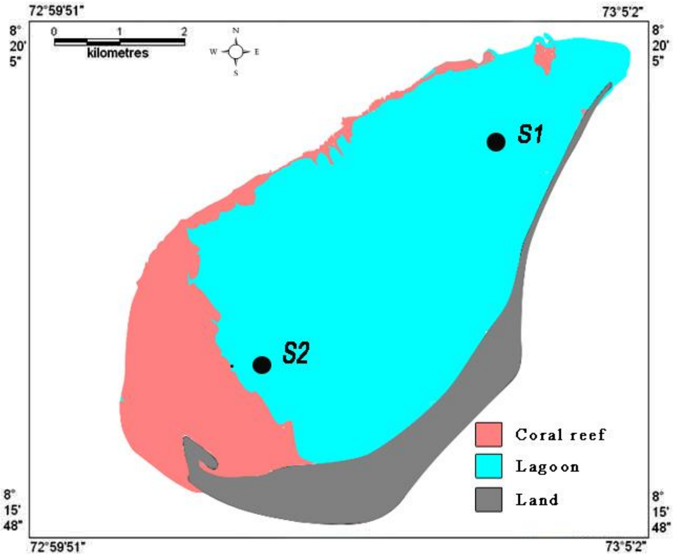

Figure 8. Sampling stations in Minicoy Island.

Table1. Details of sampling locations and seasons in 5 islands of Lakshadweep archipelago.

Stations	Location	Sampling dates & Seasons
Agatti	10^{0}50’42.75” N 72^{0}09’47.93”E	10th March 2015(Winter monsoon) & 20th March 2016 (Spring inter-monsoon)
Bangaram	10^{0}56’27.38” N 72^{0}17’29.02”E	9th March 2015 (Winter monsoon)
Kavaratti	10.55’93° N, 72.63’58° E	24th April 2013 (Spring inter-monsoon) & 13th October 2013 (Fall inter-monsoon) 30th January 2014 (Winter monsoon), 9th March 2015 (Winter monsoon) & 22nd March 2016 (Spring inter-monsoon)
Kalpeni	10^{0}06’29.14” N 73^{0}38’31.66”E	8th October 2013(Fall inter-monsoon), 31st January 2014 (Winter monsoon)
Minicoy	8^{0}17’59.98” N 73^{0}02’31.16”E	9th October 2013(Fall inter-monsoon), 24th January 2014 (Winter monsoon) & 26th July 2014 (Summer monsoon)

3.1.6. Study locations in Oceanic waters of Minicoy Island

This study based on 18 surface (Fig.9) zooplankton samples from leeward and windward sides of Minicoy Island during cruise 338 of Fishery and Oceanic Research Vessel *Sagar sampada*, 13 to 18 April 2014. Stations 3 to 20 in the leeward side and 21 to 38 in the windward side.

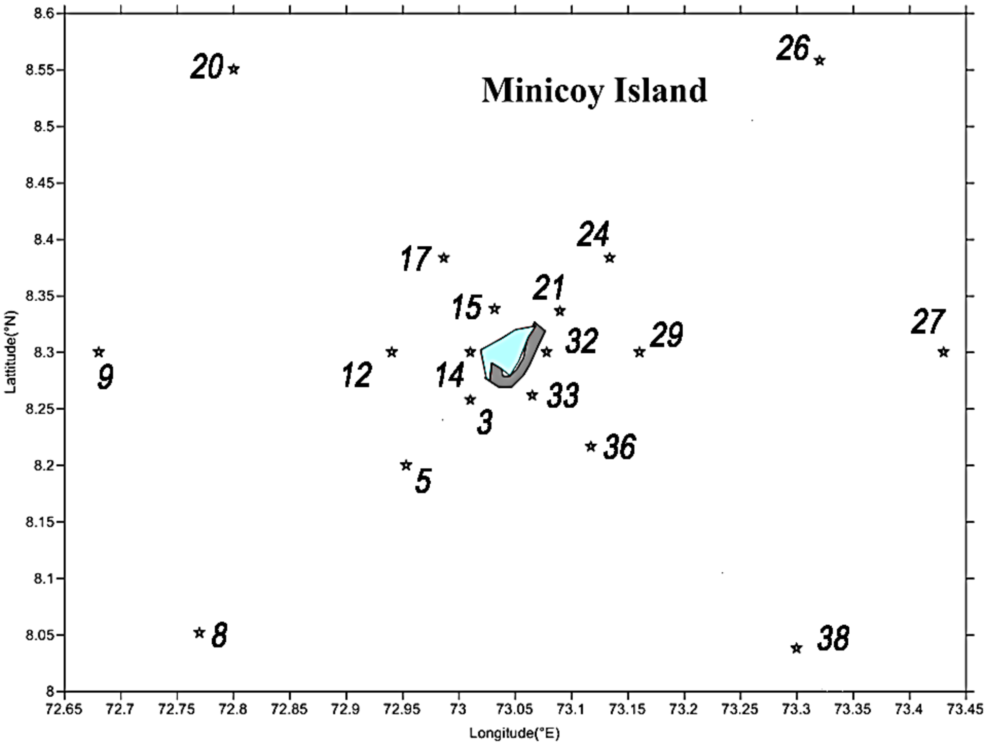

Figure 9. Sampling stations around leeward and windward side of Minicoy Island during spring intermonsoon 2015.

Table 2. Details of sampling stations and sampling time around the leeward and windward side of Minicoy Island during spring intermonsoon 2015 in cruise 338.

Cruise & St. No	Date	Time	Latitude	Longitude
338 03	13.04.15	8:15 AM	8.494	73.149
338 05	13.04.15	11:10AM	8.457	73.244
338 08	13.04.15	7:30PM	8.061	73.302
338 09	14.04.15	6:30AM	8.074	72.928
338 12	14.04.15	1:45PM	8.355	73.101
338 14	14.04.15	5:30PM	8.399	73.128
338 15	15.04.15	7:45AM	8.558	73.185
338 17	15.04.15	10:40AM	8.324	73.103
338 20	15.04.15	5:10PM	8.349	72.855
338 21	16.04.15	7:00AM	8.808	72.820
338 24	16.04.15	12:50PM	8.481	73.238
338 26	16.04.15	3:45PM	8.514	73.128
338 27	17.04.15	7:15AM	8.348	73.18
338 29	17.04.15	10:45AM	8.546	73.17
338 32	17.04.15	4:45PM	8.604	73.578
338 33	18.04.15	7:30AM	8.444	73.509
338 36	18.04.15	10:40AM	8.301	73.245
338 38	18.04.15	4:00PM	8.3	73.01

3.1.7. Study locations in coastal waters of South-West coast of India.

This study based on surface zooplankton samples collected from coastal waters of South-West coast of India. During cruise 338 of FORV *Sagar Sampada*, (11th to 27th April 2015) samples collected from off Trivandrum to Ratnagiri and during cruise 345, (30th October 2015 to 11th November 2015) samples collected from off Trivandrum to Goa (Table 3).

Table 3. Details of sampling stations and sampling time along coastal waters of the south-west coast of India during spring intermonsoon and fall intermonsoon 2015

Cruise & St. No	Date	Time	Latitude	Longitude
338 02	11.04.15	7:10 PM	8.451	76.021
338 39	20.04.15	9:20AM	11.00	75.11
338 45	22.04.15	9:55AM	12.24	74.32
338 47	23.04.15	10:10AM	13.20	73.61
338 48	24.04.15	7:15AM	14.09	73.46
338 51	25.04.15	7:15AM	15.03	73.61
338 52	26.04.15	1:45PM	16.16	73.46
338 53	27.04.15	12:00AM	17.09	73.03
345 01	30.10.15	04:15 PM	8.70	76.61
345 07	02.11.15	07:55 AM	9.74	75.82
345 09	03.11.15	08:25 AM	10.58	75.50
345 15	06.11.15	11:00 AM	12.21	74.39
345 18	08.11.15	10.30 AM	13.25	73.92
345 22	10.11.15	07:00AM	14.98	73.08
345 23	11.11.15	08:30 AM	15.62	72.88

3.2 HYDROGRAPHIC PARAMETERS

3.2.1 Physical parameters

From lagoon waters of Lakshadweep, water samples were collected from the surface region by using 1.7 litres Niskin sampler (Fig. 10). Surface water samples were collected and stored in 500 ml sterile plastic bottles. The **water temperature** was measured in situ, using a 0-50°precision thermometer. **Salinity** was measured by Mohr-Knudsen method (Strickland and Parsons, 1972). The halides present in the water samples were treated with standard silver nitrate solution and potassium chromate as an indicator. The values were recorded as practical salinity units (psu). **Dissolve oxygen** was estimated by the modified Winkler method (APHA,2005). This method depends on the oxidation of manganese dioxide by the oxygen dissolved in the samples, resulting in the formation of a tetravalent compound, which on acidification liberates iodine equivalent to the dissolved oxygen present in the sample. The quantity of iodine released was determined by titration with sodium thiosulphate. The results are expressed in the unit, milligrams per litre (mgL^{-1}).

Figure 10. General Oceanics Niskin water Sampler 1.7 L Model No: 1010.

In *FORV Sagar Sampada* (Fig. 11) sampling conducted in coastal waters of Southwest coast of India, the temperature and salinity were obtained using Conductivity- Temperature- Depth profiler (CTD, Sea-Bird Electronics Model 911 series, Sea-Bird Inc.) attached with sensors for understanding oceanic processes (Fig. 12). The values at 5m depth in the vertical profiling of the CTD were considered for the determination of Sea Surface Temperature (SST), Sea Surface Salinity (SSS) and Density (Sigma t). This depth is chosen to eliminate any possible bias in the profile data due to 'skin effects' at the ocean surface (Fairall et al., 1996). Dissolved oxygen (DO) was analyzed by the modified Winkler method (APHA, 2005).

Figure 11. Fisheries and Oceanic Research Vessel *Sagar Sampada.*

Figure 12. Operation of CTD, Sea-Bird Electronics Model 911 series onboard *FORV Sagar Sampada.*

3.3 BIOLOGICAL VARIABLES

3.3.1 Chlorophyll-a

Chlorophyll-a is taken as the index of phytoplankton biomass during the present study. The acetone extraction method was used for the chlorophyll estimation (Parsons et al., 1984). One litre of water samples free of zooplankton was filtered through Whatman GF/F filter paper of porosity 0.7µm. , The filter paper with filtrate was placed in a stoppered test tube containing 10 ml of 90% aqueous acetone for the extraction of pigments. The filtrate gently grounded with a homogeniser and stoppered the test tube. This operation must be conducted in a semi-darkened area. The test tube with the solution was subsequently transferred to a dark coloured cloth bag, and placed in a refrigerator for 24 hours. The extract was then transferred to a graduated centrifuge tube. The volume made up to 10ml with 90% acetone and centrifuged for 20 minutes at 5000 rpm, and the supernatant solution used for determination of optical density using Perkin Elmer (Lambda 25) UV/VIS Spectrophotometer. For the determination of optical densities at different wavelengths, viz. 750, 664, 647 and 630 nm, the maximum absorption wavelength of the pigments. All the extinction values were corrected for a small turbidity blank by subtracting the optical density of 750nm from the 665, 645 and 630nm absorptions. The following equation used to calculate the chlorophyll-a concentration (Strickland and Parsons, 1972; APHA, 2005).

Chlorophyll a (C) = $11.85\ E665 - 1.54\ E645 - 0.08\ E630$

Where ‘E’ is the absorbance at different wavelengths in the respective wavelengths.

$$\textbf{Chlorophyll a mg/ litre} = \frac{C \times v}{V \times 1}$$

Where ‘v’ is the volume of acetone (ml),

‘V’ is the volume of water (litre) filtered and

‘I’ is the path length (cm) of the cuvette.

3.3.2 Mesozooplankton Sampling and Analysis

Zooplankton samples were collected inside the lagoon waters by a simple plankton net (mesh size: 200 µm; mouth area: 0.3 m^2; Length 1.5 m) attached to a calibrated flow meter (General Oceanics 2030R with a standard rotor) (Fig.13 and 14). Where onboard FORV *Sagar Sampada*, zooplankton was collected by using Bongo Net (mesh size: 200 µm; mouth area: 0.28 m^2; Length 2.5m) (Fig. 15) attached with a calibrated flow meter.

Biomass estimation of the mesozooplankton was done following the biovolume method. The term biomass indicates the amount of living matter present in the mesozooplankton sample. It is of critical importance in evaluating secondary production in the system. For this estimation, at first, the zooplankton sample collected was sieved using a 200 µm mesh net. Absorbent paper removed the excess water, and the displacement volume (DV) was measured (Harris et al., 2000). The biomass per unit area was obtained from the DV by using the following calculation,

Biomass = DV / VWF
VWF = DH × A
Where, DV = Displacement volume
VWF = Volume of water filtered
DH = Depth of haul
A = Mouth area of the net

The biomass is expressed in ml / m^3.

Figure 13. Operation of simple plankton net in lagoon waters of Lakshadweep during 2013-2015.

Figure 14. Flowmeter used for the study (General Oceanics 2030R with a standard rotor).

Figure 15. Operation of Bongo net onboard *FORV Sagar Sampada* during April 2015

Figure 16. Folsom plankton splitter.

After the estimation of the biomass, the zooplankton samples were immediately preserved in 4% buffered formalin (Steedman, 1976; Harris et al., 2000) and then stored in wide-mouthed plastic containers for further detailed analysis on the abundance and species wise composition. The mesozooplankton taxa were sorted from the whole sample or an aliquot (50%) using a Folsom plankton splitter (Sell and Evans, 1982) (Fig. 16) and counted under a stereomicroscope.

The zooplankton was primarily sorted to the major taxonomic groups according to the standard identification manuals (Newell and Newell, 1973; Todd and Laverack, 1991). The abundance is expressed as individuals / m^3 by using the formula,

$$\text{Abundance (ind. /m}^3\text{)} = \frac{\text{No. of individuals of the particular taxa}}{\text{The volume of water filtered}}$$

3.4. TAXONOMY OF CALANOID COPEPODS

The formalin fixed samples were sorted, counted, and identified to the group level. Calanoid specimens were sorted from the original samples and immersed in a 50:50 solution of glycerine and distilled water. Oral parts and swimming legs were dissected from glycerine-mounted specimens; line drawings were made using a drawing tube attached to the bright-field compound microscope (Lynx LM). The sorted samples were identified to species level using published literature (Mori, 1964; Bradford and Jillett, 1980; Mauchline, 1998; Conway et al., 2003; Prusova et al., 2012). The descriptions are based on adult morphology, and all specimens described based on adults. The terminology used for the description of calanoids follows that of Huys and Boxshall, (1991).

Abbreviations used in the description, figures and keys:

A1:	antennule
A2:	antenna
Ans:	anal somite
Ce:	cephalosome
CR:	caudal rami
Enp:	endopod; Enp1-3- endopod segments 1-3
Exp:	exopod; Exp1-3 – exopod segments 1-3
Gns:	genital somite

Md:	mandible
Mdp:	mandibular palp
Mx1:	maxillule
Mx2:	maxilla
Mxp:	maxillipede
P1-5:	swimming legs 1-5
Pd1-5:	pedigerous somites 1-5
Pr:	prosome
R:	rostrum
TL:	total length – length from the top of a head to the end of CR, excluding caudal setae
Ur:	urosome, Ur1-5 – urosomites 1-5, the last somite being the anal somite

3.4.1. External morphology of calanoid copepod

The classification of copepods is mainly based on body divisions into functional regions and segmentation and armature of the various limbs. The major body articulation subdivides the body into an anterior part- the **prosome** (Pr) and the posterior part of the **urosome** (Ur). The anterior region of the prosome covered by the dorsal cephalic shield is the **cephalosome** (Ce) which comprises the five cephalic somites bearing the **antennules** (A1), **antennae** (A2), **mandibles** (Md), **maxillules** (Mx1) and **maxillae** (Mx2), respectively, and the first thoracic somite is also fused to the cephalosome, forming a **cephalothorax**. This somite nears the first pair of swimming legs- pereiopods (P1) and is also called the first pedigerous somite (pd1); each of five pedigerous somites bears a pair of swimming legs (P1-P5). The urosome in calanoids includes the anterior somite corresponding to the seventh thoracic somite (genital somite). In females of calanoida, it is usually fused with the first abdominal somite, forming a genital double-somite; in the males, all the urosomites are separated. The abdomen is the limbless post- genital region of the body. The last somite of urosome is the anal somite (in which the median anus opens either terminally or dorsally) bearing a pair of caudal rami (CR). The swimming legs usually have two basal segments: coxa and basis. Two rami are articulated to the basis: an outer **exopod** (Exp) and inner **endopod** (Enp). Spines and setae border the exopods. The fifth legs are sexually dimorphic. Sometimes the female fifth legs are absent, but when present, can be biramous or uniramous; they are always present in the male, and can be of a simple uniramous form or a large, complex and highly asymmetrical (Fig. 17).

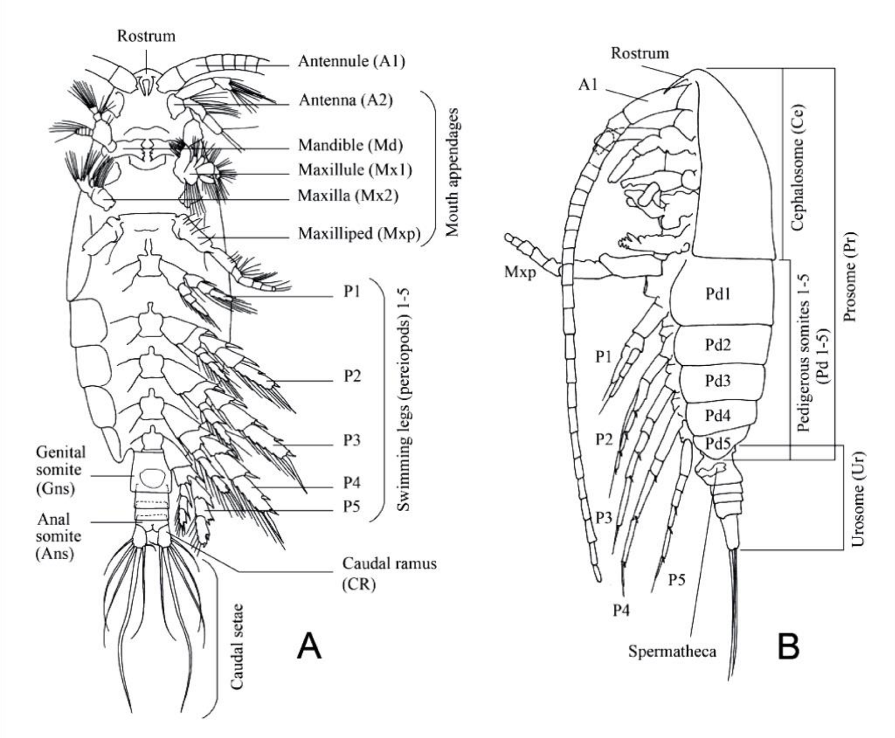

Figure 17. External morphology of calanoid copepods: diagram of an adult female. A-ventral view; B- lateral view, Source: Prusova et al. 2012.

3.5. MOLECULAR ANALYSIS

3.5.1. Preservation of sample

Collected samples screened through 500 µm mesh to remove the fish and prawn larvae. Sample rinsed with GFC filtered seawater to reduce the contamination and preserved in 95% ethanol to facilitate DNA isolation. The preservative was changed within 24 hours to maintain the preservative as clear. (Bucklin 2000; Sanu et al. 2016).

3.5.2. DNA Extraction

Alcohol-preserved copepods were rehydrated in 500 µl sterile distilled water for 10–12 h at room temperature (Bucklin et al. 1995, 1996a, b) before extraction of DNA. Genomic DNA was extracted from individual copepods using the DNeasy Blood & Tissue Kit (Qiagen) following the spin column protocol for purification of total DNA from animal tissues. Copepod individuals cut into two half's and place in a 1.5ml microcentrifuge tube and 180 µl ATL buffer, 20 µl proteinase K is added into this tube. The microcentrifuge tube vortex occasionally, and incubate at 56°C for 2hrs. After the incubation, add 200 µl of AL Buffer and 200 µl 100% ethanol (96–100%) to the sample. The mixer vortex again. After the vortex, place the mixture in a DNeasy Mini spin column with 2 ml collection tube (provided). Centrifuge the column at 6000 x g (8000 rpm) for 1 min. Flow-through and discard the collection tube. Place DNeasy Mini spin column in new 2 ml collection tube and add 500 µl, AW1 Buffer. Centrifuge the column at 8000 rpm. Flow- through and discard collection tube.

Place the DNeasy Mini spin column in new 2 ml collection tube and add 500 µl AW2 Buffer, centrifuge the column at 20,000 x g (14,000 rpm) for 3 min. Flow- through and discard the collection tube. To allow the excess flow through to the collection tube, once again place the DNeasy Mini spin column in old collection tube (step 5) and centrifuge the column at 14,000 rpm for 1 min. Flow-through and collection tube and discarded out after that allow DNeasy membrane to dry one minute at room temperature. After dry the membrane, place the column in a clean 2 ml microcentrifuge tube; add 200 µl Buffer AE directly into the DNeasy membrane. The DNeasy membrane again incubates at room temperature for 1 min, and then centrifuge at 6000 x g (8000 rpm) for 1 min. The flow-through contains the DNA. Collect DNA and store at 4°C until further analysis.

3.5.3. PCR- Amplification

i. PCR reaction mix

The PCR kit used was the Takara Clontech EmeraldAmp® GT PCR Master Mix (Takara Bio, Otsu, Shiga Prefecture, Japan).

The reaction mixture consisted of

Autoclaved de ionized water	**7.5 µl**
Master Mix	**12.5 µl**
Forward Primer 1 µM/µl	**0.5 µl**
Reverse Primer 1 µM/µl	**0.5 µl**
DNA template	**4.0 µl**
Volume for one reaction	**25 µl**

ii. Primers

The primer pair LCO-1490 (5′-GGTCAACAAATCATAAAGATATTGG-3′) and HCO-2198 (5′-TAAACTTCAGGGTGACCAAAAAATCA-3′) was used for amplifying mtCOI gene sequences from the selected samples (Folmer et al., 1994).

iii. PCR Program

STEPS	ACTION	TIME
Initial denaturation	94°C	5 min
Denaturation	94°C	1 min
Annealing	37°C	2 min
Extension	72°C	3 min
Go to	Step 2	40 times
Final extension	72°C	10min
Hold	4 °C	

iv. Agarose gel electrophoresis

Agarose gel electrophoresis viewed amplified PCR products. Dissolve 1 gram of agarose in 100 ml of 1X Tris-acetate ethylenediamine tetraacetic acid (TAE) buffer. Place Agarose mixture in the microwave oven in 1 min, 1 min and 30-sec interval with constant shaking. Swirl the mixture make sure that agarose has melted without any formation of lumps or particles. Allow to cool for several minutes and add one drop (2 ul) of Ethidium bromide (4 mg/ml on to it. Pour Agarose solution into a sealed gel tray without air bubbles. After the gel completely hardens, remove the comb carefully and immerse the gel in 1X TAE running buffer. Load PCR amplified products (1:1 ratio with gel loading dye) into wells, with 100 bp DNA in first well. Connect electrical leads to the electrophoresis chamber and run with a current of 90V for 30 min. Remove the gel carefully and view with Gel documentation system with UV Filter. Amplified products exhibiting intense bands after agarose gel (1.2 %) electrophoresis were purified using the NucleoSpin® Gel and PCR Clean-up (MACHEREY-NAGELGmbH & Co. KG, Düren, Germany). Purified products were sent to SciGenom Labs (SciGenom Labs Pvt. Ltd., Kerala, India) for sequencing.

3.6. Statistical analysis

The statistical software PRIMER V.6 used for univariate and multivariate statistical analysis and plotting of data. The Pearson correlation coefficient was found in both the cases using SPSS (7.5) software. GRAPHER 8, SURFER 11 and ORIGIN 7 were used for suitable graphical representations

3.6.1. Univariate analysis

The univariate analysis uses diversity indices, which attempt to combine the data on abundance within a species in a community into a single number. The state of the community can be understood by this number.

Species richness – Margalef's index (Margalef, 1968)

Margalef's species richness is a measure of the number of species present, making some allowance for the number of individuals belonging to each species. It was calculated according to the formula,

$$\mathbf{d = (S\text{-}1)/ \log_{e} N}$$

where

d = species richness
S = total number of species
N = total number of individuals

Species evenness – Pielou's index (Pielou,1966)

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

$$\mathbf{J' = H'/\log_{2} S \text{ or } H'/\ln_{2} S}$$

where

J' = evenness
H' = species divesrsity
S = total number of species

Species diversity – Shannon index (Shannon and Weaver, 1963)

For measuring the variation in zooplankton species diversity of the region, diversity index (H') was calculated using the Shannon- Wiener's formula (1949)

$$\mathbf{H' = \frac{3.3219\ (N \log N - \Sigma ni - \log \mathit{ni}}{N}}$$

where

H' = the species diversity in bits of information per individual

ni = number of individuals of the ith species

N = total number of individuals in the collection

Σ = summation

Species dominance – Simpson's index (Simpson, 1949)

Simpson index assigns to the measure of dominance in a community

$$\mathbf{D = 1/\lambda}$$

where

$\lambda = \Sigma Pi2$

Pi = ni/N

Ni = number of individuals of i, i_2 etc.

N = total number of individuals.

Species-Abundance distributions

The k-dominance plot

k-dominance plot shows the cumulative percentage (the percentage of the k-th most dominant plus all more dominant species) about species (k) rank or log species (k) rank. The cumulative curve is used for comparing biodiversity. When k-dominance curve is used for analysing the biodiversity between many habitats, it is called as multiple k-dominance curves.

3.6.2. Multivariate methods

Multivariate methods of classification and ordination were used to compare communities by the identity of the component species as well as their relative importance regarding abundance or biomass. Classification analyses assign entities to groups, whereas ordinations place them spatially so that similar entities are close and dissimilar ones are distant.

Non-metric multidimensional scaling (MDS): In MDS plots the Bray-Curtis similarity was used to construct a map in which those having more similarity were placed near and samples having lower similarity far away. The goodness of fit of the MDS was found by calculating the stress value.

3.6.3. Molecular analysis

Sequences were compiled using BioEdit 7.0.9 (Hall 1999). BioEdit offers a diversity of simple sequence manipulation and analysis tools for both nucleic acids and proteins, and for both alignments and single sequences. BioEdit reads and writes several formats, retains GenBank field data, and offers its binary file format for fast read and writes of extensive files.

The sequence alignment was performed using ClustalX (Thompson et al. 1997). ClustalX is a new windows interface for the widely-used progressive multiple sequence alignment program CLUSTAL W and providing an integrated system for performing multiple sequences and profile alignments and analysing the results.

Phylogenetic analysis using a maximum likelihood tree (ML) and intraspecific pairwise sequence distance within the species was calculated using the Kimura 2- parameter model in Molecular Evolutionary Genetics Analysis version 5 (MEGA5) (Tamura et al., 2011). The newest addition in MEGA5 is a collection of maximum likelihood (ML) analyses for inferring evolutionary trees, selecting best-fit substitution models (nucleotide or amino acid), inferring ancestral states and sequences (along with probabilities), and estimating evolutionary rates site-by-site.

* * *

Chapter - 4

HYDROGRAPHY OF LAGOON AND COASTAL WATERS

4.1. INTRODUCTION

Each hydrographic parameter has its role in an ecosystem. The knowledge about these parameters was important in understanding the dynamics of the ecosystem. The interaction of an organism with its surrounding environment determines the size of its population and distribution. In the coastal ecosystem, such as coral reefs, seagrasses and salt marshes are controlled by climate, tidal activities and freshwater influx etc. High biotic diversity is the characteristic feature of coral reef lagoon and surrounding open ocean zones. Since the surface-depth ratio of the lagoon is larger than that of the open sea, both are subjected to extreme variations in properties. The hydrographical conditions in the reef and lagoons are further determined by the factors such as regional precipitation and the radiation resulting in surface heating and cooling (Andrews and Picard, 1990). The chemical composition of seawater is affected by a wide variety of chemical transport mechanisms. The factors considered are sea surface temperature (SST), sea surface salinity (SSS), dissolved oxygen (DO) and chlorophyll a. Salinity has an essential role in the distribution of physical and chemical parameters. Salinity increases conductivity whereas it reduces the dissolving rate of oxygen. Salinity variation affects the structural and functional responses of an aquatic organism and also influences the species composition and abundance of an ecosystem. Salinity and salinity-temperature interactions of zooplankton control their distributions in coastal and estuarine situations. Temperature, Salinity and Temperature/Salinity distributions characterise the geographical distributions of many species.

Copepods are more tolerant of changes in salinity when fed than when starved, inferring that they require energy to cope with the stressful circumstances, the energy that may be required for the osmoregulatory processes. Lower temperature results in higher survival rates over a broader range of salinity changes than higher temperatures. The thermal tolerance of copepods usually demonstrates that individual species are fit to live in the environment that they inhabit. Oceanic species are less thermal tolerant than that of species living in the coastal environment especially estuaries.

Oxygen dissolved in water plays a significant physical as well as a biochemical role in the life of aquatic organisms. The distribution of the dissolved oxygen in the marine environment is controlled by the exchange with the atmosphere and the biological processes of photosynthesis and respiration. Oxygen from the atmosphere dissolves in seawater at the surface. The amount that can be dissolved is dependent upon the temperature and salinity. Zooplankton especially the copepods usually live in well-oxygenated environments. A few marine species appear adapted to low oxygen minimum layers. As hard-bodied animals, calanoid copepods like other crustaceans have little or no ability to take up dissolved organic compounds and nutrients through their epidermis. Studies have shown that copepod species tend to aggregate at a depth of maximum chlorophyll-a in the water column and changes in the phytoplankton abundance and size affect fecundity of copepods (Herman, 1983; Peterson and Bellantoni, 1987). Depending upon the availability of phytoplankton, herbivorous copepods predominates in highly productive systems and very much less prominent in oligotrophic waters. In this chapter, the spatial and temporal variations of hydrographical parameters in lagoon waters of Lakshadweep islands and coastal waters of the south-west coast of India are discussed.

4.2. RESULTS

The stations selected along the coastal waters based on depth and it ranges from 50 to 100 meters (Fig.1). The lagoon stations were shallow, and it varies from 3 to 10 meters inside the lagoon.

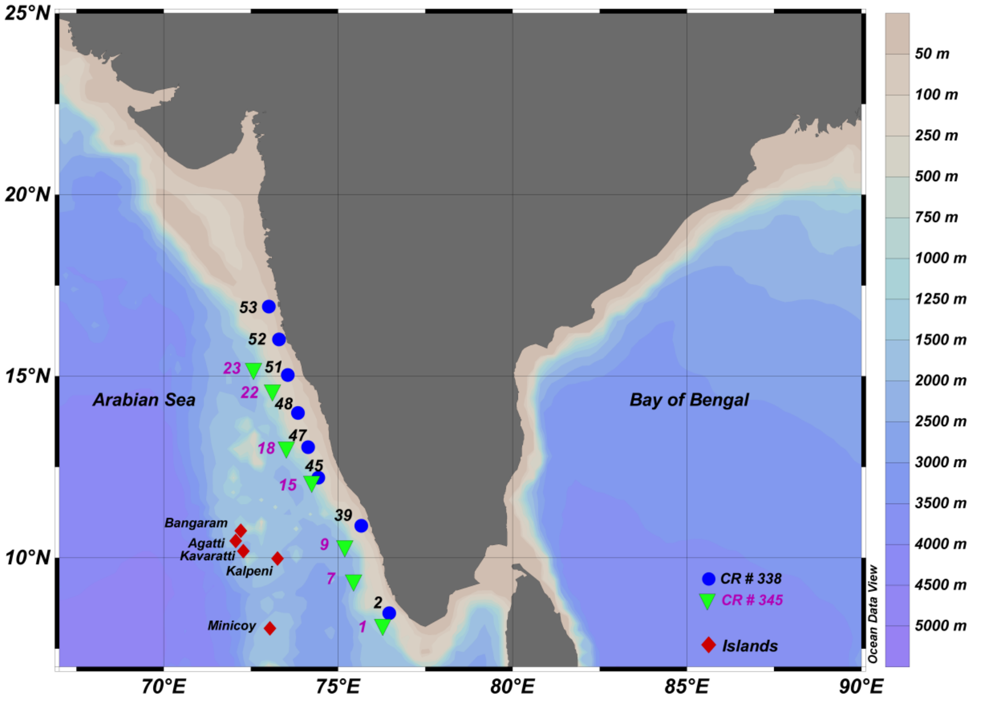

Figure 1. Bathymetry of all stations along coastal waters of the south-west coast of India.

4.2.1. Hydrography of Lagoon waters

I. Agatti

The surface temperature varied from 29ºC during winter monsoon 2015 to 30ºC during spring intermonsoon 2016. Salinity ranges from 34 to 35 psu respectively (Table 1). Chlorophyll a ranges from 0.25 to 0.47 mg/m^3 during winter monsoon 2015 (Avg: 0.36±0.12) and 0.22 to 0.42mg/m^3 during spring intermonsoon 2016 (Average: 0.33±0.1). In both, the periods of sampling, station 2 (S2) showed the highest chlorophyll value (0.47 and 0.42 mg/m^3). Dissolved oxygen ranges from 3.35 to 3.54ml/L during winter monsoon 2015 (Average: 3.22±0.1) and 3.22 to 3.41 ml/L during spring intermonsoon(Av: 0.33±0.1) (Table 1).

Table 1. Hydrographic parameters recorded in Agatti atoll.

Parameters	WM-15				SIM-16			
	S1	S2	S3	Average	S1	S2	S3	Average
Salinity (psu)	34	34	34	34	35	35	35	35
Water temperature (^{0}C)	29	29	29	29	30	30	30	30
DO (ml/L)	3.35	3.54	3.45	3.22±0.1	3.22	3.34	3.41	3.32±0.1
Chlorophyll -a (mg/m^3)	0.28	0.47	0.25	0.36±0.12	0.36	0.42	0.22	0.33±0.1

II. Bangaram

The sea surface temperature recorded during the sampling period was 28 °C and salinity was 34 psu. Dissolved oxygen ranges from 6.02 to 6.12ml/L (Avg: 6.07±0.05). The chlorophyll-a concentration ranged from 0.19 to 0.21mg/m^3 (Avg: 0.2±0.01) (Table 2).

Table 2. Hydrographic parameters recorded in Bangaram during winter monsoon 2015.

Parameters	WM-15			
	S1	**S2**	**S3**	**Average**
Salinity (psu)	34	34	34	34
Water temperature (^{0}C)	28	28	28	28
DO (ml/L)	6.12	6.02	6.07	6.07±0.05
Chlorophyll -a (mg/m^3)	0.21	0.19	0.19	0.2±0.01

III. Kalpeni

During fall intermonsoon 2013, the salinity observed was 35 psu and during winter monsoon 2014, it was 36psu. Dissolved oxygen and chlorophyll-a concentration were highest during fall intermonsoon 2013 in station 1 (6.11 ml/L and 0.68mg/m^3 respectively). During winter monsoon 2014, the average values of DO observed were 4.98±0.1ml/l, and chlorophyll-a concentration was 0.15mg/m^3 (Table3)

Table 3. Hydrographic parameters recorded in Kalpeni lagoon.

Parameters	FIM-13			WM-14		
	S1	**S2**	**Average**	**S1**	**S2**	**Average**
Salinity (psu)	35	35	35	36	36	36
Water temperature (^{0}C)	28	28	28	29	29	29
DO (ml/L)	6.11	6.05	6.08±0.04	5.05	4.9	4.98±0.1
Chlorophyll-a (mg/m^3)	0.68	0.67	0.67±0.1	0.15	0.15	0.15

IV. Kavaratti

The salinity observed during the study period ranges from 33psu (fall intermonsoon 2014) to 36 (winter monsoon 2015). The salinity observed was 34psu during spring intermonsoon 2013, and it was 35psu during winter monsoon 2015 and spring intermonsoon 2016 (Table 4 & 5). The sea surface temperature ranges from 28°C (SIM 2013, WM2016) to 30 °C (SIM 2016).

Table 4. Hydrographic parameters recorded in Kavaratti atoll from spring intermonsoon 2013 to winter monsoon 2014.

Parameters	SIM-13				FIM-13				WM-14			
	S1	**S2**	**S3**	**Avg.**	**S1**	**S2**	**S3**	**Avg.**	**S1**	**S2**	**S3**	**Avg.**
Salinity (psu)	34	34	34	34	33	33	33	33	36	36	36	36
Water temperature (⁰C)	28	28	28	28	27	27	27	27	29	29	29	29
DO (ml/L)	6.02	5.92	5.86	5.93±0.08	6.12	6.24	5.9	6.09±0.17	4.76	6.89	6.53	6.06±1.1
Chlorophyll-a (mg/m³)	0.51	0.52	0.49	0.51±0.02	0.46	0.46	0.45	0.46±0.01	0.53	0.52	0.55	0.53±0.02

Table 5. Hydrographic parameters recorded in Kavaratti atoll during winter monsoon 2015 and spring intermonsoon 2016.

Parameters	WM-15				SIM-16			
	S1	**S2**	**S3**	**Avg.**	**S1**	**S2**	**S3**	**Avg.**
Salinity (psu)	35	35	35	35	35	35	35	35
Water temperature (⁰C)	28	28	28	28	30	30	30	30
DO (ml/L)	4.73	4.9	5.2	4.94±0.2	4.55	4.78	4.39	4.57±0.2
Chlorophyll-a (mg/m³)	0.14	0.15	0.15	0.15±0.01	0.14	0.14	0.14	0.14±0

The lowest dissolved oxygen value observed in station 3 during spring intermonsoon 2014 (4.39ml/L) and highest observed in station 2 during winter monsoon 2014 (6.89ml/L). Chlorophyll-a concertation in the seawater ranged from 0.14 to 0.55mg/m^3. During winter monsoon 2015 and spring intermonsoon 2016, the chlorophyll-a concentration was lower compared to the other seasons (Table.5).

V. Minicoy

The surface salinity in lagoon waters of Minicoy ranges from 33 (fall intermonsoon 2013) to 35 psu (winter monsoon 2014). Temperature varies from 26°C during summer monsoon 2014 to 29°C during winter monsoon 2014. Lowest DO was observed in station one during winter monsoon 2014 (3.9ml/L), and the highest value was observed in the same station during summer monsoon 2014 (5.7ml/L). Chlorophyll-a concentration ranges from 0.18 (S2, Winter monsoon 2014) to 0.23 mg/m^3 (S1, Fall intermonsoon 2013) (Table 6).

Table 6. Hydrographic parameters recorded in Minicoy during fall intermonsoon 2013 to summer monsoon 2014.

Parameters	FIM-13			WM-14			SM-14		
	S1	**S2**	**Avg.**	**S1**	**S2**	**Avg.**	**S1**	**S2**	**Avg.**
Salinity (psu)	33	33	33	35	35	35	34	34	34
Water temperature (⁰C)	27	27	27	29	29	29	26	26	26
DO (Ml/L)	4.2	4.5	4.35	3.9	4.3	4.10	5.8	5.2	5.50
Chlorophyll-a (mg/m^3)	0.23	0.21	0.22	0.19	0.18	0.19	0.21	0.21	0.21

4.2.2. Hydrography of Oceanic and coastal waters.

I. Oceanic waters around Minicoy

The surface temperature around oceanic stations in the leeward and windward side of the Minicoy Island ranges from 30.18 to 30.92°C (Fig. 2). Surface salinity ranges from 33.16 to 34.92psu (Fig. 3) Dissolved oxygen value in the surface water ranges from 2.51 to 4.92ml/L (Fig. 4). The concertation of chlorophyll-a ranges from 0.25 to 0.29mg/m^3 (Fig. 5).

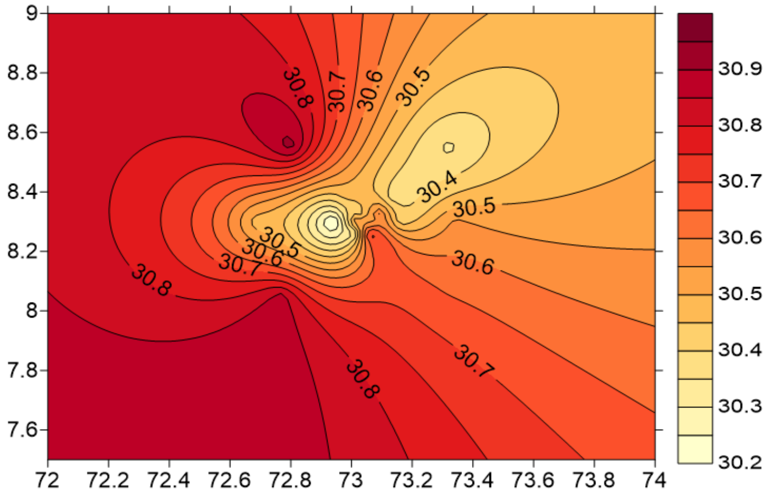

Figure 2. Sea surface temperature distribution along with leeward and windward stations of Minicoy Island during spring intermonsoon 2015.

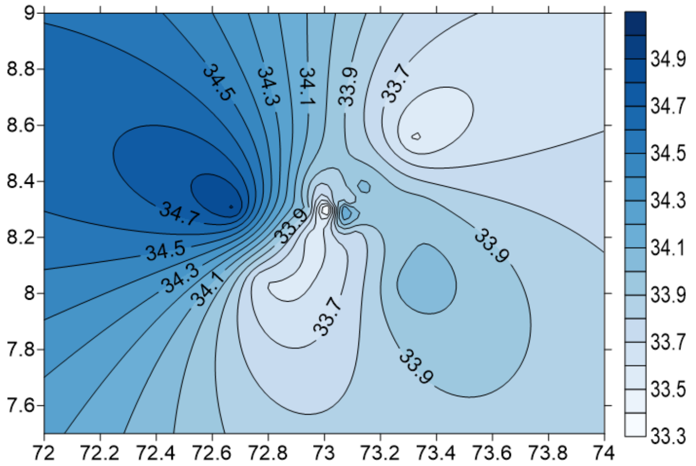

Figure 3. Sea surface salinity distribution along with leeward and windward stations of Minicoy Island during spring intermonsoon 2015.

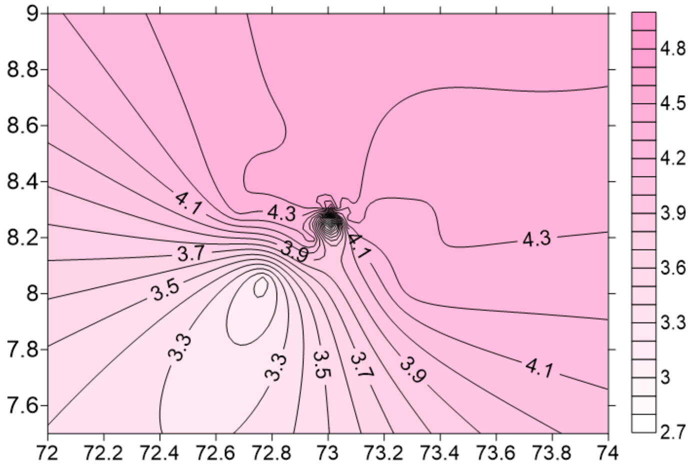

Figure 4. Dissolved oxygen in the surface waters along with leeward and windward stations of Minicoy Island during spring intermonsoon 2015.

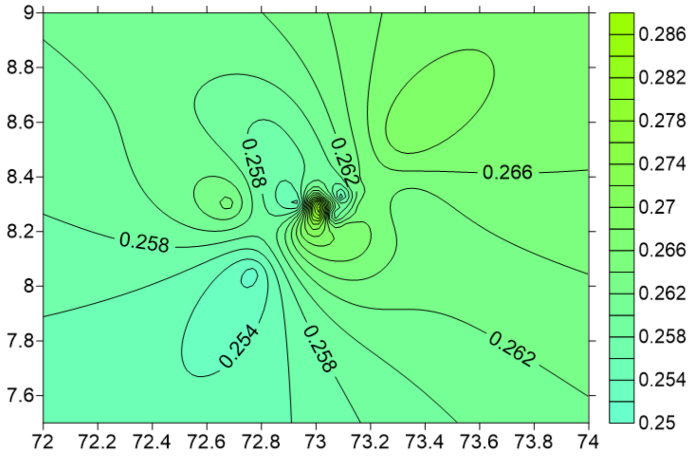

Figure 5. Chlorophyll-a concentration along with leeward and windward stations of Minicoy Island during spring intermonsoon 2015.

II. Coastal waters of the south-west coast of India during spring intermonsoon 2015.

The surface temperature varies from 30.22 to 31.09°C (Fig. 6-A). The lowest temperature was recorded in station 59 (Ratnagiri) and highest observed in station 2 (Trivandrum). The surface salinity ranged from 34.26 to 35.37psu (Fig. 6-B). The lowest salinity was recorded in Trivandrum (Station 2) and highest recorded in Ratnagiri (Station 53). The dissolved oxygen value in the surface waters ranges from 2.51 to 4.49ml/L (Fig. 7-A). The lowest chlorophyll-a concertation was recorded in Trivandrum (0.27mg/m^3) and highest observed in Goa (station 52, 1.38mg/m^3) and Karwar (0.87mg/m^3) (Fig. 7-B).

III. Coastal waters of the south-west coast of India during fall intermonsoon 2015.

Sea surface temperature during fall intermonsoon along south-west coast India ranges from 29.61 to 29.82°C. The lowest temperature was observed in off Trivandrum (Station1) and highest observed in Goa (station 22) (Figure 8-A) Salinity of surface waters ranges from 34.81 to 36.38 psu (Karwar) and 35.54psu were observed in the station 22 (Fig. 8-B). Dissolved oxygen ranges from 3.81 to 3.9ml/L (Fig.9-A). Chlorophyll-a concentration were lowest (0.17mg/m^3) observed in Trivandrum and highest (0.24mg/m^3) observed in station7 (Fig. 8-B).

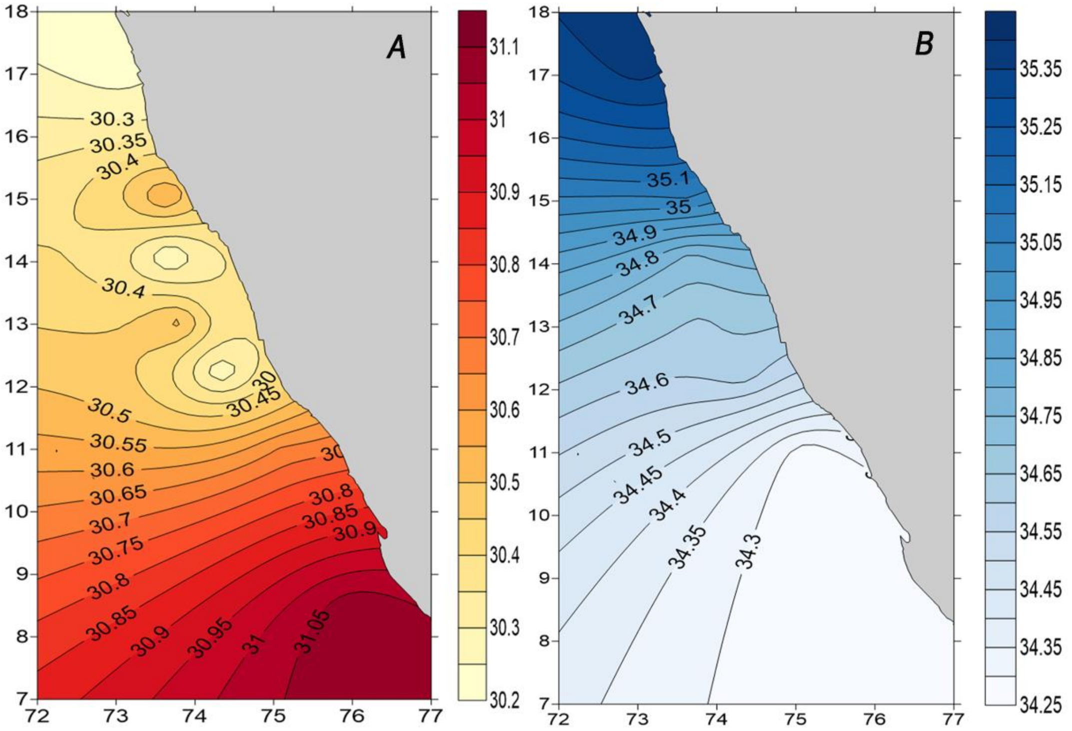

Figure 6. Sea surface temperature (A) and salinity (B) variations along coastal waters of the south-west coast of India during spring intermonsoon 2015.

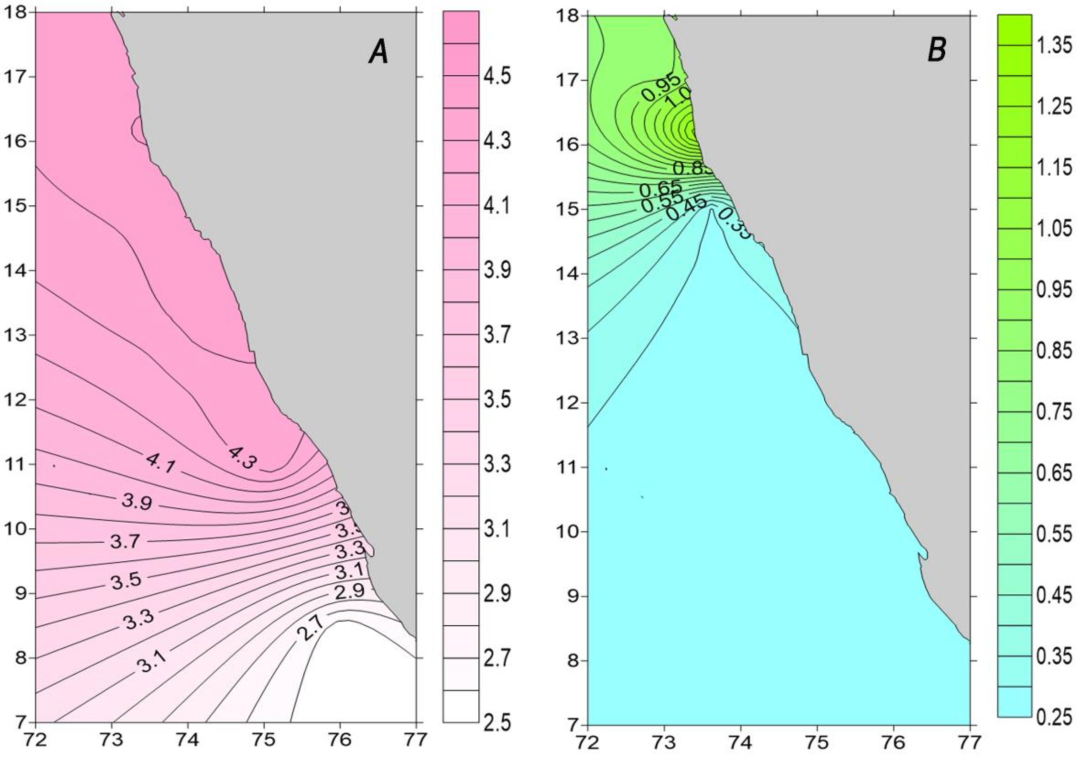

Figure 7. Dissolved oxygen (A) and concentration of chlorophyll-a (B) in the surface waters along coastal waters of the south-west coast of India during spring intermonsoon 2015.

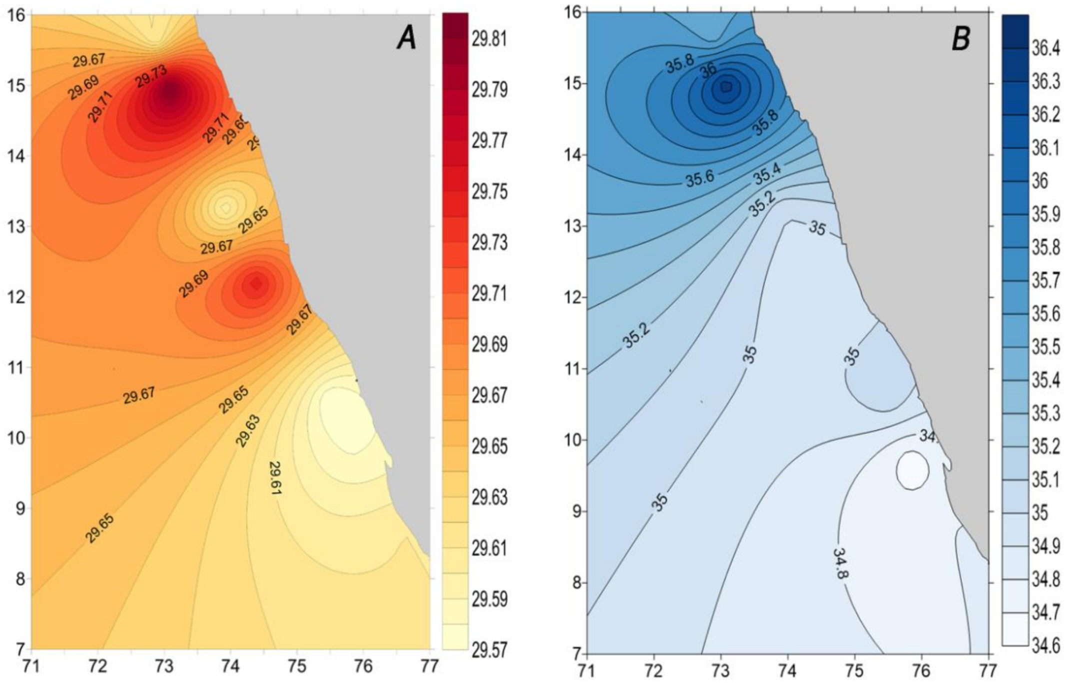

Figure 8. Sea surface temperature (A) and salinity (B) variations along coastal waters of the south-west coast of India during fall intermonsoon 2015.

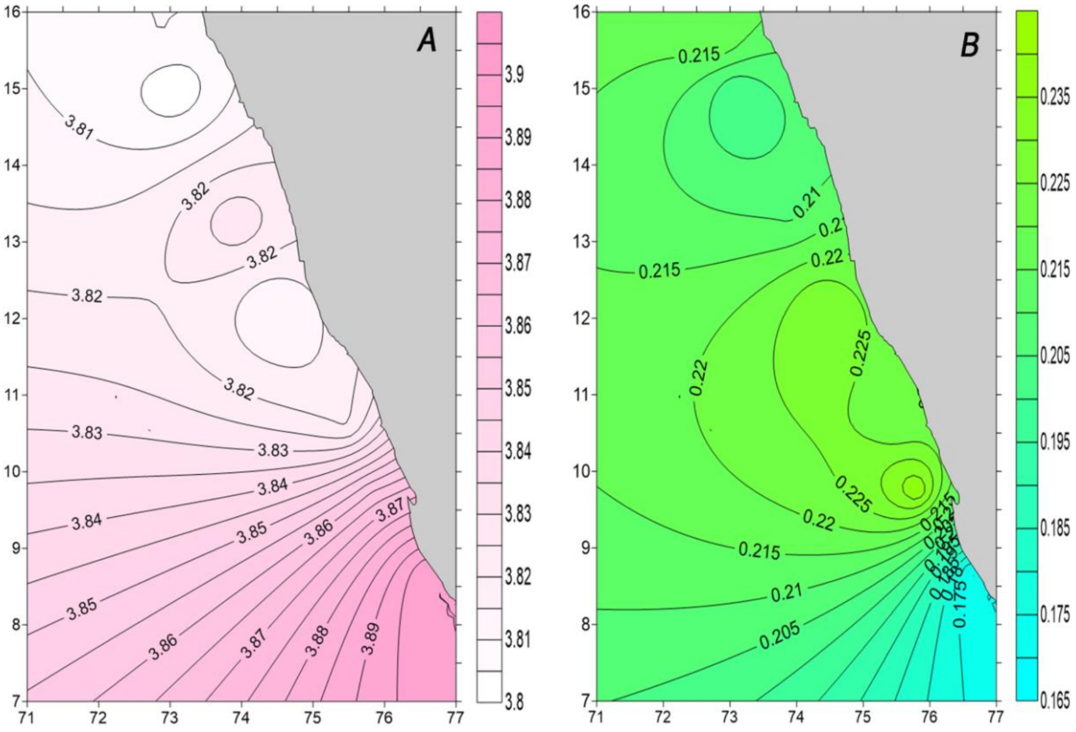

Figure 9. Dissolved oxygen (A) and concentration of Chlorophyll a (B) in the surface water along the coastal waters of the south-west coast of India during fall intermonsoon 2015.

4.3. DISCUSSION

Seasonal changes in the climate in the marine environment play an important role in the ecological cycle in the Arabian Sea. The biological productivity of the seas in this region is dependent on the complex physical, chemical and biological process active in the medium and subsequently transferred to different trophic levels. The water temperature and salinity inside the lagoon were higher throughout the study period. The highest surface water temperature of 30°C was observed in Agatti and Kavaratti, and highest salinity of 36 psu was observed during winter monsoon 2014 in Kalpeni. The salinity values did not vary much in the lagoon stations. Goswami, (1979) reported that the surface salinity in Kavaratti remained higher throughout the study period (29.7 to 31.9 ppt). The occurrence of high values of all these parameters could be attributed to the shallow depth of the lagoon. Further, Qasim and Sankaranarayanan (1970) proposed that heavy surf breaking across the reef creates a unidirectional flow of seawater towards the entrance of the lagoon, which may also contribute to high salinity (Sanu et al., 2014). The most optimum growth of coral reefs observed in the temperature range between 25 and 29 ˚C (Qasim and Bhattathiri, 1972). Mayer et al. (1914) reported physiological stress in some corals at a temperature between 31.8 and 36.4^{o}C and death at a temperature exceeding 35.8^{o}C. In the present study, the temperature recorded below the maximal level (26-30^{o}C). The hydrobiology of the Minicoy lagoon with a comparative study of all the lagoons of Lakshadweep was carried out by Girijavallabhan (1989) during January-March when a maximum SST of 30 ^{o}C to 35 ^{o}C was observed. They also noticed that temperature remained above 30^{o}C throughout the day and night. A similar observation was also reported by Koya (2000) and Vargis (2005). Prabhakaran (2008) documented a range of 26 ^{o}C to 31.2 ^{o}C from Minicoy Lagoon. During the peak phase of El niño (March 2016), Vineetha et al., (2018) observed the highest surface salinity of 34.8 ^{o}C in Kavaratti atoll. During the same period, the highest SST of 33 ^{o}C was observed in Kavaratti atoll in the present study.

In the oceanic stations around the Minicoy Island during spring intermonsoon 2015, the average surface water temperature observed was

30.53±0.19°C and the salinity was 33.9±0.39 psu. During the same period, temperature ranges from 30.22 to 31.09°C and salinity 34.26 to 35.37psu in the coastal stations of the Arabian Sea. The records of Patil and Ramamithram (1963) from Lakshadweep offshore waters indicate that the sea surface temperature was quite high during the period and it varied between 28°C and 29 °C. During spring intermonsoon 2015, it is observed that the temperature increases towards the southern latitudes and salinity increases towards northern latitudes (Fig.6-A, B). During fall intermonsoon, SST was less compared to spring intermonsoon (29.61 to 29.82 °C) (Fig.8-A) Surface salinity was comparatively slightly higher than spring intermonsoon (34.81 to 36.38psu) and increases towards the northern latitudes as observed during spring intermonsoon 2015 (Fig.8-B). In both the seasons, salinity showed a progressive increase towards Northern latitudes. Lathika et al., (2013) observed the SST value of 26 °C from the southeastern Arabian Sea during spring intermonsoon. Jyothibabu et al. (2013) observed surface temperature values of 25.45°C to 34.47°C around the eastern part of the Indian Ocean.

Atoll lagoons are habitats generally fed by saline water from the adjacent sea and receive freshwater inputs mainly from rainfall. Typically, the freshwater supply from precipitation become hypersaline in lagoon waters (Bamber, 2010) due to the high saline condition. In the present study, the salinity values ranged from 30psu to 36psu. A salinity range of 27 to 35ppt was reported by Vargis (2005) and 31.15-35.48ppt by Prabhakaran (2008) in Minicoy Lagoon. Qasim and Sankaranarayanan (1970) reported that the high salinity in the lagoon might be due to the unidirectional flow of sea water towards the entrance of the lagoon which in turn is created by the heavy surf breaking across the reef. The same can also be due to the fresh water influx during south-west monsoon season (June to September) which consecutively could be from precipitation. As per the records, another mystifying factor for high saline conditions is water loss due to evaporation in all lagoons. Hypersaline conditions results due to minimal replenishment of water but an input of full strength seawater will trim down salinity in these conditions. Along the Southwest coast of India, during spring intermonsoon 2015, surface salinity ranged from 34.26psu to 35.37psu. During fall intermonsoon 2015, it ranged from 34.81psu to 36.38psu. In general, coastal region (lagoons, showed comparatively high surface salinity (35.53psu to 36.13psu) and low saline waters in the open ocean stations (33.76psu – 34.88psu). This observation was previously reported from various parts of the ocean and adjoining coasts by several workers (Murty et al.,1968; Shetye et al.,1993; Jyothibabu, 2004).

The lagoon ecosystems are net autotrophic and release oxygen into the water column; dissolved oxygen is usually high. The dissolved oxygen in the surface waters was observed during fall intermonsoon 2013 inside the Kavaratti atoll (6.09±0.17 ml/L). The lowest value was observed in Agatti lagoon during spring intermonsoon 2016 (3.32±0.1 ml/L). The lagoon ecosystems in the oceanic stations around the Minicoy Island; the average dissolved oxygen value was 4.19±0.54 ml/L which comparatively lower than the lagoon stations of Minicoy. Prevalence of saturated condition of dissolved oxygen value irrespective of the stations and seasons was observed in the present study inside the lagoon stations that could be due to the active photosynthesis by seaweeds as well as seagrasses (Sanu et al., 2014). In the present study in Lagoon waters, a slightly higher DO value (6.09±0.17 ml/L) observed during fall intermonsoon. It might be due to a higher primary production occurring in the ocean surface during this period as well as higher oxygen solubility in colder and less saline water. However, studies from various parts of the Arabian Sea depicted parameter mentioned above peak values in the monsoon period (Qasim et al.,1969; Haridas et al., 1973; Pillai et al. 1975; Jyothibabu et al., 2006; Haridevi, 2013). Prabhakaran (2008) observed a minimum DO value of 1.46ml/L during the neap tides in the Minicoy Lagoon. Paul and Ramamithram (1963) reported a DO value of 4.3-4.6 ml/L from offshore Laccadive (Lakshadweep) waters which agree with the present observation around the oceanic waters of Minicoy island (4.19±0.54 ml/L). During spring intermonsoon 2015, the average DO observed along the coastal stations was 4.21±0.64ml/L and which is lower (3.83±0.04 ml/L) during fall intermonsoon. During spring intermonsoon, dissolved oxygen increases towards the northern latitudes (Fig.7-A) while during fall intermonsoon, it progressively increases towards the southern latitudes (Fig. 9-A).

During the study, the chlorophyll-a distribution inside the lagoon ranges from 0.14 (Kavaratti, spring intermonsoon 2016) to 0.68±0.01 mg/m^3 (Kalpeni, fall intermonsoon 2013). The observed chlorophyll-a concentration was agreed with the observation of Robin et al., (2012) (0.15-0.68 mg/m^3) from Kavaratti lagoon. As a good indicator of phytoplankton dominance, values of chlorophyll in lagoon less than 2.5mg/m^3 could be termed as oligotrophic. Hence the present study it can be established that lagoon waters of Lakshadweep are oligotrophic as the pigment concentration was below 1mg/m^3. Distribution of chlorophyll-a from south to north in the Lakshadweep Sea during south-west monsoon season showed a value of 2.23-4.62 mg/m^3 by Balachandran et al., (1997). These very high concentrations of chlorophyll-a compared to the present study may be due to the highly productive nature of south-west monsoon season and prevalence of rich phytoplankton biomass. The average concentration of Chlorophyll-a around oceanic stations of Minicoy observed was 0.26±0.01mg/m^3. The average concentration during spring intermonsoon 2015 along coastal waters was 0.47±0.39mg/m^3. The average chlorophyll-a concentrations during fall intermonsoon were lower when compared to spring intermonsoon (0.21±0.02mg/m^3). In both the seasons, the concentration of Chlorophyll-a progressively increases towards northern latitudes. Prasannakumar et al., (2001) recorded chlorophyll-a values of 0.4-0.05 mg/m^{3}during spring intermonsoon, 0.01-0.35 mg/m^3 during fall intermonsoon, 0.09-1.34 mg/m^3 during the summer monsoon and 0.03-0.8 mg/m^3 during winter monsoon from central and eastern Arabian Sea which are in general agreement with the present study. Peak chlorophyll-a values ranging from 8-22.7mg/m^3 were reported from the southeastern Arabian Sea during summer monsoon by Lathika et al., 2013. The values of chlorophyll-a obtained from different lagoons of Lakshadweep was fairly close to those found in waters of the Great Barrier reefs of Australia (0.06 to 0.24mg/m^3) (Jeffrey, 1968). Honey et al. (2014) observed comparatively higher chlorophyll-a values (0.91 to 1.72mg/m^3) from the Andaman Islands.

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Chapter - 5

ZOOPLANKTON COMMUNITY ANALYSIS

Contents

5.1. INTRODUCTION

Zooplankton plays a vital role in structuring and regulating the coastal marine food web and also in the functioning of the biological pump (Chiba et al., 2006). Marine zooplankton comprises of 60-80 different types of organisms (Rashiba, 2010). As their community structure and function are highly susceptible to changes in the environmental conditions regular monitoring of their distribution as well as their interactions with various physicochemical parameters is inevitable for the sustainable management of the ecosystem (Kusum et al., 2014). Of all the marine zooplankton groups, copepods mainly calanoid copepods are the dominant groups in marine subtropical and tropical waters and exhibit considerable diversity in morphology and habitats they occupy (Madhupratap, 1991; Cornils et al., 2005). Further, copepods are significant in fisheries as it forms an important food item to the fishes, maintaining regenerated primary production and carbon flux (Madhupratap, 1997). The first intensive studies that generated the scientific knowledge of the mesozooplankton community of the Arabian Sea were the international Indian Ocean Expedition (IIOE 1960-1965) (http://www.iioe-2.incois.gov.in). The present chapter is aimed to develop baseline data on mesozooplankton abundance, distribution and seasonal variation in (**A**) lagoon waters of five coral islands of Lakshadweep, (**B**) Oceanic waters around Minicoy Island and (**C**) coastal waters of the south-west coast of India. The focus is to enhance our understanding of zooplankton with specific attributes in the diversity and distribution of calanoid copepods.

A. Zooplankton community in lagoon waters of Lakshadweep

5.2 ZOOPLANKTON COMMUNITY IN AGATTI ATOLL

The volume of water filtered ranges from 158 to 182 m^3 in winter monsoon 2015 and 138 to 162m^3 during spring intermonsoon 2016. Total zooplankton abundance was ranged from 37 to 46 ind. /m^3 during winter monsoon 2015 and it was ranged from 36 to 56 ind. /m^3 during spring intermonsoon 2016 (Fig. 1). Zooplankton biomass was highest in station 2 (S2) during both the sampling periods (0.04 ml/m^3) and station 3 showing 0.02ml/m^3 during both the seasons (Fig. 2).

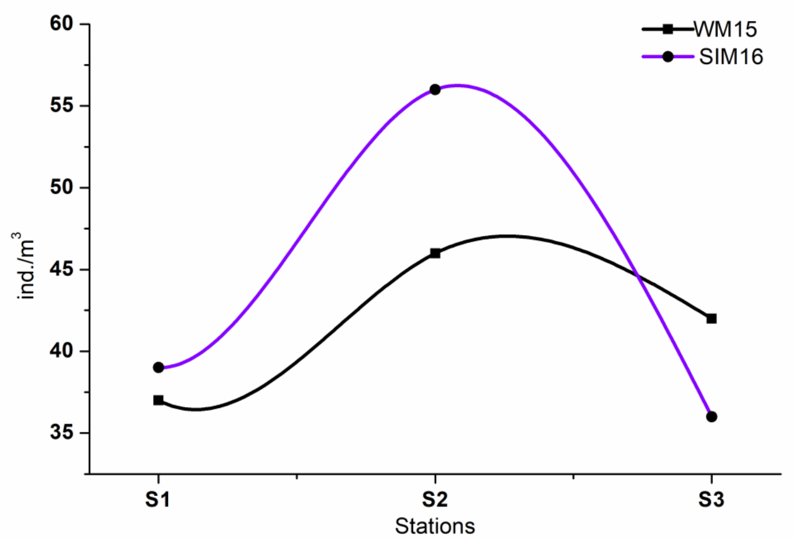

Figure 1. Zooplankton density in Agatti atoll during winter monsoon 2015 and spring intermonsoon 2016.

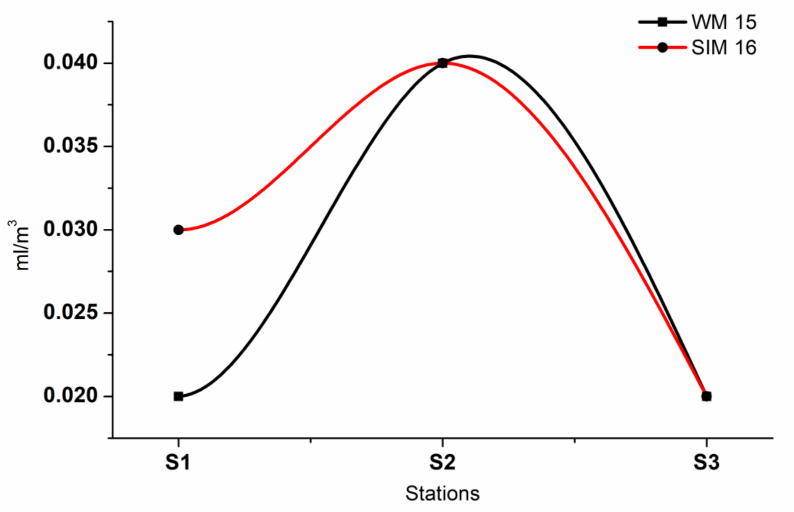

Figure 2. Zooplankton biomass in Agatti atoll during winter monsoon 2015 and spring intermonsoon 2016

5.2.1 Major groups of zooplankton

The list and percentage contribution of major zooplankton groups were observed during the study period are represented in table 1. In total sixteen groups of holoplankton and seven different types of meroplankton were recorded from Agatti. During the winter monsoon 2015, meroplankton percentage composition was higher than that of holoplankton. While during spring intermonsoon 2016, holoplankton formed the primary composition of plankton (Table 1). Molluscan veliger larvae were the primary component in the meroplankton during winter monsoon 2015 (52.2, 49.3 and 45.9%) followed by copepods (26.1, 29.6 and 40.4%). Among the copepods, calanoid copepods were the dominant share (13.1, 15.6 and 21.9%). Euphausiacea dominated among the holoplankton (33.2, 32.1 and 29%) during spring intermonsoon 2016 and about half share to the total zooplankton contributed by the copepods (57.1, 48.8 and 50%).

Table 1. Percentage composition of various taxonomic groups of holo and meroplankton to total zooplankton in the Agatti atoll during winter monsoon 2015 and Spring intermonsoon 2016.

	WM-15			SIM-16		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**
Total zooplankton (Ind./ m^3)	**37**	**46**	**42**	**39**	**56**	**36**
Biomass (ml/m^3)	**0.02**	**0.04**	**0.02**	**0.03**	**0.04**	**0.02**
Holoplankton						
Calanoida	13.1	15.6	21.9	32.9	26.5	28
Cyclopoida	11.3	13.7	18.5	22.1	20.1	21
Harpacticoida	1.8	0.3	-	2.1	2.3	1
Copepod Total	**26.1**	**29.6**	**40.4**	**57.1**	**48.8**	**50**
Foraminifera (Planktonic)	4.5	0.5	1.2	-	1	3
Radiolaria	0.3	0.3	-	0.7	0.3	1
Cladocera	1.2	1.1	1.5	0.3	0.3	-
Amphipoda	0.3	0.3	-	-	-	-
Ostracoda	0.3	0.5	0.3	0.3	0.8	-
Isopoda	0.3	-	-	0.3	-	-
Cumacea	-	0.3	0.3	-	-	-
Euphausiacea	4.5	3.0	2.4	33.2	32.1	29
Chaetognatha	0.9	3.8	0.6	0.0	0.5	1
Tunicata	0.3	0.3	0.3	0.0	-	-
Hydromedusae	0.3	1.3	0.9	0.0	-	1
Siphonophora	1.5	1.9	1.8	1	1	2
Pteropoda	0.3	1.3	1.2	1.7	1	1
Holoplankton total	**40.7**	**44.2**	**51.1**	**94.8**	**85.9**	**87**
Meroplankton						
Decapoda larvae	2.1	3.5	0.9	2.4	1.3	-
Stomatopoid larvae	0.6	0.3	0.6	1.4	0.5	-
Cirripede larvae	0.6	0.8	0.3	0.3	0.3	1
Fish eggs & larvae	3	1.6	0.9	0.0	10.5	9
Mollusca (Veligers)	52.2	49.3	45.9	1.0	1.5	3
Echinoderm larvae	0.3	0.3	-	-	-	-
Polychaete larvae	0.6	-	0.3	-	-	-
Meroplankton total	**59.4**	**55.8**	**48.9**	**5.2**	**14.1**	**13**

5.2.2 *Diversity of zooplankton groups*

The Shannon (H’) index almost the same during both the sampling period (Table 2). The Margalefs richness index (d) of the zooplankton shows the lowest value during winter monsoon 2016 (3.82±0.32). The Pielous evenness (j’) highest (0.63± 0.03) during spring intermonsoon 2016. Table 2 further represents the Simpsons index shows lower value during wintermonsoon2015 (0.72±0.01).

Table 2. Mean estimates of diversity index of zooplankton in lagoon waters of Agatti during 2015-16.

	H'	j'	Lambda	d
WM-15	2.48±0.13	0.57±0.01	0.72±0.01	5.2±0.63
SIM-16	2.49±0.20	0.63± 0.03	0.78±0.03	3.82±0.32

5.2.3. *The contribution of calanoid copepods*

Twenty three species belonging to 11 families and 15 genera were identified during the study period. Families Clausocalanidae and Temoridae were observed only during winter monsoon 2015. Whereas, Scolecitrichidae and Candacidae were observed only during spring intermonsoon 2016. In both the seasons, Pontellidae were dominated (30±1.6%, 29±1.9%) followed by Acartidae (15±0.4%, 20.5±1.1%). Euchaetidae contributes the least during winter monsoon-15 (1±0.1%), and Scolecitrichidae during spring intermonsoon 2016 (4.1±0.3%) (Fig. 3). *Subeucalanus subcrassus, Clausocalanus arcuicornis, C.furcatus, Temora discaudata, Temora turbinata and Pontellopsis perspicax* observed only during winter monsoon 2015. *Subeucalanus elongatus, Scolecithrix danae, Euchaeta marina, Acartia negligence, Candacia catula, C.truncata Pontellopsis armata* and *Labidocera acuta* were observed only during spring intermonsoon 2016. In both, the collection, the highest abundance of copepods were seen in station 1 (S1). The highest number of Calanoid species was found in spring intermonsoon 2016 (17 species) and the lowest in winter monsoon 2015 (14 species) (Table 3).

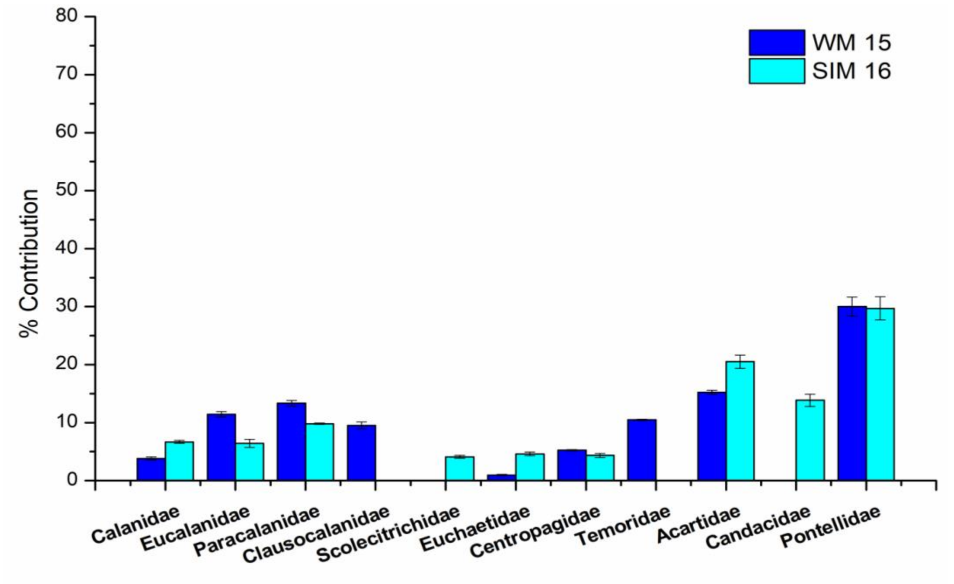

Figure 3. Percentage contribution of calanoid families in Agatti atoll during winter monsoon 2015 and SIM 2016.

Table 3. Variation in abundance (ind/m^3) of calanoid copepod species in the Agatti atoll.

	WM-15			**SIM-16**		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**
Total copepoda (Ind./ m^3)	**10**	**14**	**17**	**22**	**28**	**18**
Order: Calanoida						
Family: Calanidae						
Undinula vulgaris	-	0.5	0.3	1.1	0.9	0.6
Family: Eucalanidae						
Paraeucalanus attenuatus	0.1	0.4	0.3	0.7	0.4	0.2
Subeucalanus elongatus	-	-	-	0.3	0.9	-
Subeucalanus subcrassus	0.2	0.6	0.8	-	-	-
Family: Paracalanidae						
Acrocalanus longicornis	0.4	1.0	1.4	1.2	1.0	1.0
Family: Clausocalanidae						
Clausocalanus arcuicornis	0.3	0.4	0.1	-	-	-
Canthocalanus pauper	0.2	0.9	0.1	-	-	-
Family: Scolecitrichidae						
Scolecithrix danae	-	-	-	0.8	0.3	0.5
Family: Euchaetidae						
Euchaeta concinna	0.2	-	-	0.4	0.6	0.2
Euchaeta marina	-	-	-	0.1	0.3	0.2
Family: Centropagidae						
Centropages furcatus	0.3	0.5	0.3	0.9	0.6	0.2
Family: Temoridae						
Temora discaudata	0.4	0.3	0.4	-	-	-
Temora turbinata	0.4	0.3	0.4	-	-	-

Family: Acartidae						
Acartia fossae	0.9	0.8	1.5	0.9	1.2	0.7
Acartia negligens	-	-	-	2.3	1.9	0.6
Family: Candacidae						
Candacia catula	-	-	-	1.1	1.6	0.7
Candacia truncata	-	-	-	0.8	1.2	-
Family: Pontellidae						
Calanopia minor	0.5	0.8	2.3	-	1.7	2.0
Pontellina plumata	0.2	0.5	0.8	0.5	0.9	0.4
Pontellopsis aramata	-	-	-	0.5	0.6	1.1
Pontellopsis perspicax	0.2	0.3	0.6	-	-	-
Pontellopsis regalis	0.2	0.3	-	0.4	0.1	0.5
Labidocera acuta	-	-	-	0.7	0.9	0.9
Calanoid total	**5**	**7**	**9**	**13**	**15**	**10**
Order: Cyclopoida	4	6	8	9	11	8
Order: Harpacticoida	1	-	-	1	1	-

5.2.4. *Community structure of calanoid copepods*

The Shannon (H’) index almost the same during both the sampling periods. The observed value was 3.5±0.3 during winter monsoon 2015 and 3.7±0.1 during spring intermonsoon 2016. The Pielous evenness (j’) was the same(0.9) during both the season. The Simpson index was also showed the same value during both the sampling periods (Table 4).

Table 4. Mean estimates of diversity index of calanoid copepods in lagoon waters of Agatti during 2015-16.

	H’	**J'**	**Lambda**	**d**
WM15	3.5±0.3	0.9±0.1	0.9±0.03	0.9±0.03
SIM16	3.7±0.1	0.9±0.01	0.9±0.01	0.9±0.01

The *k*-Dominance curves revealed the sigmoid curves indicates a lower dominance and higher diversity of calanoid copepods during both the sampling periods (Fig. 4).

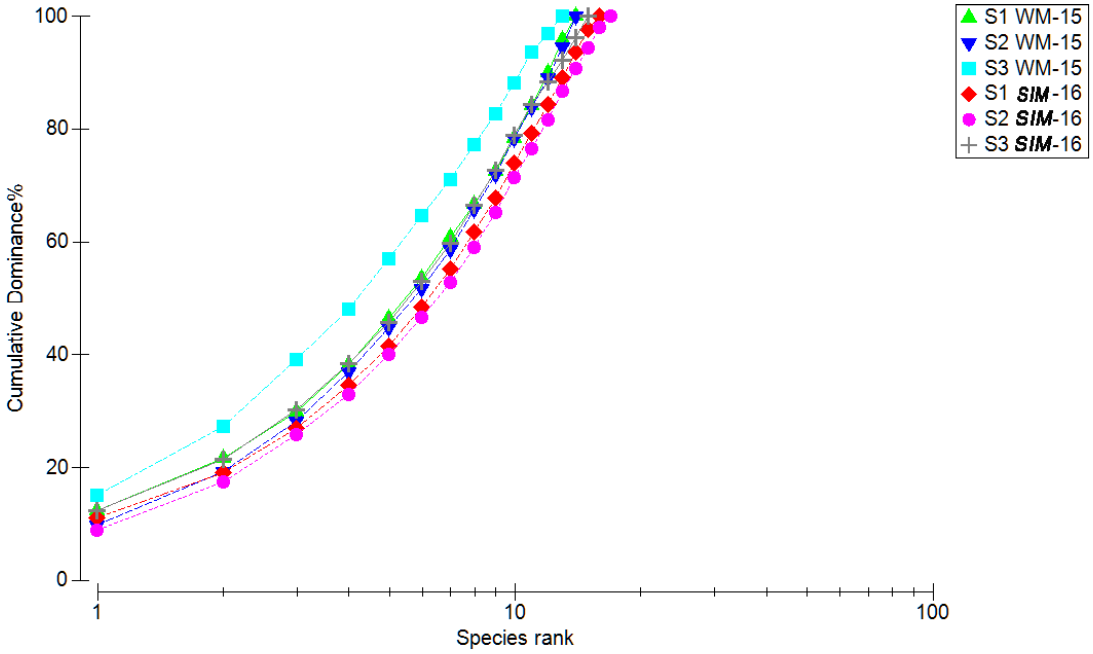

Figure 4. Cumulative dominance curves of calanoids in Agatti atoll during 2015-16.

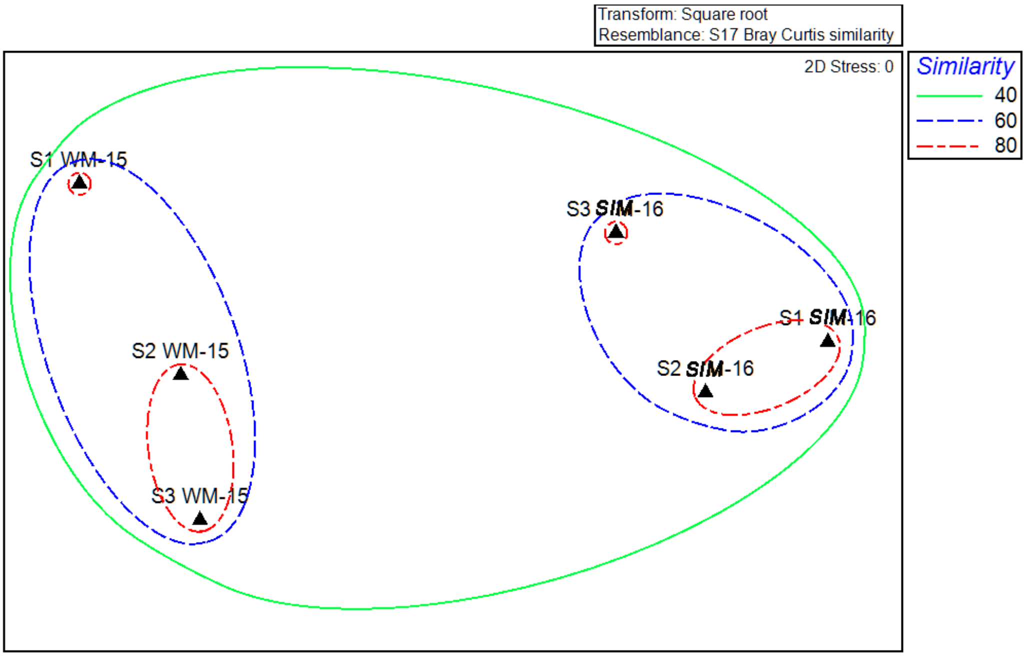

Figure 5. Multidimensional Scaling (MDS) orientation of Bray-Curtis similarity matrix of species abundance data (square-root transformed) of three stations in Agatti during 2015-16.

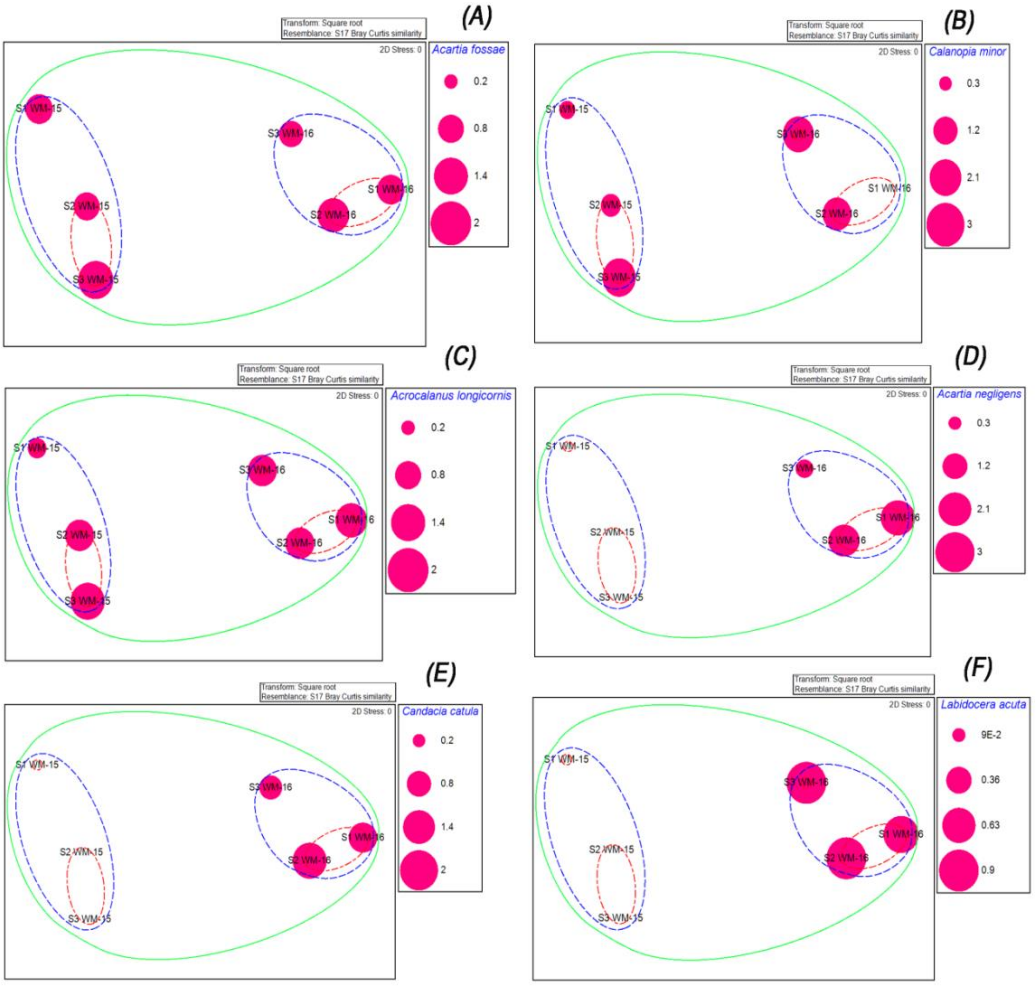

Fig. 6. Multidimensional Scaling (MDS) bubble plots of the species (A) *Acartia fossae*, (B) *Calanopia minor*, (C) *Acrocalanus longicornis*, (D) *Acartia negligens,* (E) *Candacia catula* and (F) *Labidocera acuta* in Agatti atoll 2015-16.

The results of MDS plots (Fig. 5) showed a clear separation of two samples as two seasons, winter monsoon in 2015 and spring intermonsoon 2016. The two seasons exhibited 40% similarity as together, and the stations 2 and 3during winter monsoon 2015 and station 1 and possessed 80% similarity. The MDS bubble plots indicate the species and their relative abundance which leads to the dissimilarities between seasons (Fig. 6). During winter monsoon 2015, *Acartia fossae* (18.94%) (Fig. 6A), *Calanopia minor* (13.24%) (Fig. 6B) and *Acrocalanus longicornis* (12.85%) (Fig. 6 C) formed the major share to the calanoid community while during spring intermonsoon 2016, *Acrocalanus longicornis* (11.85%) (Figure 6C), *Acartia negligens* (11.71%) (Fig. 6D) *Candacia catula* (9.71%) (Fig. 6E) and *Labidocera acuta* (9.09%) (Fig. 6F).

5.3. ZOOPLANKTON COMMUNITY STRUCTURE IN BANGARAM

The volume of water filtered ranged from 162 to 170 m^3. In Bangaram during winter monsoon the highest zooplankton biomass and density were observed in S2. Total zooplankton density ranged from 37 to 52 ind./m^3. Meroplankton becomes the significant share to the total zooplankton particularly decapod crustacean larvae contributing a dominant share (6, 79 and 78%) in Bangaram during the winter monsoon. Among copepods, cyclopoid copepods contributed the dominant share (14%) in station 1 and calanoid copepods dominated in station 2 (10%) and 3 (8%) (Table 5).

Table 5. Percentage composition of various taxonomic groups of holo and meroplankton to total zooplankton in the Bangaram during wintermonsoon 2015.

	WM-15		
	S1	**S2**	**S3**
Total zooplankton (No/ m^3)	**37**	**52**	**43**
Biomass (ml/m^3)	**0.06**	**0.09**	**0.07**
Holoplankton			
Calanoida	10	10	8
Cyclopoida	14	7	7
Harpacticoida	3	-	-
Copepod Total	26	18	15
Ostracoda	2	-	-
Euphausiacea	1	-	-
Chaetognatha	3	3	4
Holoplankton total	33	21	21
Meroplankton			
Decapoda larvae	66	79	78
Fish eggs & larvae	-	1	-
Meroplankton total	67	79	78

5.3.1 *Diversity of Zooplankton*

The diversity indices of zooplankton collected from three stations from Bangaram during winter monsoon is represented in Table 6. The Shannon index was ranged from 2.81 (station 3) to 3.16 (station1). The richness (4.74) and evenness (0.83) of zooplankton were maximum in station 1. Station 2 and 3 indicates same Simpsons' index (0.85) and higher value in station 1 (0.91) (Table 6).

Table 6. Diversity index of zooplankton from 3 stations in lagoon waters of Bangaram during winter monsoon 2015.

	H'	J'	Lambda	d
S1	3.16	0.83	0.91	4.74
S2	2.76	0.77	0.85	3.98
S3	2.81	0.76	0.85	4.48

5.3.2. *The contribution of calanoid copepods*

Eight calanoid species belonging to 7 families and eight genera were identified (Table 7). Family Calanidae dominated (39.7%) among the calanoids (Fig.7). The species *Undinula vulgaris* were the dominant calanoid observed in all stations and *Labidocera acuta* and *Pontellina plumata* were not observed in station 3.

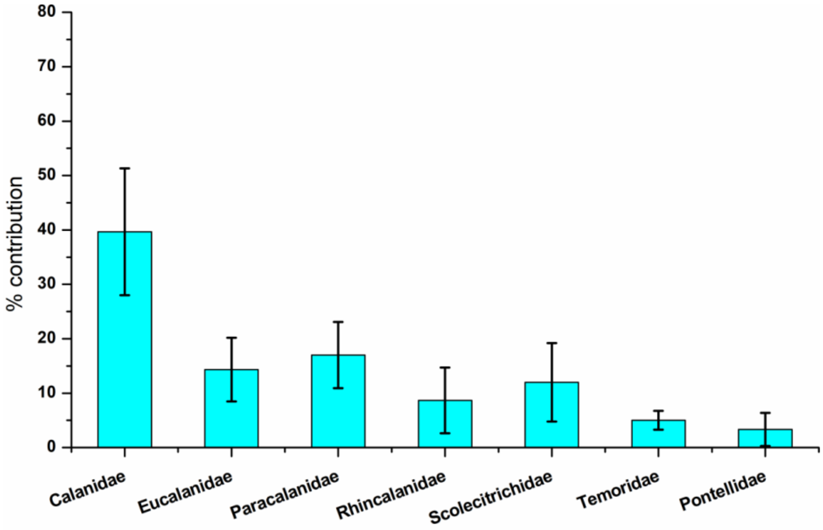

Figure 7. Percentage contribution of calanoid families in Bangaram during winter monsoon 2015.

Table 7. Variation in abundance (ind./m³) of calanoid copepod species in the Bangaram.

	WM-15		
	S1	**S2**	**S3**
Total copepoda (No/ m³)	**8**	**8**	**6**
Order calanoida			
Family: Calanidae			
Undinula vulgaris	1.3	1.1	1.5
Family: Eucalanidae			
Subeucalanus elongatus	0.4	0.9	0.4
Family: Paracalanidae			
Acrocalanus longicornis	0.4	1.2	0.5
Family: Rhincalanidae			
Rhincalanus rostrifrons	0.5	0.4	0.1
Family: Scolecitrichidae			
Scolecithrix danae	0.2	0.5	0.7
Family: Temoridae			
Temora stylifera	0.2	0.3	0.1
Family: Pontellidae			
Pontellina plumata	0.1	0.1	-
Labidocera acuta	0.1	0.1	-
Calanoid total	**2.9**	**4.4**	**3.2**
Order: Cyclopoida	4	3.3	2.6
Order: Harpacticoida	0.8	0.1	0.1

5.3.3. *Community structure of calanoid copepods*

The diversity indices of calanoid copepods collected from three stations from Bangaram during winter monsoon is given in Table 8. The Shannon index ranged from 2.43 (station 3) to 2.87 (Stations1 and 2). The richness (4.56) and evenness (0.96) of zooplankton were highest in station 1. The highest value of Simpsons' index was observed in station 1 (0.89) (Table 8).

Table 8. Diversity index of calanoid copepods from 3 stations in lagoon waters of Bangaram during winter monsoon 2015.

Stations	H'	J'	Lambda	d
S1	2.87	0.96	0.89	4.56
S2	2.87	0.96	0.84	4.06
S3	2.43	0.94	0.85	3.59

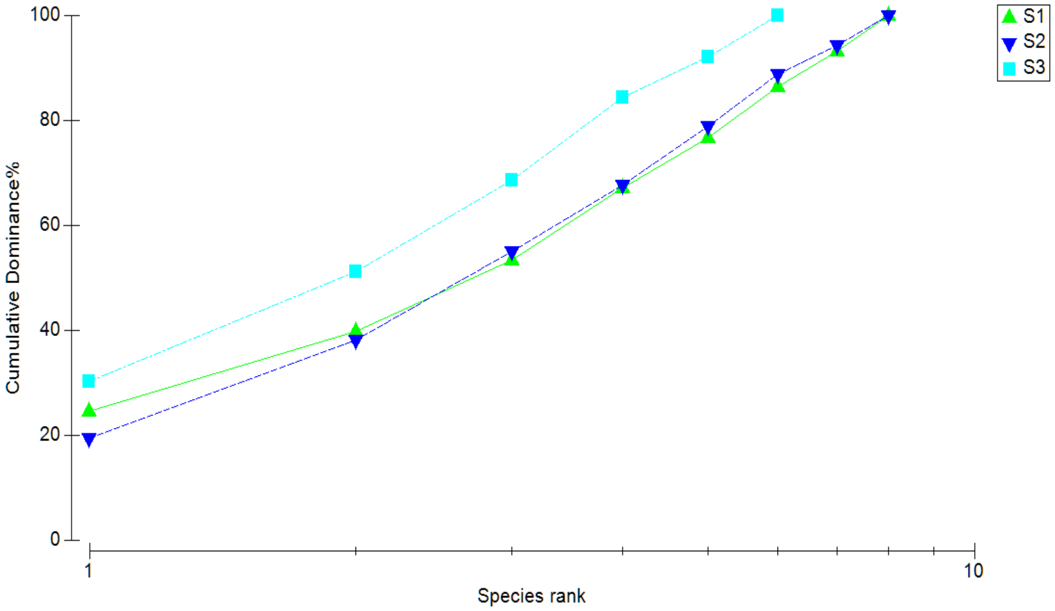

Figure 8. K-dominance curves of calanoids in Bangaram during winter monsoon 2015.

The *k*- dominance curves revealed the higher dominance and lower diversity of calanoid copepods from Bangaram (Fig. 8). The species *Undinula vulgaris* were the dominant species which contributes the major share in all stations, especially in station 3.

5.4. ZOOPLANKTON COMMUNITY STRUCTURE IN KALPENI ATOLL

Zooplankton biomass was higher in station 1 (0.02 ml/m^3) and lower in station 2 (0.01ml/m^3) during both the sampling periods. Total zooplankton abundance is ranging from 10 to 37 ind. /m^3 (Table 8). Seventeen groups of holoplankton and eight different types of meroplankton were recorded from Agatti. During fall intermonsoon, tunicates were not observed in the sample. During winter monsoon 2014, two holoplankton groups; ostracods and hydromedusae were not observed, and from the meroplankton, Polychaete larvae were absent. During the fall intermonsoon sampling, holoplankton composition was higher than that of meroplankton (63.5% in station 1 and 76.9% in station 2). While during the winter monsoon, meroplankton becomes the major composition (72 and 56.3%). During fall intermonsoon, calanoid copepod formed the dominant component (16.22 and 25.64%). Among the meroplankton, fish eggs and larvae (14.85 and 10.26%) dominated during fall intermonsoon. Decapod crustacean larvae dominated (41.31 and 42.05%) during the winter monsoon. In this period, Euphausiacea dominated among the holoplankton (19.14 and 30.11%) and copepods were only the fourth abundant group (5.29 and 6.25%).

Table 9. Percentage composition of various taxonomic groups of holo and meroplankton to total zooplankton in the Kalpeni atoll during fall intermonsoon 2013 and winter monsoon 2014.

	FIM 13		**WM 14**	
	S1	**S2**	**S1**	**S2**
Total zooplankton (No/ m^3)	**31**	**11**	**37**	**10**
Biomass (ml/m^3)	**0.02**	**0.01**	**0.02**	**0.01**
Holoplankton(%)				
Calanoida	16.22	25.64	2.02	3.98
Cyclopoida	2.70	5.13	1.76	1.14
Harpacticoida	1.35	2.56	1.51	1.14
Copepod Total	**20.27**	**33.33**	**5.29**	**6.25**
Foraminifera (Planktonic)	4.05	2.56	0.25	0.57
Radiolaria	2.70	2.56	0.25	1.14
Cladocera	1.35	-	0.25	1.14
Amphipoda	1.35	2.56	-	0.57
Ostracoda	4.05	2.56	-	-
Isopoda	5.41	5.13	0.25	-
Cumacea	1.35	2.56	0.50	0.57
Mysidacea	1.35	2.56	0.25	0.57
Euphausiacea	4.05	2.56	19.14	30.11
Chaetognatha	10.81	12.82	0.50	0.57
Tunicata	-	-	0.25	1.14
Hydromedusae	1.35	2.56	-	-
Siphonophora	1.35	2.56	0.50	0.57
Pteropoda	4.05	2.56	0.50	0.57
Holoplankton total	**63.5**	**76.9**	**28.0**	**43.8**
Meroplankton (%)				
Decapoda larvae	13.51	5.13	41.31	42.05
Stomatopoid larvae	1.35	-	0.76	0.57
Cirripede larvae	2.70	-	0.25	1.14
Fish eggs & larvae	14.86	10.26	29.47	11.36
Mollusca (Veligers)	1.35	2.56	-	0.57
Echnoderm larvae	1.35	2.56	0.25	0.57
Polychaete larvae	1.35	2.56	-	-
Meroplankton total	**36.5**	**23.1**	**72.0**	**56.3**

5.4.1. *The diversity of zooplankton group.*

The mean diversity indices of zooplankton collected from two stations from Kalpeni during fall intermonsoon 2013 and winter monsoon 2014 represented in Table 9. Shannon index (3.23±0.16), Evenness (0.72±0.01), Simpson's index (0.80±0.03) and richness (4.19±0.46) were higher during fall intermonsoon (Table 9).

Table 9. Mean estimates of diversity index of zooplankton in lagoon waters of Kalpeni during fall intermonsoon 2013 and winter monsoon 2014.

	H'	**J'**	**Lambda**	**d**
FIM 13	3.23±0.16	0.72±0.01	0.80±0.03	4.19±0.46
WM14	2.53±0.09	0.58±0.02	0.78±0.01	4.07±0.07

5.4.2. *The contribution of calanoid copepods*

A total of 16 species belonging to 8 families and 13 genera were identified during the study period. Families Calanidae, Candacidae and Acartidae were present during both the seasons. Whereas, Calanidae, Centropagidae, Pontellidae and Psuedodiaptomidae were observed only during fall intermonsoon. Eucalanidae and paracalanidae were observed only during the winter monsoon. During fall intermonsoon 2013, Pontellidae contributed the most (46%), and during winter monsoon 2014, Acartidae (31.2%) followed by Eucalanidae (27%) that adds the significant share (Fig. 9). In the family Calanidae, *Cosmocalanus darwini* was observed during fall intermonsoon season and *Undinula vulgaris* observed in winter monsoon. *Acartia amboinensis* and *A. erythraea* from the family Acartidae observed during the winter monsoon, and *A. negligens* observed only during fall intermonsoon period. The average abundance of calanoid copepod was higher during the intermonsoon period. In both the seasons, the highest abundance of copepods and other zooplankton was observed in station 1 (S1). The highest number of copepod species was found in fall intermonsoon (10 species) and the lowest in winter monsoon (7 species). In the present study, the copepod density ranged from 4 to 6 ind./m^3 (Table 10).

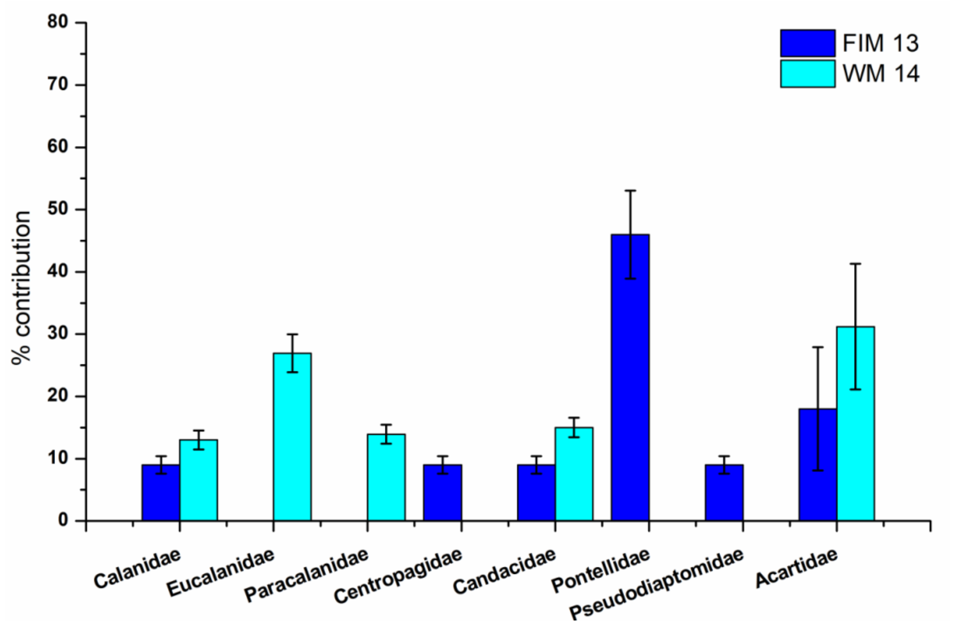

Figure 9 Percentage contributions of calanoid families in Kalpeni atoll during fall intermonsoon 2013 and winter monsoon 2014.

Table 10. Variation in abundance (ind/m³) of calanoid copepod species in the Kalpeni atoll, during fall intermonsoon 2013 and winter monsoon 2014.

	FIM-13		WM-14	
	S1	**S2**	**S1**	**S2**
Total Copepoda (ind./m³)	**6**	**4**	**4**	**4**
Order: Calanoida				
Family: Calanidae				
Cosmocalanus darwini	0.4	0.3	-	-
Undinula vulgaris	-	-	0.09	0.06
Family: Eucalanidae	**-**	**-**		
Paracalanu sindicus	-	-	0.09	0.06
Subeucalanus subcrassus	-	-	0.09	0.06
Family: Paracalanidae	**-**	**-**		
Acrocalanus longicornis	-	-	0.09	0.06
Family: Centropagidae				
Centropages furcatus	0.4	0.3	-	-
Family: Candacidae				
Candacia catula	0.4	0.3	9	6
Family: Pontellidae				
Calanopia thompsoni	0.4	0.3	-	-
Labidocera pavo	0.4	0.3	-	-
L. kroyeri	0.4	0.3	-	-
Pontellopsis perspicax	0.4	0.3	-	-
Pontellina plumata	0.4	0.3	-	-

Family: Pseudodiaptomidae				
Pseudodiaptomus serricaudatus	0.4	0.3	-	-
Family: Acartidae				
Acartia amboinensis	-	-	0.09	0.06
A. erythraea	-	-	0.19	0.06
A. negligens	1.2	0.3	-	-
Calanoid total	**5**	**2.9**	**0.7**	**0.4**
Order :Cyclopoida	0.87	0.41	3	1.47
Order :Harpacticoida	0.4	0.3	0.6	0.1

5.4.3. *Community structure of calanoid copepods*

The mean diversity indices of zooplankton collected from two stations from Kalpeni represented in table 11. The Shannon index (3.26±0.09), Simpson's index (0.90±0.02) and richness (1.95) values of calanoids were highest during fall intermonsoon 2013 and evenness (0.99±0.02) value was highest during winter monsoon 2014.

Table 11. Mean estimates of diversity indices of calanoid copepods in lagoon waters of Kalpeni during fall intermonsoon 2013 and winter monsoon 2014.

	H'	j'	Lambda	d
FIM13	3.26±0.09	0.98±0.03	0.90±0.02	1.95±0
WM14	2.77±0.05	0.99±0.02	0.86±0.01	1.30±0

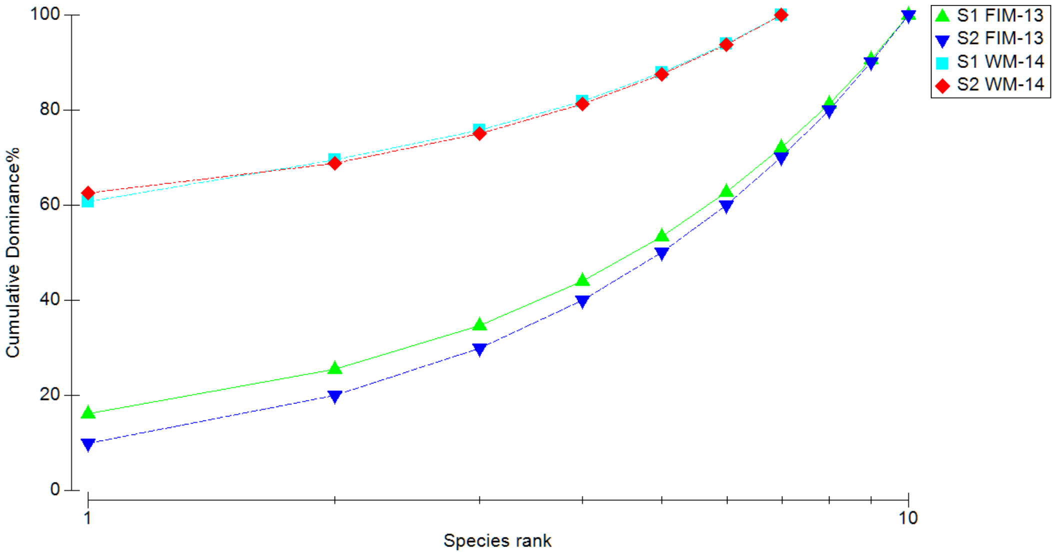

Figure 10. *k*- Dominance curves of calanoids in Kalpeni during fall intermonsoon 2013 and winter monsoon 2014.

The *K*-dominance curves revealed the lower dominance and highest diversity of calanoid copepods during fall intermonsoon 2013 and higher dominance of species *Candacia catula* and lower diversity during winter monsoon 2014 (Fig. 10).

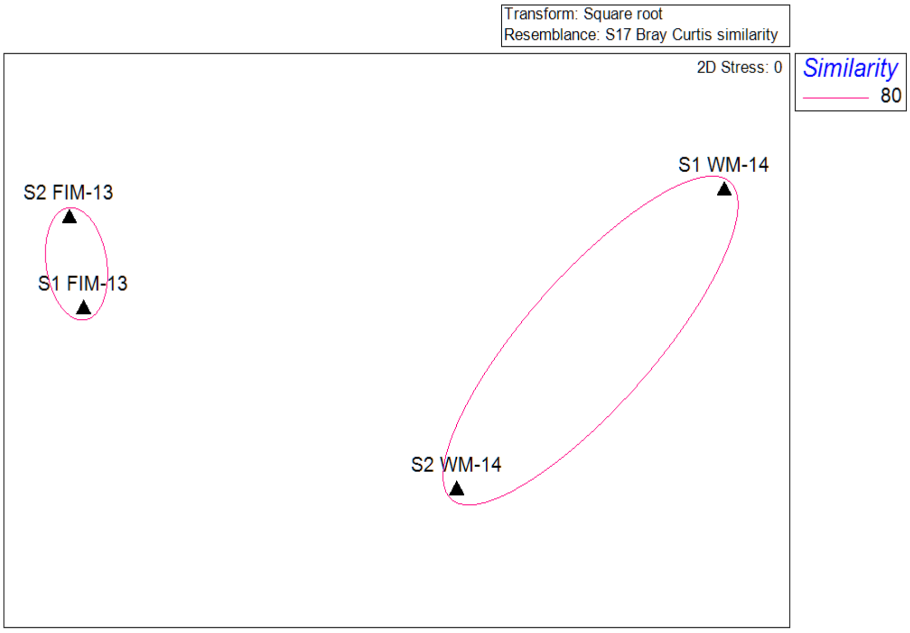

Figure 11. MDS orientation of Bray-Curtis similarity matrix of species abundance data (square root transformed) of two stations in Kalpeni during fall intermonsoon 2013 and winter monsoon 2014.

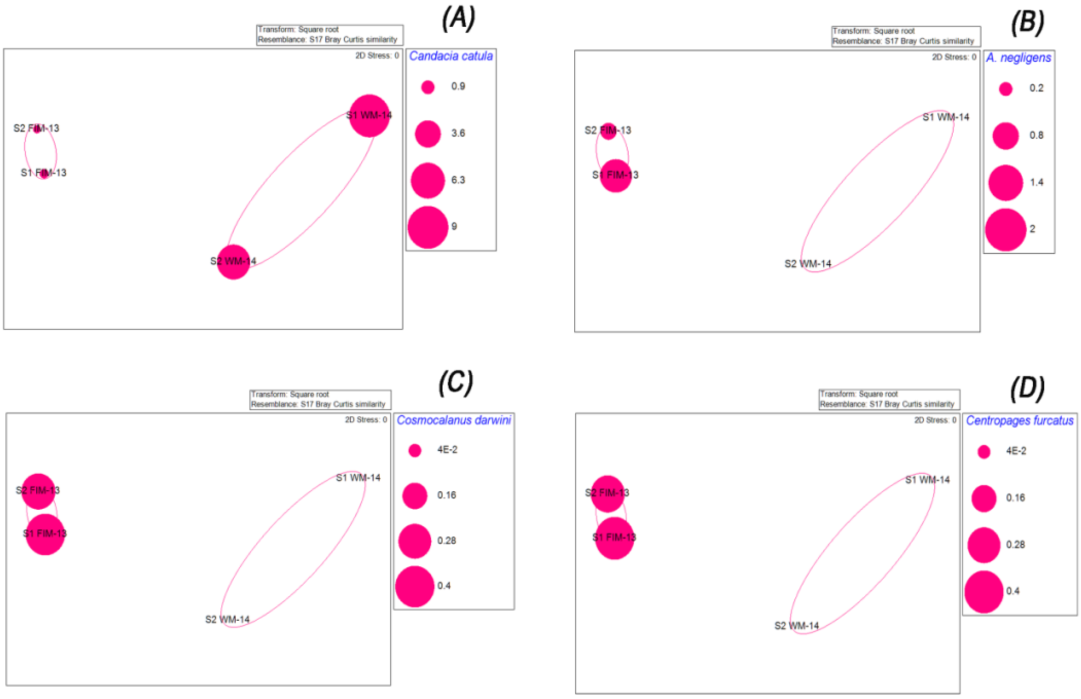

Figure 12. MDS bubble plots of the species *Candacia catula* (A), *Acartia negligens* (B), *Cosmocalanus darwini* (C) and *Centropages furcatus* (D) in Kalpeni.

The results of MDS plots (Fig. 11) showed a clear separation of samples as two seasons with 80% similarity. The MDS bubble plots indicate the species and their percentage contribution which leads to the dissimilarities between the two seasons (Fig. 12). The bubble plots of the species *Candacia catula* (Fig. 12A), *Acartia negligens* (Fig. 12B), *Cosmocalanus darwini* (Fig. 12C) and *Centropages furcatus* (Fig. 12D) indicates the relative abundance during the study period.

5.5. ZOOPLANKTON COMMUNITY STRUCTURE IN KAVARATTI ATOLL

The volume of water filtered ranges from 135 to 177 m^3 during spring intermonsoon, 118-194m^3 during fall intermonsoon, 167-210m^3 during winter monsoon 2014, 152-172m^3 winter monsoon 2015 and 130-165m^3 during spring intermonsoon 2016. Zooplankton density in Kavaratti atoll ranged from 8±3.46 to 22±6.24 ind./m^3 (Fig. 13). Zooplankton biomass ranged from 0.01 to 0.15±0.06 ml/ m^3 during the study period (Fig.14). The average highest zooplankton density and biomass observed during winter monsoon 2014, and it is lower during spring intermonsoon 2016 (Figs. 13, 14).

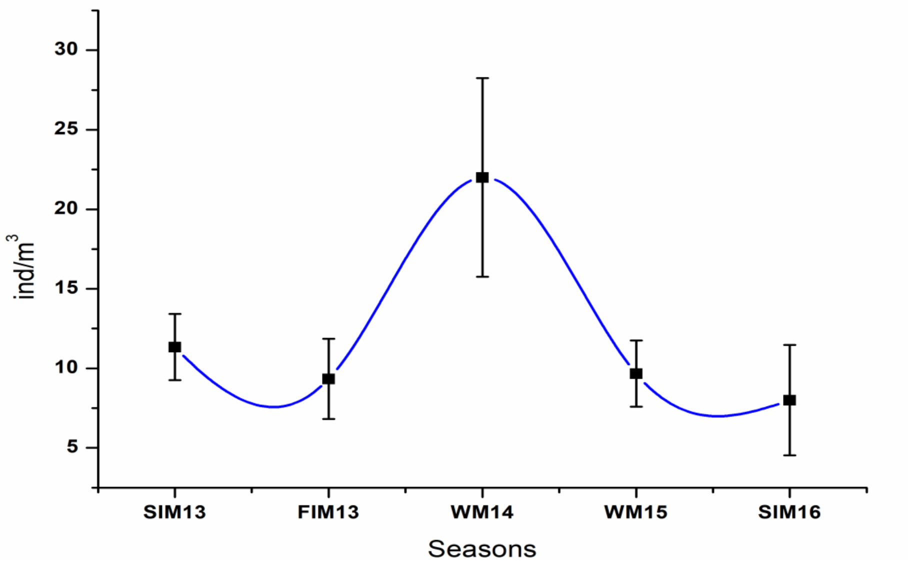

Figure 13. Zooplankton density in Kavaratti atoll during spring intermonsoon 2013 to spring intermonsoon 2016.

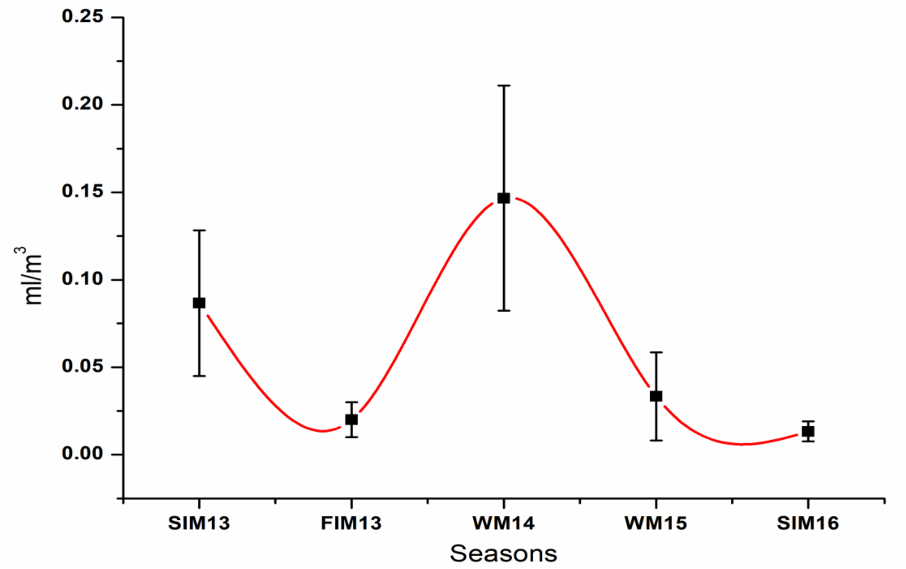

Figure 14. Zooplankton biomass in Kavaratti atoll during spring intermonsoon 2013 to spring intermonsoon 2016.

During the study period, seventeen holoplankton groups and seven meroplankton groups were identified from Kavaratti atoll. Cirripede larvae and echinoderm larvae were not found during winter monsoon 2015 and cirripede larvae, fish larvae and eggs, molluscan larvae and polychaete larvae were not observed during spring intermonsoon 2016. Copepod percentage composition was higher compared to other zooplankton groups during the study period except in station 2 and station 3 during the fall inter-monsoon season (39.3%, 27.7%) and winter monsoon 2015 (19.6%,19.9%) (Table 13). Cyclopoid copepods become the dominant share among the total copepod composition during spring intermonsoon 2013(50.6%, 15.8% and 47.2%) (Table 12). Total zooplankton abundance is ranging from 6 to 29 ind /m^3 (Table 12 and 13). Holoplankton composition was higher than that of meroplankton except during spring intermonsoon 2015 in station 2 and station 3 due to the abundance of molluscan veligers (68.9% and 53.8%) (Table 13).

Table 12. Percentage composition of various taxonomical groups of holo and meroplankton to total zooplankton in the Kavaratti atoll during spring intermonsoon 2013 to winter monsoon 2014.

	SIM-13			**FIM-13**			**WM-14**		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Total zooplankton (No/m^3)	**12**	**9**	**13**	**12**	**7**	**9**	**29**	**17**	**20**
Biomass (ml/m^3)	**0.04**	**0.12**	**0.1**	**0.03**	**0.01**	**0.02**	**0.22**	**0.1**	**0.12**
Holoplankton									
Calanoid	16.1	7.0	25.5	41.2	23.4	17.0	51.9	68	61.6
Cyclopoids	50.6	15.8	47.2	16.0	12.4	8.5	33.7	19	25.8
Harpacticoids	16.0	8.1	14.4	2.1	3.4	2.1	4.29	1.7	3.05
Copepod Total	**82.7**	**30.9**	**87.2**	**59.3**	**39.3**	**27.7**	**89.9**	**89**	**90.5**
Foraminifera (Planktonic)	1.53	3.2	0.5	1.2	1.4	1.1	0.2	1.7	0.69
Radiolaria	0.17	0.2	0.3	0.4	1.4	-	0.07	0.1	0.1
Cladocera	0.34	0.2	0.2	0.4	-	-	0.14	-	-
Amphipoda	0.17	-	0.2	-	0.7	1.6	0.07	0.1	0.1
Ostracoda	4.41	13.1	1.1	0.8	1.4	1.1	2.11	0.8	3.74
Isopoda	0.17	-	-	0.4	-	0.5	-	-	-
Cumacea	-	0.2	0.2	-	0.7	0.5	-	0.1	-
Mysidacea	-	-	0.2	0.8	0.7	-	-	0.1	-
Euphausiacea	0.34	3.6	0.9	0.4	0.7	1.6	0.14	0.4	0.3
Chaetognatha	0.85	0.9	1.1	3.3	6.2	2.7	3.54	0.8	0.59
Tunicata	0.85	1.4	0.2	-	2.8	1.1	-	-	-
Hydromedusae	0.51	0.5	0.3	0.4	1.4	1.6	0.34	0.4	0.2
Siphonophora	0.17	-	0.3	0.4	-	-	0.2	0.2	-
Pteropoda	0.17	0.2	0.2	0.4	-	1.1	0.14	0.1	-
Holoplankton total	92.4	54.4	92.6	68.3	56.6	40.4	96.8	94	96.2
Meroplankton									
Decapoda larvae	2.0	9.9	3.9	27.2	33.8	51.1	1.02	0.5	0.49
Stomatopoid larvae	0.2	0.2	-	1.2	-	1.1	0.07	-	-
Cirripede larvae	-	0.2	-	-	0.7	-	-	-	0.2
Fish eggs & larvae	3.4	29.6	2.2	-	0.7	2.7	1.29	5.1	1.87
Mollusca (Veligers)	1.4	5.2	1.1	2.9	6.9	3.2	0.61	0.7	1.18
Echnoderm larvae	0.2	0.2	-	0.4	0.7	1.6	0.14	0.1	-
Polychaete larvae	0.5	0.2	0.3	-	0.7	-	0.07	-	0.1
Meroplankton total	7.6	45.6	7.4	31.7	43.4	59.6	3.2	6.4	3.84

Table 13. Percentage composition of various taxonomical groups of holo and meroplankton to total zooplankton in the Kavaratti atoll during winter monsoon 2015 and spring intermonsoon 2016.

	WM-15			SIM-16		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**
Total zooplankton (No/m^3)	**9**	**12**	**8**	**6**	**6**	**12**
Biomass (ml/m^3)	**0.03**	**0.01**	**0.06**	**0.01**	**0.01**	**0.02**
Holoplankton						
Calanoid	37.7	17.4	15.4	30.2	35.0	45.2
Cyclopoids	26.9	1.7	3.2	12.7	15.0	13.9
Harpacticoids	1.7	0.4	1.3	1.6	3.3	3.5
Copepod Total	**66.3**	**19.6**	**19.9**	**44.4**	**53.3**	**62.6**
Foraminifera (Planktonic)	1.1	-	0.6	19.0	13.3	13.0
Radiolaria	0.6	0.4	0.6	4.8	3.3	0.9
Cladocera	-	0.4	-	-	1.7	-
Amphipoda	0.6	-	-	-	1.7	0.9
Ostracoda	0.6	-	1.3	-	-	0.9
Isopoda	1.1	-	0.6	-	1.7	-
Cumacea	0.6	-	1.3	1.6	1.7	-
Mysidacea	0.6	-	0.6	-	3.3	3.5
Euphausiacea	0.6	2.6	1.3	3.2	1.7	2.6
Chaetognatha	3.4	0.4	-	6.3	1.7	1.7
Tunicata	-	0.4	-	1.6	1.7	1.7
Hydromedusae	9.7	1.3	1.9	3.2	1.7	3.5
Siphonophora	6.3	1.3	3.8	9.5	6.7	4.3
Pteropoda	0.6	-	0.6	-	1.7	0.9
Holoplankton total	92.0	26.4	32.7	93.7	95.0	96.5
Meroplankton						
Decapoda larvae	0.6	1.3	5.1	1.6	1.7	1.7
Stomatopoid larvae	0.6	-	3.2	-	3.3	1.7
Cirripede larvae	-	-	-	-	-	-
Fish eggs & larvae	6.9	3.4	4.5	4.8	-	-
Mollusca (Veligers)	-	68.9	53.8	-	-	-
Echnoderm larvae	-	-	0.6	-	-	-
Polychaete larvae	-	-	-	-	-	-
Meroplankton total	8.0	73.6	67.3	6.3	5.0	3.5

5.5.1. *The diversity of zooplankton groups*

The mean diversity indices of zooplankton collected from three stations in Kavaratti atoll is represented in Table 14. Highest Shannon index observed during spring intermonsoon 2016 (3.0±0.24) and lowest seen during winter monsoon 2014 (1.7±0.13). Lowest evenness observed during winter monsoon 2014 (0.4±0.03) and highest during spring intermonsoon 2016 (0.8±0.11). Simpson index ranged from 0.6±0.06 (winter monsoon 2014) to 0.8±0.05 (fall intermonsoon 2013 and spring intermonsoon 2016). Species richness is varied from 3.2±0.63 to 4.2±0.13. Highest richness index observed during spring intermonsoon 2013 (Table 14).

Table 14. Mean estimates of diversity indices of zooplankton in lagoon waters of Kavaratti during spring intermonsoon 2013 to spring intermonsoon 2016.

	H’	J'	Lambda	d
SIM13	2.6±0.47	0.6±0.11	0.7±0.09	4.2±0.13
FIM13	2.7±0.28	0.6±0.06	0.8±0.05	3.8±0.13
WM14	1.7±0.13	0.4±0.03	0.6±0.06	3.5±0.45
WM15	2.3±0.58	0.6±0.11	0.7±0.14	3.3±0.63
SIM16	3.0±0.24	0.8±0.11	0.8±0.05	3.2±0.63

5.5.2. *The contribution of calanoid copepods*

A total of 27 calanoids belonging to 11 families and 15 genera were identified during the study period (Table 15 and 16). Comparatively, the most abundant calanoid copepod family during the study was Pontellidae having five species followed by Acartiidae that was represented by four species. Representatives of more than half (>15 species) of the total calanoid species were observed in all the seasons. The family Candacidae, Calanidae, and Pontellidae dominated in spring intermonsoon 2013 and winter monsoon2014, while representatives of the family *Temoridae, Pseudodiaptomidae* and *Centropagidae* dominated in fall intermonsoon monsoon 2013. However, the species dominance pattern varies with seasons (Figure 15). Members of calanoid copepods in the order of their abundance during spring intermonsoon 2013 was *Labidocera acuta, Calanopia minor*, *Candacia catula* and *Undinula vulgaris*, while during winter monsoon 2014, it follows as *Candacia catula*, *Labidocera acuta*, *Labidocera madurae*, and *Calanopia minor*. In fall intermonsoon 2013, *Temora discaudata, Pseudodiaptomus serricaudatus, Undinula vulgaris* and *Centropages orsinii* dominated in the samples.

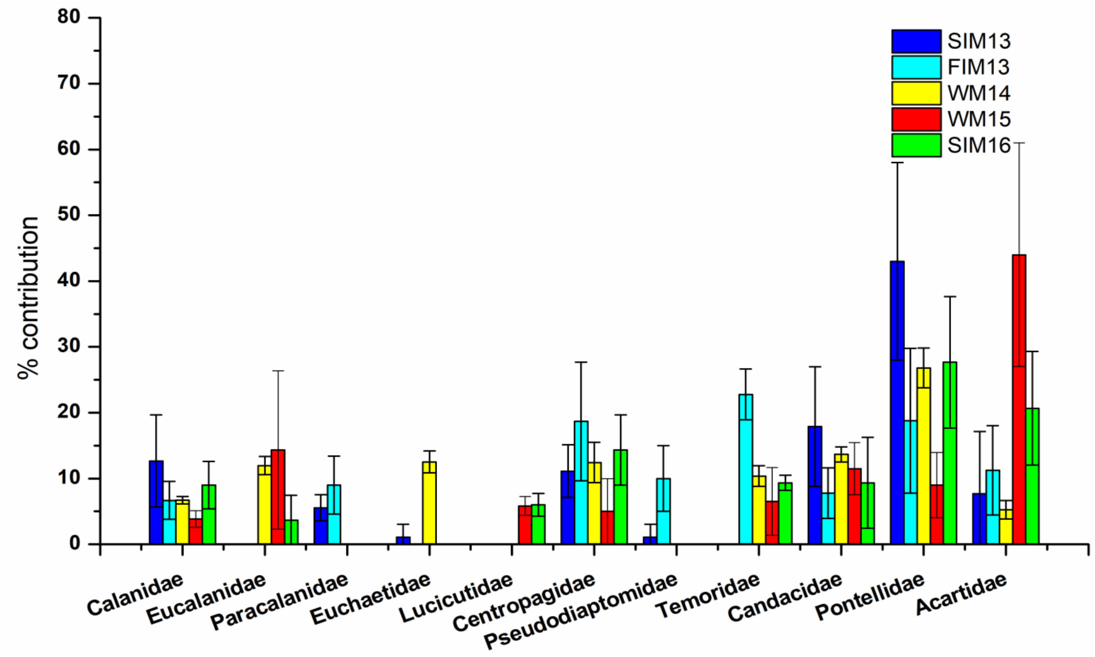

Figure 15 Percentage contribution of calanoid families in Kavaratti atoll during spring intermonsoon 2013 to spring intermonsoon 2016.

Acartia erythraea, Acartia negligens and *Candacia catula* were dominant during intermonsoon 2015, and during spring intermonsoon 2016, *Labidocera acuta*, *Acartia amboinensis*, and *Centropages furcatus* were dominant (Table 16). *Cosmocalanus darwini* and *Calocalanus plumulosus* were found exclusively during spring intermonsoon 2013, whereas *Euchaeta longicornis* was present only during winter monsoon 2014 (Table 15). *Bestiolina sp., Calocalanus pavo* and *Paeudodiaptomus serricaudatus* were found only during spring and fall intermonsoon 2013. *Candacia simplex* was seen only during the spring intermonsoon period (2013 and 2016). No spatial differences in the distribution of calanoid copepods were observed.

Table 15. Variation in abundance (ind/m^3) of calanoid copepod species in the Kavaratti atoll during spring intermonsoon 2013 to winter monsoon 2014.

	SIM-13			FIM-13			WM-14		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Total copepoda (Ind./ m^3)	**10**	**3**	**11**	**7**	**3**	**3**	**26**	**15**	**18**
Order: Calanoida									
Family: Calanidae									
Cosmocalanus darwini	0.1	-	0.1	-	-	-	-	-	-
Undinula vulgaris	0.2	-	0.5	0.6	0.1	0.1	1.0	0.8	0.8
Family: Eucalanidae									
Subeucalanus mucronatus	-	-	-	-	-	-	0.5	0.4	0.5
Subeucalanus subcrassus	-	-	-	-	-	-	0.8	0.5	0.7
Subeucalanus sp.	-	-	-	-	-	-	0.6	0.3	0.4
Family: Paracalanidae									
Bestiolina sp.	0.1	-	0.1	0.5	0.1	0.1	-	-	-
Calocalanus pavo	0.1	-	0.1	0.1	0.1	0.1	-	-	-
Family: Euchaetidae									
Euchaeta longicornis	-	-	-	-	-	-	0.7	0.5	0.7
Euchaeta marina	-	-	0.1	-	-	-	1.0	0.8	1.0
Family: Lucicutidae									
Lucicutia flavicornis	-	-	-	-	-	-	-	-	-
Family: Centropagidae									
Centropages gracilis	-	-	-	0.1	0.2	0.1	0.5	0.3	0.3
Centropages furcatus	-	-	-	0.6	0.1	0.1	0.8	0.5	0.4
Centropages orsini	0.1	-	0.1	0.5	0.2	0.1	1.0	0.6	0.5
Family: Pseudodiaptomidae									
Pseudodiaptomus serricaudatus	-	-	0.1	0.9	0.1	0.2	-	-	-
Family: Temoridae									
Temora discaudata	-	-	-	1.0	0.5	0.4	0.8	0.7	0.8
Temora turbinata	-	-	-	0.1	0.1	0.1	0.5	0.5	0.7
Family: Candacidae									
Candacia bradyi	-	-	-	0.1	0.1	0.1	-	-	-
Candacia catula	0.2	0.2	0.4	0.1	0.1	0.1	2.1	1.7	1.8
Candacia simplex	-	-	0.1	-	-	-	-	-	-
Family: Pontellidae									
Calanopia minor	0.3	-	0.6	0.1	0.1	0.1	1.2	1.0	0.9
Labidocera acuta	0.2	0.1	0.6	0.1	0.1	0.1	1.3	1.0	1.0
Labidocera madurae	-	-	-	-	-	0.1	1.3	0.8	1.0
Labidocera minuta	-	-	-	-	-	0.1	-	-	-
Pontellina plumata	0.1	-	-	0.4	0.1	0.1	0.3	0.4	0.3

Family: Acartidae									
Acartia centrura	-	-	-	-	-	-	-	-	-
Acartia erythraea	-	-	-	0.3	0.2	0.1	0.2	0.2	0.2
Acartia amboinensis	-	-	0.1	-	-	-	0.5	0.3	0.5
Acartia negligens	0.2	-	-	0.1	0.1	0.2	-	-	-
Order: Cyclopoida	6.0	1.4	6.1	2.0	0.9	0.8	9.9	3.3	5.2
Order: Harpacticoida	1.9	0.7	1.9	0.3	0.3	0.2	1.3	0.3	0.6

Table 16. Variation in abundance (ind/m^3) of calanoid copepod species in the Kavaratti atoll during winter monsoon 2015 and spring intermonsoon 2016.

	WM-15			**SIM-16**		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**
Total copepoda (Ind./ m^3)	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Order: Calanoida	**6**	**2**	**2**	**3**	**3**	**7**
Family: Calanidae						
Cosmocalanus darwini						
Undinula vulgaris	-	-		-	-	-
Family: Eucalanidae	0.1	0.1	0.1	0.1	0.2	0.6
Subeucalanus mucronatus						
Subeucalanus subcrassus	-	0.2	0.1	-	0.1	0.2
Subeucalanus sp.	0.1	0.1	0.1	-	-	-
Family: Paracalanidae	0.1	0.2	-	-	-	0.1
Bestiolina sp.						
Calocalanus pavo	-	-	-	-	-	-
Family: Euchaetidae	-	-	-	-	-	-
Euchaeta longicornis						
Euchaeta marina	-	-	-	-	-	-
Family: Lucicutidae	-	-	-	-	-	-
Lucicutia flavicornis						
Family: Centropagidae	0.3	0.1	0.1	0.1	0.2	0.3
Centropages gracilis						
Centropages furcatus	0.1	0.1	-	-	0.1	0.3
Centropages orsini	-	-	-	0.1	0.2	0.2
Family: Pseudodiaptomidae	0.1	0.1	-	0.1	0.1	0.3
Pseudodiaptomus serricaudatus						
Family: Temoridae	-	-	-	-	-	-
Temora discaudata						
Temora turbinata	0.2	-	-	0.1	0.1	0.2
Family: Candacidae	0.1	0.1	0.1	0.1	0.1	0.2
Candacia bradyi						
Candacia catula	0.1	0.1	0.1	0.1	0.1	0.1
Candacia simplex	0.2	0.3	0.1	0.1	-	0.1

Family: Pontellidae	**-**	**-**	**-**	**0.1**	**-**	**0.2**
Calanopia minor						
Labidocera acuta	0.3	0.1	0.1	0.2	-	0.1
Labidocera madurae	-	-	-	0.5	0.4	0.7
Labidocera minuta	-	-	-	-	-	-
Pontellina plumata	-	-	-	-	-	-
Family: Acartidae	-	0.1	-	-	-	0.4
Acartia centrura						
Acartia erythraea	-	-	-	-	0.1	0.1
Acartia amboinensis	1.1	0.6	0.7	-	0.1	0.3
Acartia negligens	-	-	0.1	0.2	0.2	0.4
Order: Cyclopoida	1.1	0.1	-	0.1	0.1	0.4
Order: Harpacticoida	2.4	0.4	0.3	0.8	0.9	1.6
	0.2	0.2	0.1	0.1	0.2	0.4

5.5.3. Community structure of calanoid copepods

The mean diversity indices of calanoid copepods from Kavaratti atoll is represented in Table 17. Highest Shannon diversity index was observed during spring intermonsoon 2013 (2.58±0.94) and lowest observed during spring intermonsoon 2016 (0.62±0.3). The highest evenness was observed during spring intermonsoon 2013 (0.92±0.04). Simpson index ranged from 0.22±0.1 (spring intermonsoon 2016) to 0.79±0.14 (spring intermonsoon 2013). Species richness ranged from 0.45±0.16 (spring intermonsoon 2016) to 1.59±1.03 (spring intermonsoon 2013) (Table 17).

Table 17. Mean estimates of diversity indices of calanoid copepods in lagoon waters of Kavaratti during spring intermonsoon 2013 to spring intermonsoon 2016.

	H'	J'	Lambda	d
SIM13	2.58±0.94	0.92±0.04	0.79±0.14	1.59±1.03
FIM13	1.76±1.1	0.48±0.62	0.47±0.46	1.31±0.4
WM14	1.29±0.43	0.38±0.3	0.36±0.19	0.91±0.46
WM15	0.96±0.47	0.44±0.17	0.33±0.14	0.59±0.28
SIM16	0.62±0.3	0.30±0.13	0.22±0.1	0.45±0.16

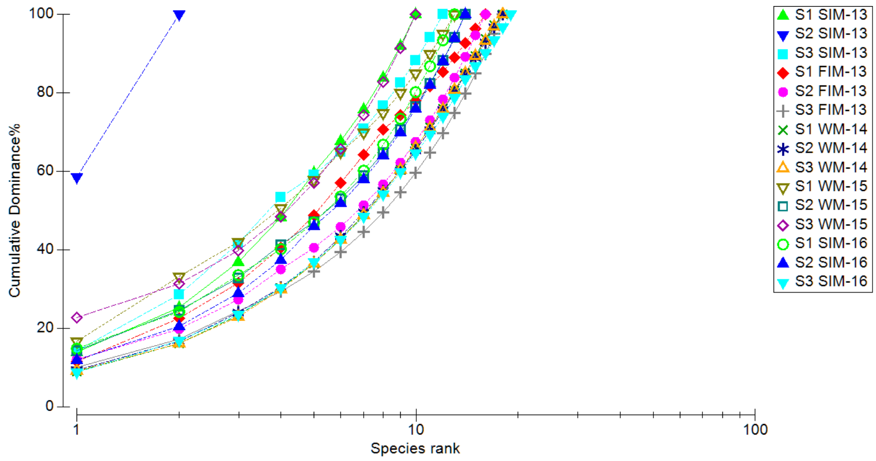

Figure 16. *K*-dominance curves of calanoid species n Kavaratti during 2013-2016.

The *K*-dominance curves (Fig. 16) revealed the lower dominance and highest diversity almost in all seasons. Station 2 during spring intermonsoon 2013 showed the highest dominance and lower diversity due to the dominance of two species *Candacia catula* and *Labidocera acuta* (Table 15).

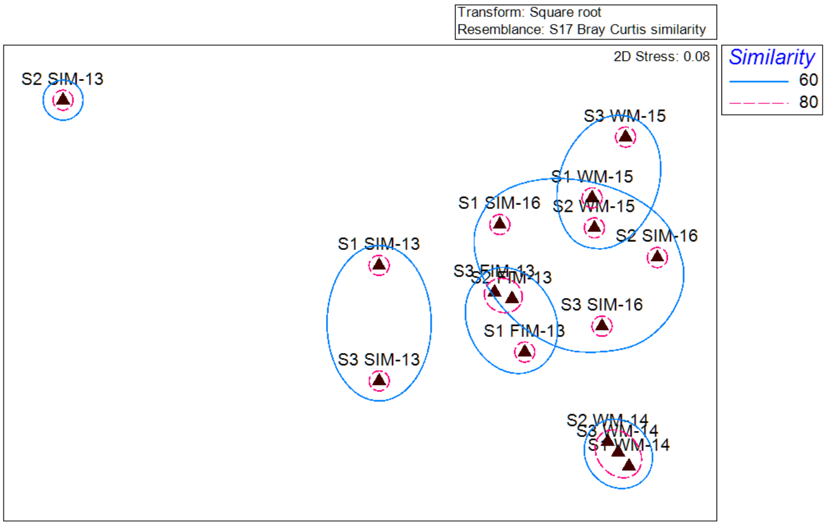

Figure 17. MDS orientation of Bray-Curtis similarity matrix of calanoid species abundance data (square root transformed) of three stations in Kavaratti during 2013-2016.

The results of MDS plots (Fig. 17) showed a clear separation of samples as three with 60% similarity. Station 2 (S2) during spring intermonsoon 2013 and all stations during winter monsoon 2014 plotted separately based on the variation in species diversity.

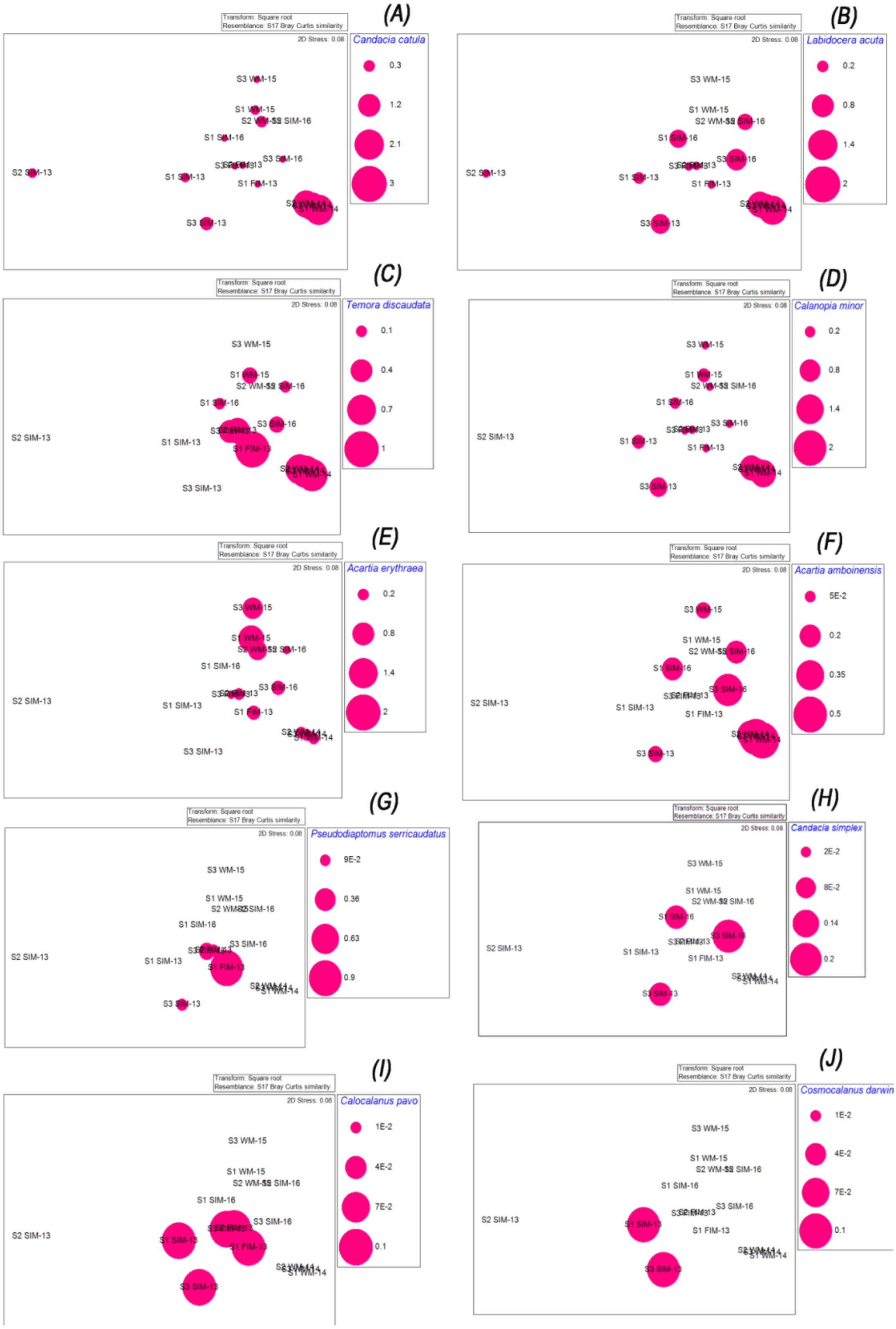

Figure 18. MDS bubble plots of the species (A) *Candacia catula*, (B) *Labidocera acuta*, (C) *Temora discaudata*, (D) *Calanopia minor*, (E) *Acartia erythraea*, (F) *A.amboiensis*, (G) *Pseudodiaptomus serricaudatus*, (H) *C.simplex*, (I) *Calocalanus pavo*, (J) *Cosmocalanus darwini.*

The MDS bubble plots indicate the species and their percentage contribution which leads to similarities or dissimilarities between seasons (Figure18). The bubble plots of the species, *Candacia catula*, *Labidocera acuta*, *Temora discaudata*, *Calanopia minor*, *Acartia erythraea*, *A.amboiensis*, *Pseudodiaptomus serricaudatus*, *C.simplex*, *Calocalanus pavo*, and *Cosmocalanus darwini* (Fig. 18 A-J) indicates the relative abundance and presence and absence in stations and seasons during the study period.

5.6. ZOOPLANKTON COMMUNITY STRUCTURE IN MINICOY LAGOON

The volume of water filtered ranges from 160-162 m^3 during fall intermonsoon, 146-150 m^3 during the winter monsoon, 160-180m^3 during the summer monsoon. Zooplankton abundance ranged from 13±1.4 (fall intermonsoon 2013) to 27±0.4ind/m^3 (winter monsoon 2014) (Fig.19). The biomass ranged from 0.03±0.01 (fall intermonsoon 2013) to 0.2±0.02ml/m^3 (winter monsoon 2014) (Fig. 20).

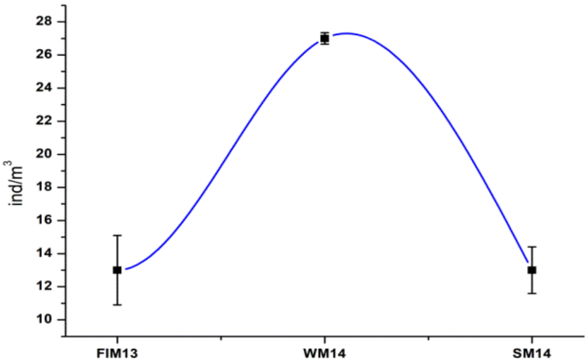

Figure 19. Zooplankton density in Minicoy during fall intermonsoon 2013 to summer monsoon 2014.

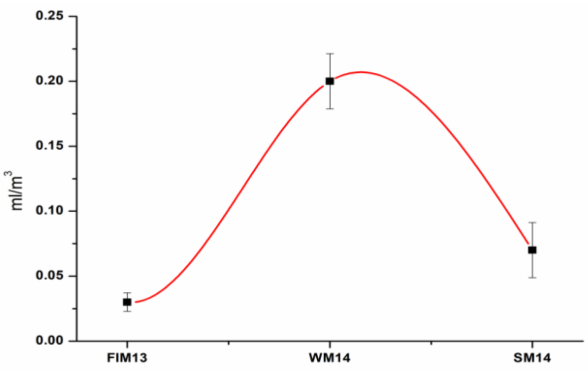

Figure 20. Zooplankton biomass in Minicoy during fall intermonsoon 2013 to summer monsoon 2014.

A total of sixteen holoplankton groups and six meroplankton groups were observed form the lagoon waters of Minicoy. Among holoplankton, cyclopoid copepods formed the significant share among the total copepod composition during fall intermonsoon (26.7% in S1 and 25.7% in S2), and during other two seasons, calanoid copepods contribute significant share (Table 18). Total zooplankton abundance was ranged from 11 to 27 ind./m^3 during the study period. During the fall intermonsoon, 2013 station 2 showed higher meroplankton abundance than the holoplankton composition (60.6%) due to the increased density of veliger larvae (53.7%). The foraminifers, ostracods and pteropods under the holoplankton and molluscan veligers, echinoderm larvae under the meroplankton were seen only during fall intermonsoon 2013. The holoplankton groups radiolarian, isopods, mysidacea, tunicata, hydromedusae and meroplankton groups stomatopod larvae, cirripede larvae and polychaete larvae were not observed during winter monsoon 2014. During summer monsoon 2014, cladocerans and pteropods were not seen in the collected samples. Holoplankton composition was higher than that of meroplankton in all other stations and seasons (Table 18).

5.6.1. *The diversity of zooplankton groups*

The mean diversity indices of zooplankton collected from two stations in lagoon waters of Minicoy is represented in Table 19. The highest values of all four indices were observed during fall intermonsoon 2013 and lowest during winter monsoon 2014. Highest Shannon index observed was 2.61±0.71, and the lowest value was 1.56±0.26. Evenness ranged from 0.49±0.08 to 0.64±0.16. Simpson index ranged from 0.47±0.09 to 0.75±0.14 Species richness was varied from 1.74 to 3.47±0.31.

Table 18. Percentage composition of various taxonomic groups of holo and meroplankton to total zooplankton in the Minicoy lagoon during fall intermonsoon 2013 to summer monsoon 2014.

	FIM-13		WM-14		SM-14	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**
Total zooplankton (No/m^3)	**14**	**11**	**26**	**27**	**15**	**13**
Biomass (ml/m^3)	**0.03**	**0.02**	**0.20**	**0.14**	**0.05**	**0.08**
Holoplankton						
Calanoida	8.3	6.3	76.9	66.9	49.8	40.8
Cyclopoida	26.7	25.7	5.8	9.1	9.9	11.7
Copepod Total	**34.9**	**32.0**	**82.7**	**76.0**	**59.6**	**52.5**
Foraminifera (Planktonic)	0.5	0.6	-	-	-	-
Radiolaria	0.9	0.6	-	-	0.4	0.4
Cladocera	2.8	0.6	0.5	2.0	-	-
Amphipoda	0.0	0.0	1.1	0.5	0.8	0.4
Ostracoda	12.4	1.1	-	-	-	-
Isopoda	-	-	-	-	0.4	0.4
Cumacea	4.6	-	0.5	0.5	0.8	0.4
Mysidacea	-	-	-	-	0.4	0.4
Euphausiacea	0.5	1.1	6.3	7.0	5.3	7.4
Chaetognatha	0.5	0.6	2.6	3.0	2.5	3.5
Tunicata	0.5	0.6	-	-	0.4	0.4
Hydromedusae	1.4	1.1	-	-	2.9	2.6
Siphonophora	6.4	-	2.1	2.5	1.2	0.9
Pteropoda	2.3	1.1	-	-	-	-
Holoplankton total	**67.6**	**39.4**	**95.9**	**91.6**	**74.8**	**69.4**
Meroplankton						
Decapoda larvae	23.9	4.6	4.2	8.6	23.8	29.1
Stomatopoid larvae	1.4	1.1	-	-	0.4	0.4
Cirripede larvae	-	-	-	-	0.4	0.4
Mollusca (Veligers)	5.5	53.7	-	-	-	-
Echinoderm larvae	0.5	0.6	-	-	-	-
Polychaete larvae	0.9	0.6	-	-	0.4	0.4
Meroplankton total	**32.2**	**60.6**	**4.2**	**8.6**	**25.1**	**30.4**

Table 19. Mean estimates of diversity indices of zooplankton in lagoon waters of Minicoy during fall intermonsoon 2013 to summer monsoon 2014.

Seasons	H’	J'	Lambda	d
FIM13	2.61±0.71	0.64±0.16	0.75±0.14	3.47±0.31
WM14	1.56±0.26	0.49±0.08	0.47±0.09	1.74±0
SM14	2.29±0.07	0.57±0.02	0.71±0.03	3.26±0

5.6.2. *The composition of calanoid copepods*

A total of 21 calanoid species belonging to 10 families and 13 genera were identified during the study period from Minicoy lagoon (Table 20). The most abundant calanoid copepod family during the study was Pontellidae (26±1.4% to 34±3.5%) having five species followed by Acartiidae (11±3.5% to 33±0.8%) that was represented by three species (Figure 21). The family Pontellidae and Acartidae were dominated in all the seasons, but Family Tortanidae becomes the most dominant during the winter monsoon. A new species *Tortanus minicoyensis* sp. nov. (Holotype: Adult female, 2.82mm, preserved in a vial in 2% formaldehyde/ seawater with a drop of glycerol added (ZSI- C6655/2, paratypes: 5 intact females ZSI- C6657/2; 5 males ZSI- C6658/2) of the genus *Tortanus*, subgenus *Atortus* is described during the winter monsoon period. The new species is included in the *Tropicus* group, which is mainly distributed in the tropical and subtropical waters of South East Asia. *Acrocalanus longicornis,* and *Calanopia thompsoni* were found exclusively during the summer monsoon period, whereas *Centropages orsinii* and *Tortanus minicoyensis* sp.nov present only during winter monsoon 2014 (Table 18). *Clausocalanus acruicornis, Euchaeta marina,* and *Pontellina plumata* were not observed during the winter monsoon period.

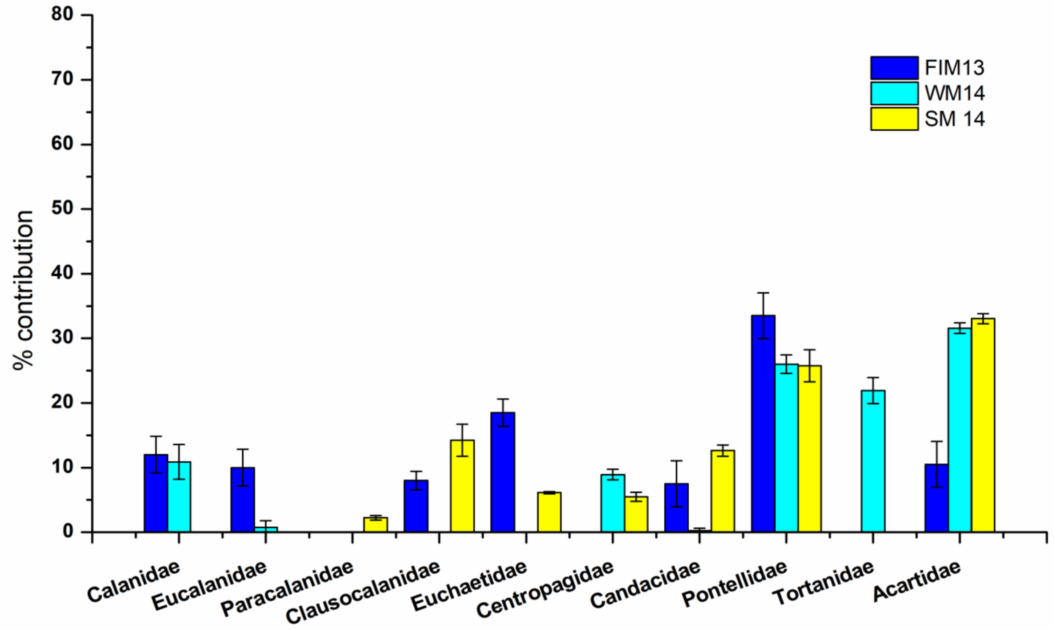

Figure 21. Average percentage composition of calanoid families in Minicoy lagoon during fall intermonsoon 2013 to summer monsoon 2014.

Table 20. Variation in abundance (Ind./m³) of calanoid copepod species in the Minicoy lagoon.

	FIM-13		WM-14		SM-14	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**
Total copepoda (ind./ m³) **Order: Calanoida**	**5**	**3**	**22**	**20**	**9**	**7**
Family: Calanidae						
Undinula vulgaris	0.3	0.1	1.8	2.3	-	-
Family: Eucalanidae						
Subeucalanus subcrassus	0.1	0.1	0.3	-	-	-
Family: Paracalanidae						
Acrocalanus longicornis	-	-	-	-	0.1	0.1
Calocalanus plumulosus	-	-	-	-	0.1	-
Family: Clausocalanidae						
Clausocalanus arcuicornis	0.1	0.1	-	-	1.0	0.8
Family: Euchaetidae						
Euchaeta longicornis	0.1	0.1	-	-	0.4	0.3
Euchaeta marina	0.1	0.1	-	-	0.1	-
Family: Centropagidae						
Centropages gracilis	-	-	0.1	-	0.4	0.3
Centropages orsinii	-	-	1.8	1.5	-	-
Family: Candacidae						
Candacia bradyi	0.1	0.1	-	-	0.8	0.7
Candacia catula	-	-	0.1	-	0.1	-
Family: Pontellidae						
Calanopia thompsoni	-	-	-	-	0.1	0.1
Labidocera acuta	-	-	1.5	1.1	0.6	0.3
Labidocera madurae	0.3	0.1	1.4	1.9	0.3	0.1
Labidocera detruncata	0.1	0.1	2.5	1.5	0.8	0.6
Pontellina plumata	0.1	0.1	-	-	0.4	0.1
Family: Tortanidae						
Tortanus minicoyensis	-	-	3.8	3.5	-	-
Tortanus sp.	-	-	0.3	0.7	-	-
Family: Acartidae						
Acartia bispinosa	-	-	4.38	3.6	1	1
Acartia erythraea	0.13	0.06	1.78	1.3	1.3	0.78
Acartia negligens	-	-	0.27	0.5	0.1	-
Order: Cyclopoida	**7**	**6**	**91**	**90**	**8**	**8**

5.6.3. *Community structure of calanoid copepods*

The mean diversity indices of calanoid copepods from lagoon water of Minicoy were represented in Table 21. Highest Shannon index was observed during summer monsoon 2014 (3.36±0.22) and the lowest observed during winter monsoon 2014 (3.23±0.04). Almost similar evenness observed during winter and summer monsoon 2014 (0.89) with slight variation during fall intermonsoon 2013 (0.97±0.03). Simpson index ranged from 0.88 (winter monsoon 2014) to 0.9±0.02 (fall intermonsoon 2013). Species richness is ranged from 1.95 (fall intermonsoon 2013) to 2.83±0.62 (summer monsoon 2014) (Table.21).

Table 21. Mean estimates of diversity indices of calanoid copepods in lagoon waters of Minicoy during fall intermonsoon 2013 to summer monsoon 2014.

Seasons	H'	J'	Lambda	d
FIM13	3.24±0.11	0.97±0.03	0.90±0.02	1.95±0
WM14	3.23±0.04	0.89±0.45	0.88±0	2.39±0.45
SM14	3.36±0.22	0.89±0.01	0.89±0.01	2.83±0.62

The K-dominance curves revealed the sigmoid curves indicates a lower dominance and highest diversity of calanoid copepods of all seasons and stations during the study period in lagoon waters of Minicoy (Fig. 22). The MDS plot (Figure 23) showed a clear separation as three seasons. Fall intermonsoon 2013 and summer monsoon 2014 exhibited 40% similarity and stations during winter monsoon 2014 plotted separately in MDS. The MDS bubble plots (Fig. 24) of the species *Euchaeta marina* (Figure 24A), *Clausocalanus arcuicornis* (Fig. 24B), *Pontellina plumata* (Fig 24C), *Acrocalanus longicornis* (Fig. 24D), *Calanopia thompsoni* (Fig. 24E), *Centropages orsinii* (Fig. 24F), *Tortanus minicoyensis* (Fig. 24G), *Acartia bispinosa* (Fig. 24H) indicates the percentage contribution of the species during the seasons.

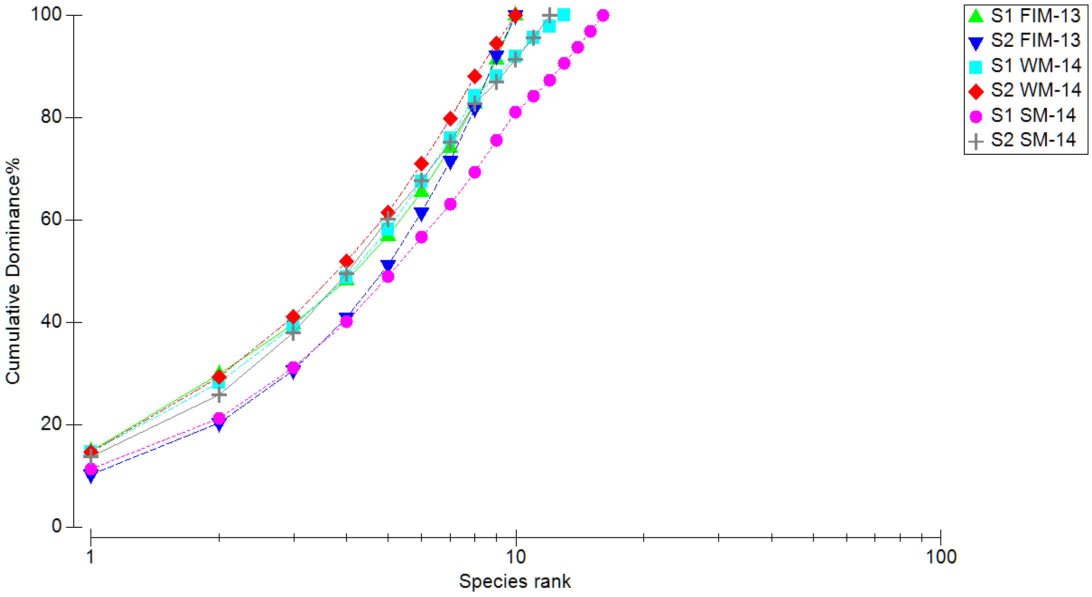

Figure 22. *K*-dominance curves of calanoids in Minicoy during 2013-14.

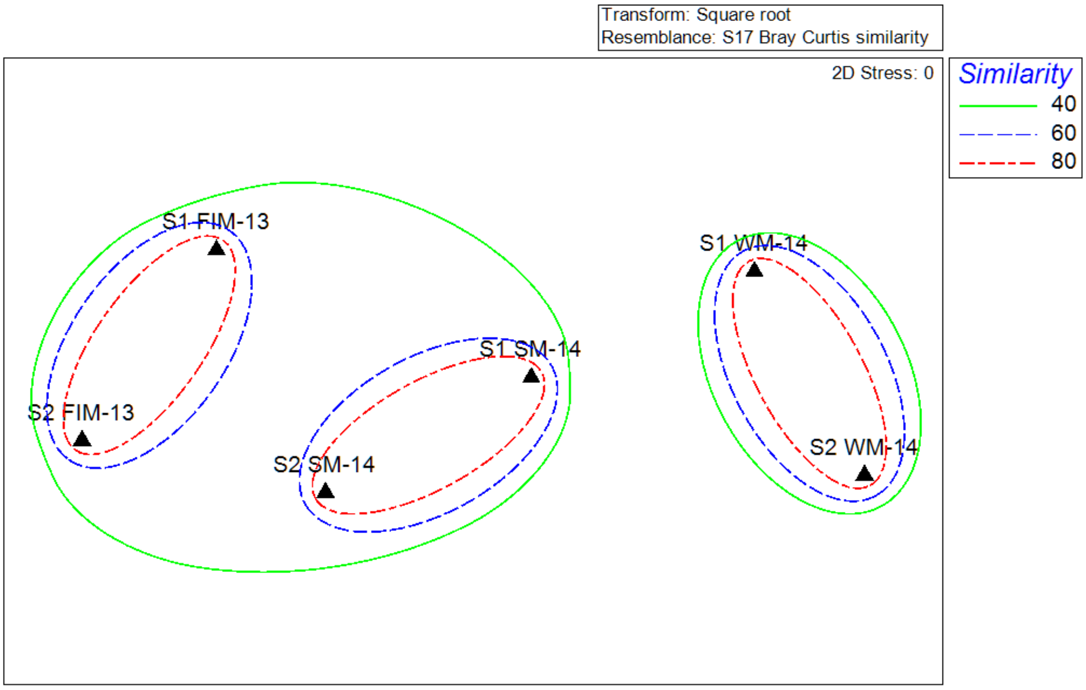

Figure 23. MDS orientation of Bray-Curtis similarity matrix of calanoid species abundance data (square root transformed) of two stations in Minicoy during 2013-2014.

Figure 24. MDS bubble plots of the species (A) *Euchaeta marina*, (B) *Clausocalanus arcuicornis*, (C) *Pontellina plumata*, (D) *Acrocalanus longicornis*, (E) *Calanopia thompsoni*, (F) *Centropages orsinii* (G) *Tortanus minicoyensis* (H) *Acartia bispinosa*.

B. Zooplankton community in Oceanic stations around Minicoy Island

5.7. ZOOPLANKTON COMMUNITY STRUCTURE IN THE OCEANIC STATIONS AROUND MINICOY ISLAND.

Zooplankton density and biomass was higher compared to the lagoon samples. Zooplankton abundance is ranged from 16 to 42 ind./m^3 (average 27±9.38) and total biomass 0.08- 0.18ml/m^3 (average 0.12±0.03) on the leeward side (Table 22 and 23). In all stations on the leeward side, holoplankton composition was higher than that of meroplankton. Among the holoplankton, calanoid copepods become significant share except station 7 (calanoids 25.8%, cyclopoids 26.5%) and 8 (calanoids 23.2%, cyclopoids 43.3%). Chaetognaths become dominant groups after calanoids in all stations. In the windward side of Minicoy, zooplankton abundance ranging from 13 to 55 ind/m^3 (average 33±13.08) and biomass range between 0.1 to 0.15ml/m^3 (average 0.12±0.02) (Table 20 and 22). In station 10, chaetognaths become significant share (52.2%) to the holoplankton and in station 11, copepods and chaetognaths nearly contribute equal share (26.7, 27.2%). In stations 15 and 17, cyclopoid copepods dominate over cyclopoids (Table 22). The abundance of chaetognaths is higher in the windward side than the leeward side.

Table 22. Average density and biomass of zooplankton from ocean waters of Minicoy during spring intermonsoon 2015.

	Leeward	**Windward**
Density (ind/m^3)	27±9.38	33±13.08
Biomass ml/m^3	0.12±0.03	0.12±0.02

Table 23. Percentage composition of various taxonomic groups of holo and meroplankton to total zooplankton in the leeward side of Minicoy Island during spring intermonsoon 2015.

	S3	S5	S8	S9	S12	S14	S15	S17	S20
Total zooplankton (ind/m^3)	**18**	**18**	**42**	**19**	**29**	**35**	**16**	**35**	**28**
Biomass ml/m^3	**0.12**	**0.12**	**0.08**	**0.1**	**0.16**	**0.18**	**0.12**	**0.11**	**0.11**
Holoplankton									
Calanoid	41	43	39.3	62.2	52.3	25.4	25.8	23.2	45.2
Cyclopoids	20.8	32.4	20.7	23.8	29.6	16.93	26.5	43.3	24.4
Copepod Total	**61.9**	**75.1**	**60**	**86**	**81.9**	**42.33**	**52.3**	**66.5**	**69.6**
Foraminifera (Planktonic)	0.7	1.4	0.33	-	3.4	5.8	3.68	5.5	-
Radiolaria	2.1	1	0.33	1.1	1.1	1.6	3.68	1.9	1.6
Amphipoda	1.4	1	0.67	2.3	1.7	3.2	1.47	0.3	-
Ostracoda	-	2.1	2	-	-	-	-	0.6	-
Isopoda	-	-	0.33	-	-	3.7	-	1.3	0.4
Euphausiacea	4.2	1	6	-	4	-	2.94	-	2.8
Chaetognatha	11.1	11.7	18.3	1.1	2.3	12.17	11.8	6.8	10.6
Tunicata	0.7	-	0.67	-	-	-	0.74	-	-
Hydromedusae	2.8	2.1	2	2.8	-	9.5	10.3	3.6	2.4
Siphonophora	-	-	0.67	-	-	0.5	0.74	-	0.4
Pteropoda	0.7	1	2	0.57	-	3.2	0.74	2.6	1.18
Holoplankton total	**85.5**	**95.7**	**93.3**	**93.9**	**94.4**	**82.01**	**88.3**	**89.1**	**88.8**
Meroplankton									
Decapoda larvae	8.3	-	-	2.3	2.8	1.6	2.21	4.2	-
Octopod larvae	-	2	2	-	-	-	-	0.6	-
Fish eggs & larvae	4.2	2	-	0.6	2.8	5.8	2.21	3.2	2.4
Mollusca (Veligers)	1.4	-	0.67	-	-	7.4	1.47	-	-
Echnoderm larvae	0.7	-	-	3.4	-	1.1	5.15	1.9	3.5
Polychaete larvae	-	-	4	-	-	2.1	0.74	1	5.1
Meroplankton total	**14.6**	**4.1**	**6.66**	**6.2**	**5.7**	**17.99**	**11.8**	**11.0**	**11**

Table 24. Percentage composition of various taxonomic groups of holo and meroplankton to total zooplankton in the windward side of Minicoy Island during spring intermonsoon 2015.

	S21	S24	S26	S27	S29	S32	S33	S36	S38
Total zooplankton (ind/m³)	**41**	**55**	**37**	**37**	**27**	**44**	**27**	**13**	**19**
Biomass ml/m³	**0.11**	**0.13**	**0.11**	**0.12**	**0.1**	**0.15**	**0.11**	**0.12**	**0.15**
Holoplankton									
Calanoid	9.52	17	40.8	21.3	44.4	22.4	28	21.5	42.9
Cyclopoids	5.04	10.2	18.7	13.1	7.9	28.2	33.7	17.8	23.1
Copepod Total	**14.6**	**27.2**	**59.5**	**34.4**	**52.2**	**50.5**	**61.7**	**39.3**	**66.0**
Foraminifera (Planktonic)	0.84	-	0.9	2.06	2.9	0.7	1.2	1.9	0.8
Radiolaria	3.36	0.2	0.6	1.03	1.8	1	0.4	0.9	0.8
Amphipoda	3.64	13.1	0.6	0.34	1.8	2.7	2.9	0.9	3.2
Ostracoda	1.12	16	3.6	5.84	2.5	1	2.1	1.9	1.6
Isopoda	0.56	-	1.5	0.69	-	1	-	-	-
Euphausiacea	6.16	-	5.4	10.7	4.3	10.9	6.2	8.4	0.8
Chaetognatha	53.2	26.7	16.3	29.2	26.5	15.9	8.6	16.8	11.1
Tunicata	0.28	-	-	-	-	-	-	-	-
Hydromedusae	3.08	-	2.4	1.72	-	4.7	4.5	5.6	2.4
Siphonophora	0.84	0.7	-	-	-	0.3	0.4	-	1.6
Pteropoda	1.96	-	1.2	-	-	1.7	1.6	3.7	-
Holoplankton total	**89.6**	**84**	**92.1**	**85.9**	**92**	**90.6**	**89.7**	**79.5**	**88.3**
Meroplankton									
Decapoda larvae	0.28	-	-	3.78	0.4	-	0.8	0.9	1.6
Octopod larvae	1.12	16	3.6	5.84	2.5	1	2.1	1.9	1.6
Fish eggs & larvae	3.36	-	2.4	1.72	2.9	2.7	3.7	10.3	5.6
Mollusca (Veligers)	0.56	-	1.2	1.03	1.4	2.4	1.6	1.9	1.6
Echnoderm larvae	1.12	-	0.6	1.37	0.7	2	2.1	1.9	0.8
Polychaete larvae	3.92	-	-	0.34	-	1.4	-	3.7	0.8
Meroplankton total	**10.4**	**16**	**7.9**	**14.1**	**7.9**	**9.5**	**10.3**	**20.6**	**11.9**

5.7.1. The diversity of zooplankton groups

The diversity indices of zooplankton collected on the leeward side of Minicoy stations is represented in Table 25, and the windward side is represented in Table 26. In the leeward stations, the highest Shannon index was observed in S14 (3.19) and was lowest (1.92) observed in S9. Evenness was observed lowest in S9 (0.55) and highest in S14 (0.8). Simpson's dominance indices were highest in S14 (0.86) and lowest in S9 (0.68). Richness value ranged from 2.27 (S12) to

4.15 (S3) (Table 23). In windward stations, the highest Shannon index was observed in station 36 (3.23) and lowest in S29 (2.54). Highest values of evenness (0.88) were observed in S24, and lowest (0.63) observed in station 38. Highest Simpson's dominance (0.9) observed in S36 and lowest in station 21 and 38 (0.77). The richness value ranges from 1.88 (S24) to 4.94 (S21) (Table 24). The highest average biodiversity indices were observed along with windward stations around Minicoy Island.

Table 25. Diversity indices of zooplankton groups in the leeward side of Minicoy during spring intermonsoon 2015.

Stations	H'	J'	Lambda	d
S3	2.61	0.67	0.79	4.15
S5	2.26	0.61	0.74	3.47
S8	2.58	0.63	0.78	3.80
S9	1.92	0.55	0.68	2.80
S12	2.06	0.62	0.70	2.27
S14	3.19	0.80	0.86	3.84
S15	2.94	0.72	0.84	5.01
S17	2.56	0.64	0.76	3.69
S20	2.38	0.64	0.75	3.11
Average	2.50±0.4	0.65±0.1	0.77±0.1	3.57±0.8

Table 26. Diversity indices of zooplankton groups in the windward side of Minicoy during spring intermonsoon 2015.

	H'	J'	Lambda	d
S21	2.90	0.67	0.77	4.94
S24	2.78	0.88	0.86	1.88
S26	2.63	0.66	0.78	3.68
S27	3.07	0.75	0.86	4.10
S29	2.54	0.67	0.78	3.50
S32	2.93	0.70	0.82	4.05
S33	2.73	0.67	0.79	4.24
S36	3.23	0.79	0.90	5.52
S38	2.56	0.63	0.77	4.63
Average	2.82±0.23	0.71±0.08	0.82±0.05	4.06±1.03

5.7.2. Composition of calanoid copepods

A total of 39 calanoid species belonging to 13 families and 18 genera were identified along the leeward and windward side of Minicoy Island (Table 27 and

28). Comparatively, the most abundant calanoid copepod family during the study was Pontellidae (33.5±20.1, 30.2±25.2%) followed by Candacidae (14.3±15.8% along leeward, 14.3±13.4% along windward) and Calanidae (13.2±16% along leeward and 12±11.2% along windward) (Figure 25). Spatial variation of copepod occurrence was observed in this study. The most abundant calanoid copepod family Pontellidae representatives of 17 species of calanoid copepods on average were observed in leeward stations of Minicoy while in the windward side, average species representation by 12 species. *Labidocera pavo*, *Pontella spinipes*, *Pontellopsis perpicax* and *Pontellopsis regalis* were observed only in the leeward side, and *Labidocera madurae* and *Pontella denticauda* were observed only in the windward side. *Labidocera pavo* was found exclusively in station 7. The species *Subeucalanus elongatus* (12, 20, 24, 27, 32, 33 and 38), *Scolecithrix danae* (5,12,14 & 21), *Eucaheta concinna* (3,5,8,20,26,29 and32), *Eucaheta longicornis* (3 and 32), *Centropages gracilis* (20,24 and 26), *Temora discaudata* (8,24,33 and 38), *Labidocera bataviae* (9,20 & 32), *L.detruncata* (8,20,26 &33), *L.kroyeri* (8,9,12,20 and 26) *L.madurae* (26,27,32,33 and 38), *Pontella denticauda* (33,36 & 38), *P.spinipes* (8,9,12&14), *Pontellopsis perpicax* and *Pontellopsis regalis* (14&20) Showed clear spatial occurrence (Table 27, 28).

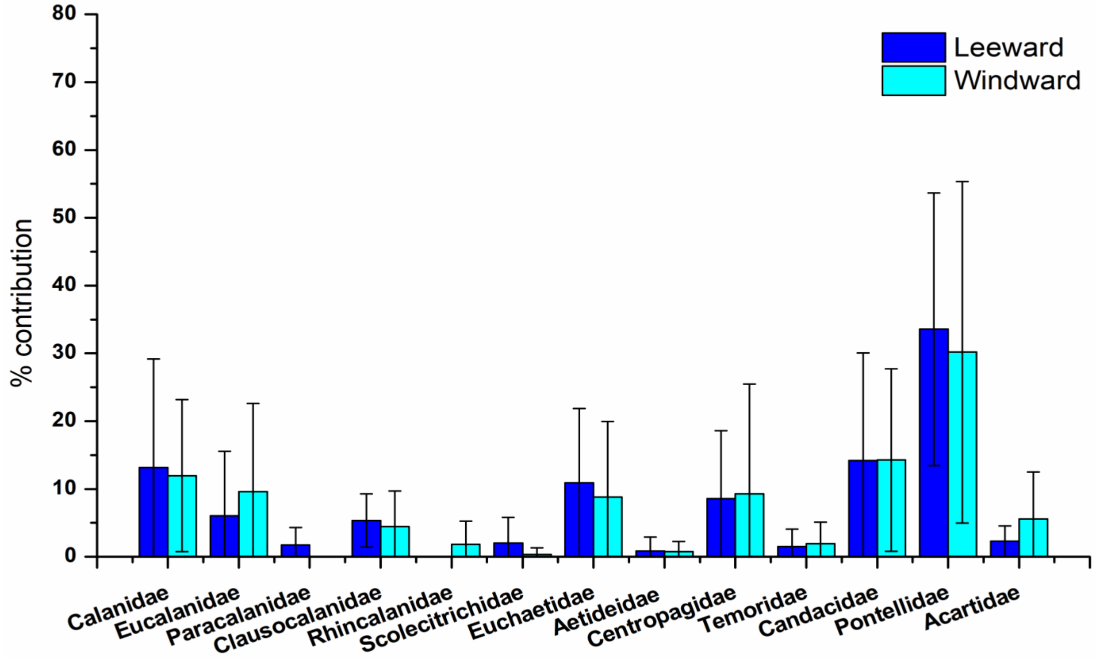

Figure 25. Average percentage composition of calanoid families along with leeward and windward directions of Minicoy Island.

Table 27. Variation in abundance (ind./m^3) of calanoid copepod species in the leeward side of Minicoy Island during spring intermonsoon 2015.

	S3	S5	S8	S9	S12	S14	S15	S17	S20
Total copepoda (ind./ m^3)	**11**	**14**	**25**	**16**	**24**	**15**	**8**	**23**	**19**
Order: Calanoida									
Family: Calanidae									
Undinula vulgaris	3.1	1.1	3.1	-	-	-	-	2.5	1.3
Family: Eucalanidae									
Paraeucalanus attenuatus	0.3	-	0.3	0.1	0.3	-	-	0.4	0.3
Paraeucalanus sewelli	-	-	-	-	1.2	1.5	0.01	0.01	0.2
Subecalanus mucronatus	-	0.3	0.3	0.1	0.2	-	-	-	0.2
Subeucalanus elongatus	-	-	-	-	0.3	-	-	-	0.01
Subeucalanus subtenuis	-	-	-	-	-	-	-	-	-
Family: Paracalanidae									
Paracalanus indicus	0.5	0.4	-	0.1	-	-	-	0.1	0.2
Family: Clausocalanidae									
Clausocalanus arcuicornis	0.5	0.8	1.9	0.7	0.3	0.2	0.01	0.2	0.8
Family: Rhincalanidae									
Rhincalanus rostrifrons	-	-	-	-	-	-	-	-	-
Family: Scolecitrichidae									
Scolecithrix danae	-	0.9	-	-	0.7	0.2	-	-	-
Family: Euchaetidae									
Euchaeta concinna	0.4	0.5	1	-	-	-	-	-	0.2
Euchaeta longicornis	0.8	-	-	-	-	-	-	-	-
Euchaeta marina	0.4	0.8	1.8	0.7	0.8	0.4	0.2	1.3	0.4
Family: Aetideidae									
Euchirella sp.	-	0.5	0.1	-	-	-	-	-	0.1
Family: Centropagidae									
Centopages calaninus	-	-	0.8	1.5	0.2	1.1	-	1.5	1.2
Centropages furcatus	-	-	0.3	1.0	0.5	-	-	-	0.5
Centropages gracilis	-	-	-	-	-	-	-	-	0.1
Family: Temoridae									
Temora discaudata	-	-	0.3	-	-	-	-	-	-
Temora stylifera	-	-	-	0.01	0.5	0.4	0.1	-	0.1
Temora turbinata	-	-	0.1	-	-	-	-	-	-
Family: Candacidae									
Candacia ethiopica	0.3	1.0	-	0.1	1.0	2.4	0.5	0.2	0.5
Candacia pachydactyla	0.3	0.8	0.3	1.3	0.3	-	0.1	-	0.2
Candacia simplex	-	0.3	0.7	-	0.7	0.9	-	-	0.3
Family: Pontellidae									
Labidocera acuta	0.01	0.01	0.8	0.01	0.5	0.01	0.01	0.01	0.1
Labidocera bataviae	-	-	-	0.4	-	-	-	-	0.1
Labidocera detruncata	-	-	0.8	-	-	-	-	-	0.1

Labidocera kroyeri	-	-	0.6	1.2	0.3	-	-	-	0.2
Labidocera madurae	-	-	-	-	-	-	-	-	-
Labidocera minuta	-	-	-	-	0.7	0.01	0.6	0.1	0.4
Labidocera pavo	-	-	-	-	-	-	0.9	-	-
Pontella denticauda	-	-	-	-	-	-	-	-	-
Pontella fera	-	-	1.9	0.7	0.3	-	0.6	1.6	0.7
Pontella sinica	-	-	0.01	0.6	1	0.6	-	-	-
Pontella spinipes	-	-	0.01	1.9	2.2	0.9	-	-	-
Pontellina plumata	-	-	0.8	0.2	2	-	0.7	-	1.3
Pontellopsis armata	0.6	0.5	-	0.8	0.8	-	0.2	-	1.5
Pontellopsis perspicax	-	-	-	-	-	0.2	-	-	0.4
Potellopsis regalis	-	-	-	-	-	0.2	-	-	0.1
Family: Acartidae									
Acartia negligens	0.4	-	0.4	0.1	0.5	-	0.12	-	0.7
Calanoid total	**7**	**8**	**16**	**12**	**15**	**9**	**4**	**8**	**13**
Order: Cyclopoida	**4**	**6**	**9**	**4**	**9**	**6**	**4**	**15**	**7**

Table 28. Variation in abundance (Ind./m^3) of calanoid copepod species in the windward side of Minicoy Island during spring intermonsoon 2015.

	S21	**S24**	**S26**	**S27**	**S29**	**S32**	**S33**	**S36**	**S38**
Total copepoda (ind./ m^3)	**6**	**15**	**22**	**13**	**14**	**22**	**17**	**5**	**13**
Order: Calanoida									
Family: Calanidae									
Undinula vulgaris	1.15	2	3.37	-	0.29	0.30	0.22	0.61	0.46
Family: Eucalanidae									
Paraeucalanus attenuatus	-	0.80	-	-	-	-	-	-	-
Paraeucalanus sewelli	-	-	1.35	-	2.26	1.34	0.67	-	0.61
Subecalanus mucronatus	-	-	-	-	-	-	-	-	-
Subeucalanus elongatus	-	0.53	-	0.25	-	0.15	0.44	-	0.15
Subeucalanus subtenuis	-	-	-	-	0.29	-	-	-	-
Family: Paracalanidae									
Paracalanus indicus	-	-	-	-	-	-	-	-	-
Family: Clausocalanidae									
Clausocalanus arcuicornis	-	1.07	2.13	0.38	0.39	0.45	0.11	-	-
Family: Rhincalanidae									
Rhincalanus rostrifrons	-	-	-	-	-	0.15	0.44	-	0.76
Family: Scolecitrichidae									
Scolecithrix danae	-	0.27	-	-	-	-	-	-	-
Family: Euchaetidae									
Euchaeta concinna	-	-	0.56	-	0.69	1.19	-	-	-
Euchaeta longicornis	-	-	-	-	-	0.3	-	-	-
Euchaeta marina	-	-	-	-	1.27	1.04	0.67	0.37	1.07

Family: Aetideidae									
Euchirella sp.	-	-	-	-	-	-	0.22	0.12	-
Family: Centropagidae									
Centopages calaninus	0.80	-	-	-	-	-	1.22	0.25	1.22
Centropages furcatus	-	-	1.35	-	-	-	-	-	-
Centropages gracilis	-	1.33	0.11	-	-	-	-	-	-
Family: Temoridae									
Temora discaudata	-	0.40	-	-	-	-	0.11	-	0.15
Temora stylifera	-	-	-	-	-	-	-	-	-
Temora turbinata	-	-	-	0.13	0.59	-	0.11	-	0.15
Family: Candacidae									
Candacia ethiopica	0.69	0.27	1.46	0.88	0.98	0.45	0.89	0.25	0.46
Candacia pachydactyla	1.03	-	0.67	0.38	0.49	0.75	-	-	-
Candacia simplex	-	-	0.45	-	-	-	-	-	-
Family: Pontellidae									
Labidocera acuta	0.11	1.2	0.34	1.13	-	0.6	0.11	0.37	1.37
Labidocera bataviae	-	-	-	-	-	0.15	-	-	-
Labidocera detruncata	-	-	1.8	-	-	-	0.44	-	-
Labidocera kroyeri	-	-	0.22	-	-	-	-	-	-
Labidocera madurae	-	-	0.67	1.38	-	0.90	0.11	-	0.15
Labidocera minuta	0.11	0.67	0.67	-	-	-	0.11	-	-
Labidocera pavo	-	-	-	-	-	-	-	-	-
Pontella denticauda	-	-	-	-	-	-	0.44	0.37	0.76
Pontella fera	-	-	-	-	1.27	-	0.89	-	0.31
Pontella sinica	-	-	-	-	2.06	0.9	-	-	-
Pontella spinipes	-	-	-	-	-	-	-	-	-
Pontellina plumata	-	-	-	0.88	-	0.3	0.22	0.12	0.15
Pontellopsis armata	-	0.67	-	0.75	0.2	-	0.11	0.25	0.15
Pontellopsis perspicax	-	-	-	-	-	-	-	-	-
Potellopsis regalis	-	-	-	-	-	-	-	-	-
Family: Acartidae									
Acartia negligens	-	0.13	-	1.64	1.37	0.9	-	0.12	0.31
Calanoid total	**4**	**9**	**15**	**8**	**12**	**10**	**8**	**3**	**8**
Order: Cyclopoida	**2**	**6**	**7**	**5**	**2**	**12**	**9**	**2**	**4**

5.7.3. Community structure of calanoid copepods

The diversity indices of calanoid copepods collected from the leeward side of Minicoy stations are represented in Table 29, and the windward side is represented in Table 30. In leeward stations, richness, evenness and Shannon indices were lowest in station 17 (S17). Highest Shannon diversity observed in S20 (4.63) and the lowest value observed is 0.94(S5). Evenness values were ranged from 0.74 to 98(S12). Simpson's dominance indices ranged from 0.8 (S3, S17) to 0.94 (S12, S20) and the richness value ranged from 2.18 to 5.94 (S20) (Table 29). In windward stations, the highest Shannon index was observed in station 33 (3.8) and lowest in S21 (2.23). The highest value of evenness (0.94) was observed in S36, and lowest (0.86) observed in S21. Simpson's dominance ranged from 0.78 (s21 to 0.92 (S32 and S33) and the richness value ranged from 1.09 (S21) to 3.96 (S33) (Table 30).

Table 29 Diversity indices of calanoid copepods in the leeward side of Minicoy during spring intermonsoon 2015.

Stations	H'	J'	Lambda	d
S3	2.91	0.81	0.80	2.35
S5	3.48	0.94	0.91	2.61
S8	3.76	0.86	0.91	4.32
S9	3.62	0.85	0.91	3.94
S12	4.12	0.92	0.94	4.54
S14	3.14	0.82	0.87	2.82
S15	3.02	0.81	0.86	2.60
S17	2.54	0.74	0.80	2.18
S20	4.23	0.88	0.94	5.94
Average	**3.42±0.57**	**0.85±0.06**	**0.88±0.05**	**3.48±1.28**

Table 30. Biodiversity indices of calanoid copepods in the windward side of Minicoy during spring intermonsoon 2015.

Stations	H'	J'	Lambda	d
S21	2.23	0.86	0.78	1.09
S24	3.27	0.91	0.89	2.37
S26	3.38	0.89	0.89	2.82
S27	3.04	0.91	0.87	1.97
S29	3.36	0.91	0.89	2.60
S32	3.72	0.93	0.92	3.27
S33	3.80	0.90	0.92	3.96
S36	3.14	0.94	0.88	1.98
S38	3.59	0.90	0.91	3.24
Average	**3.28±0.47**	**0.91±0.02**	**0.88±0.04**	**2.59±0.86**

The K-dominance curves of calanoids from the leeward side of Minicoy revealed the highest dominance of the species in the stations S17, S3, S14 and S15 and lowest diversity (Fig. 26).In the windward side, lowest dominance and highest diversity of the species was observed in all stations except S21 (Fig. 27).

The MDS plot of the leeward side of Minicoy (Fig. 28) showed a separation of three groups with an overall similarity of the stations 40% except for S14 and S15. The stations S9 & S12, S8&S20, S3&S5 formed three groups with 60% similarity. In windward side, (Fig. 29) the stations S24, S26 and remaining stations except for S21 with 40% similarity. Moreover, the stations S29 & S32, S33 & S38 forms two groups with 60% similarity.

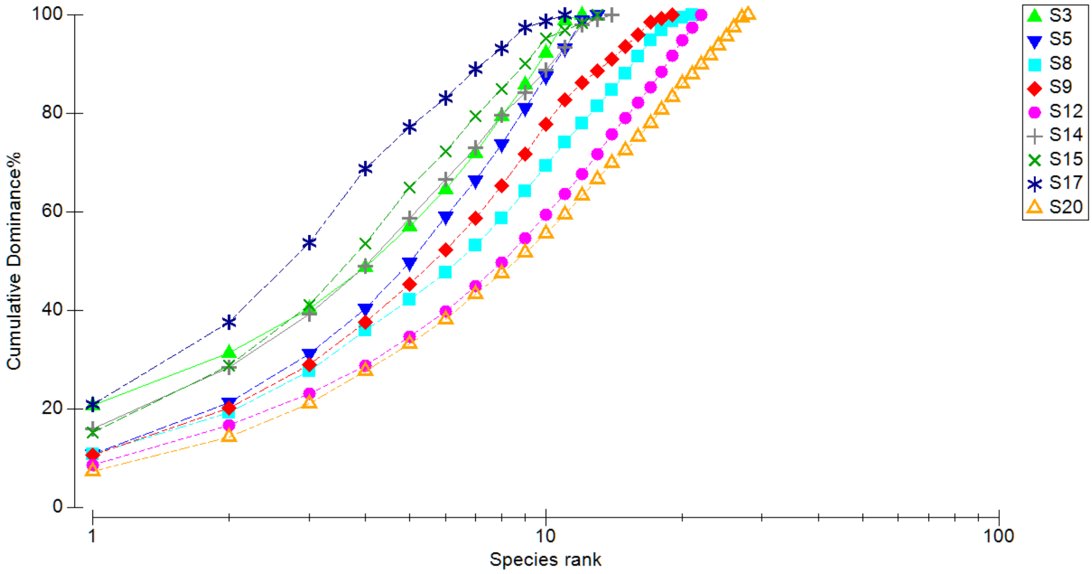

Figure 26. *K*-dominance curves of calanoids in the leeward side of Minicoy during spring intermonsoon 2015.

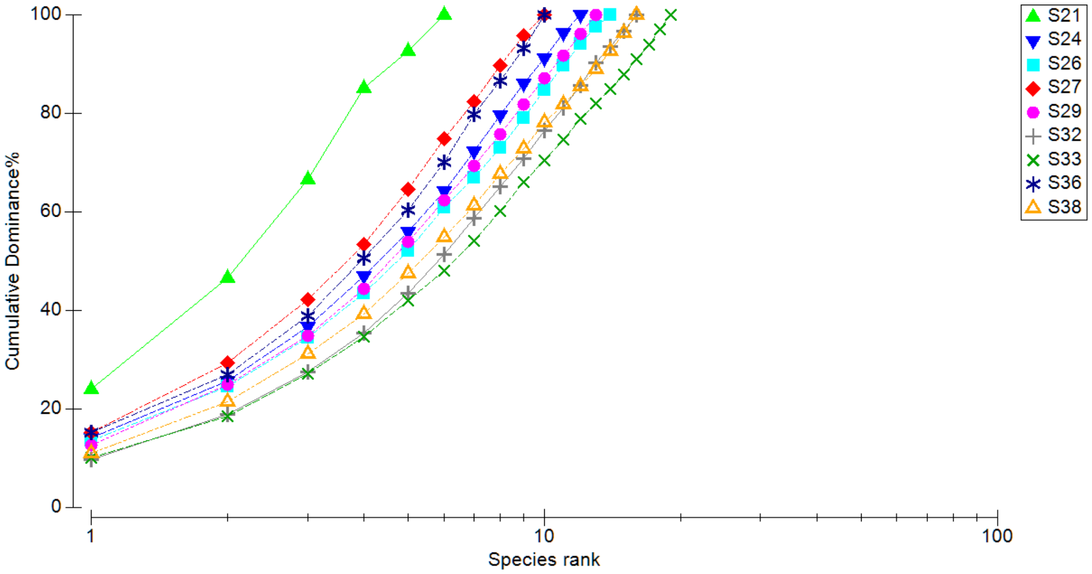

Figure 27. *K*-dominance curves of calanoids in the windward side of Minicoy during spring intermonsoon 2015.

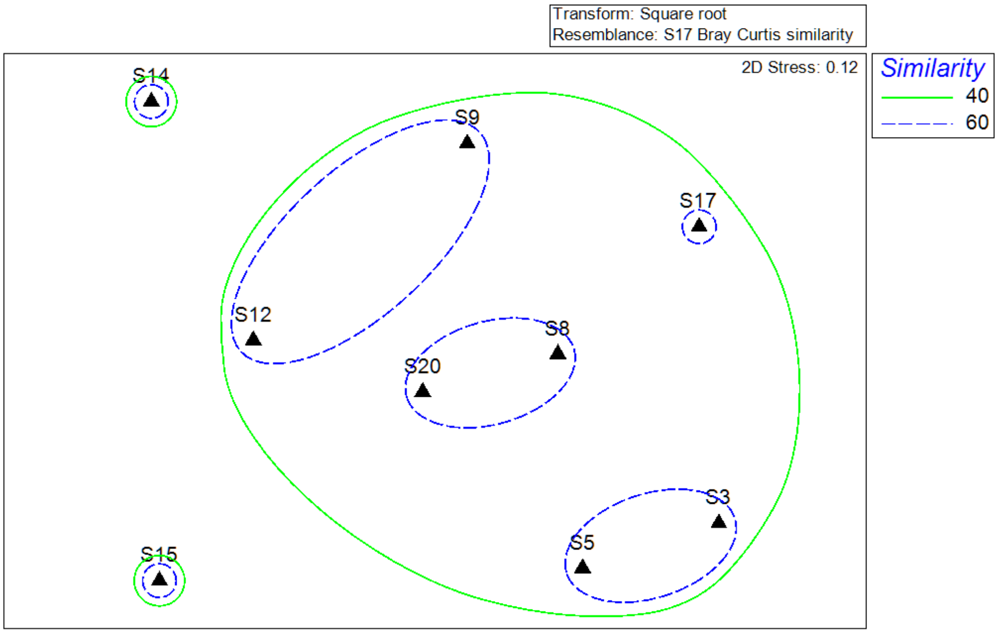

Figure 28. MDS orientation of Bray-Curtis similarity matrix of calanoid species abundance data (square root transformed) of nine stations in the leeward side of Minicoy during spring intermonsoon 2015.

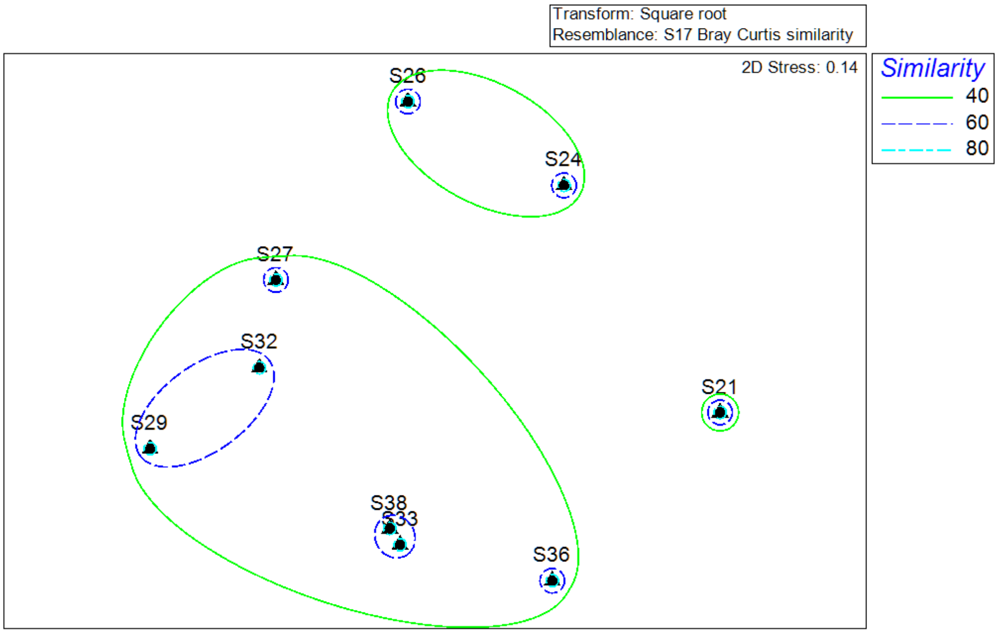

Figure 29. MDS orientation of Bray-Curtis similarity matrix of calanoid species abundance data (square root transformed) of nine stations in the windward side of Minicoy during spring intermonsoon 2015.

Figure 30. MDS bubble plots of the species (A) *Labicocera pavo*, (B) *Pontella spinipes*, (C) *Pontellopsis perspicax,* (D) *Pontellopsis regalis*, (E) *Candacia ethiopica,* (F) *Clausocalanus arcuicornis* distributed along the leeward side of Minicoy.

The MDS bubble plots of *Labicocera pavo*, *Pontella spinipes*, *Pontellopsis perspicax, Pontellopsis regalis*, *Candacia ethiopica*, and *Clausocalanus arcuicornis* (Fig. 30 A-F) from leeward side and plots of *Undinula vulgaris*, *Candacia ethiopica*, *Labidocera madurae*, *Pontellopsis armata*, *Pontella denticauda*, *Acartia negligens* (Fig. 31 A-F) from windward side indicates the percentage contribution and distribution along the stations.

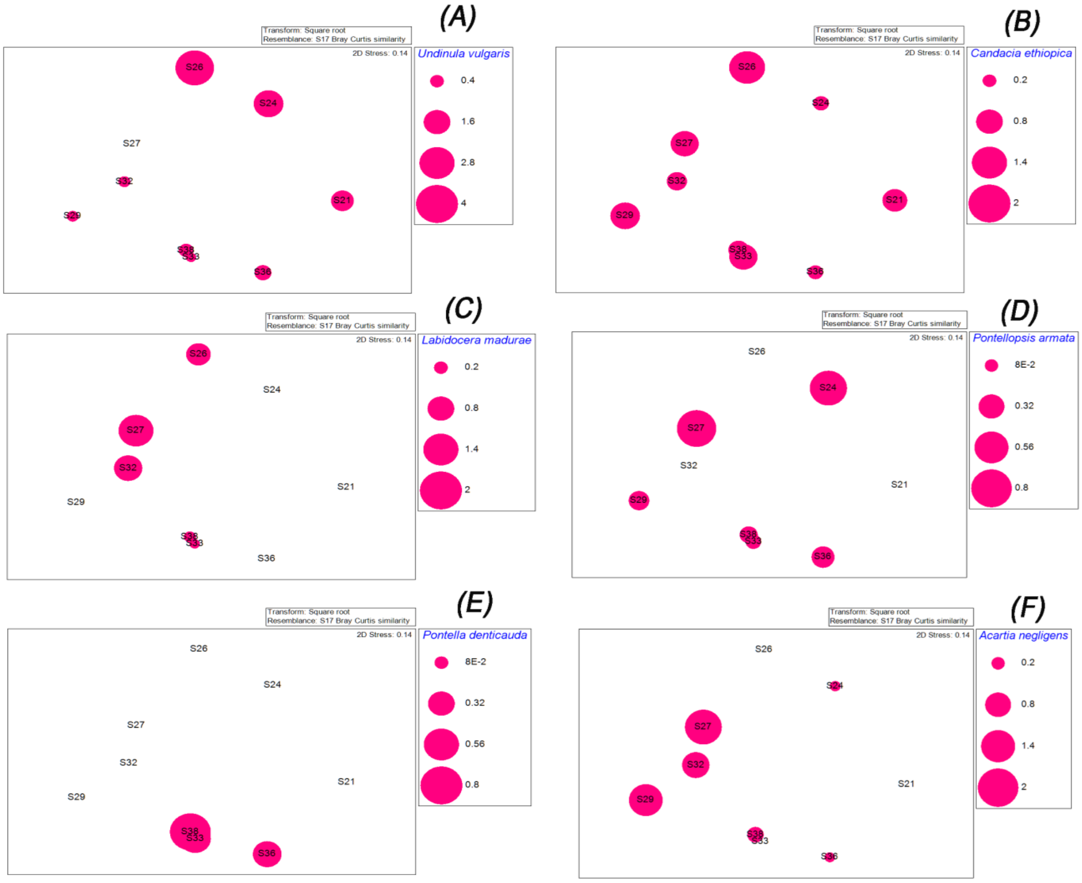

Figure 31. MDS bubble plots of the species (A) *Undinula vulgaris*, (B) *Candacia ethiopica*, (C) *Labidocera madurae,* (D) *Pontellopsis armata*, (E) *Pontella denticauda*, (F) *Acartia negligens* distributed along the windward side of Minicoy.

C. Zooplankton community in coastal waters of Southwest coast of India.

5.8. ZOOPLANKTON COMMUNITY STRUCTURE DURING SPRING INTERMONSOON 2015.

The volume of water filtered ranged from 126 -167 m^3. Zooplankton abundance ranged from 81 to 197 ind/m^3 and total biomass of 0.03 to 0.22 ml/m^3 (Table 31). Holoplankton composition was higher than that of meroplankton except station 2 (Holoplankton 46.2%, meroplankton 53.8%). Decapod larvae contributed a major share in meroplankton composition (49.7%) in station 2. Chaetognaths were the second dominant groups in most of the stations among holoplankton and copepods, and chaetognaths nearly contribute equal share (copepods 10.2%, chaetognaths 10.7%). In station 48, pteropods (8.4%), and in stations 51 and 53 hydromedusae (11.1%, 18.1%) were the second dominant groups. Planktonic foraminifera was observed only in stations 2, 39 and 45.

Table 31. Percentage composition of various taxonomic groups of holo and meroplankton to total zooplankton in the coastal waters of South West coast of India during spring intermonsoon 2015.

	S2	S39	S45	S46	S47	S48	S51	S52	S53
Total zooplankton (ind/m^3)	**197**	**99**	**83**	**90**	**109**	**95**	**81**	**116**	**149**
Biomass (ml/m^3)	0.12	0.04	0.03	0.03	0.1	0.06	0.06	0.1	0.22
Holoplankton									
Calanoid	8.63	23	22.9	26	28.4	20	29.6	29	17.4
Cyclopoids	1.52	9.1	12	14	16.5	6.3	8.64	10	2.68
Copepod Total	**10.2**	**32**	**34.9**	**40**	**45**	**26**	**38.3**	**40**	**20.1**
Foraminifera (Planktonic)	1.52	2	2.41	-	-	-	-	-	-
Radiolaria	1.02	4	7.23	4.4	6.42	6.3	3.7	0.9	1.34
Amphipoda	0.51	3	3.61	5.6	1.83	3.2	-	-	2.01
Ostracoda	1.52	7.1	6.02	6.7	2.75	2.1	6.17	7.8	5.37
Isopoda	7.11	2	-	-	1.83	3.2	6.17	3.4	-
Euphausiacea	2.54	6.1	-	7.8	0.92	-	-	-	3.36
Chaetognatha	10.7	13	12	10	11.9	7.4	9.88	13	12.8
Tunicata	3.05	3	4.82	-	3.67	3.2	2.47	-	6.04
Hydromedusae	-	2	-	-	1.83	6.3	11.1	11	18.1
Siphonophora	-	2	3.61	-	-	4.2	3.7	6	4.03
Pteropoda	2.54	8.1	6.02	3.3	3.67	8.4	1.23	1.7	2.01
Other groups	5.58	3	2.41	5.6	8.26	12	8.64	3.4	8.05
Holoplankton total	**46.2**	**88**	**83.1**	**83**	**88.1**	**82**	**91.4**	**87**	**83.2**
Meroplankton									
Decapoda larvae	49.7	5.1	3.61	5.6	2.75	4.2	4.94	7.8	8.05
Octopod larvae	1.52	-	4.82	1.1	3.67	3.2	-	-	-
Fish eggs & larvae	1.52	5.1	2.41	3.3	3.67	6.3	3.7	5.2	7.38
Mollusca (Veligers)	-	-	1.2	3.3	1.83	-	-	-	1.34
Echinoderm larvae	-	1	3.61	-	-	2.1	-	-	-
Polychaete larvae	1.02	1	1.2	3.3	-	2.1	-	-	-
Meroplankton total	**53.8**	**12**	**16.9**	**17**	**11.9**	**18**	**8.64**	**13**	**16.8**

5.8.1. Diversity of zooplankton

The diversity indices of zooplankton collected from coastal waters of the Arabian Sea is represented in Table 32. Highest Shannon index value was observed in S48 (3.78) and the lowest observed was 2.71(S2). Evenness values were ranged from 0.68(S2) to 0.92(S48). Simpson's dominance index was lowest in station 2 (0.73), and highest was in S48 (0.92), and richness value ranged from 2.31(S52) to 3.7(S39) (Table 32).

Table 32. Diversity indices of zooplankton groups along coastal waters of Arabian Sea during spring intermonsoon 2015.

Stations	H'	J'	Lambda	d
S2	2.71	0.68	0.73	2.84
S39	3.67	0.88	0.90	3.70
S45	3.64	0.89	0.91	3.62
S46	3.41	0.89	0.89	2.89
S47	3.33	0.83	0.87	3.20
S48	3.78	0.92	0.92	3.51
S51	3.26	0.88	0.87	2.73
S52	3.13	0.87	0.86	2.31
S53	3.48	0.89	0.90	2.80
Average	**3.38±0.33**	**0.86±0.07**	**0.87±0.06**	**3.07±0.47**

5.8.2. Composition of calanoid copepods

A total of 42 calanoid species belonging to 12 families and 17 genera were identified along coastal waters of the south-west coast of India during spring intermonsoon 2015. The most abundant calanoid copepod family along the south-west coast of India during the study period was Pontellidae (39 %) having 15 species, followed by Eucalanidae (16%) represented by six species, Centropagidae (7%) and Candacidae (8%) represented by four species (Table 33 and Figure 33). Spatial variation of species occurrence observed in this study. Representatives of 20 species of calanoid copepods on average were observed. The species *Paracalanus indicus* (9, 52 & 53) *Centropages furcatus* (46, 52), *Centropages orsini* (52, 53), *Candacia ethiopica* (2, 46 & 51), *C. pachydactyla* (45, 51 & 52), *Labidocera bataviae* (48, 51 &52), *L.detruncata* (48, 51 & 53), *L. kroyeri* (47,48 & 52), *Pontella denticauda*, *P.fera*, *P.sinica*, (45 & 48), *P.spinipes*, (45,48,52 & 53) , *Acartia erythraea* (45, 47) shows clear spatial occurrence in coastal waters of south-west coast of India (Table 33).

Table 33. Variation in abundance (Ind./m^3) of calanoid copepod species in the coastal waters of South West coast of India during spring intermonsoon 2015.

	S2	S39	S45	S46	S47	S48	S51	S52	S53
Total copepoda (No/ m^3)	**20**	**32**	**29**	**36**	**49**	**25**	**31**	**46**	**30**
Order: Calanoida									
Family: Calanidae									
Canthocalanus pauper	-	-	0.9	0.5	-	1	-	0.4	0.3
Undinula vulgaris	1	2.3	-	2.5	1.7	-	4	0.6	2.1
Family: Eucalanidae									
Paraeucalanus attenuatus	-	-	1	-	1	2.7	-	1	0.3
Paraeucalanus sewelli	0.7	2.7	-	-	-	-	-	0.7	0.2
Subecalanus mucronatus	5	-	-	0.2	0.7	0.5	0.1	-	0.1
Subeucalanus elongatus	-	0.8	1.2	-	2.3	-	-	-	0.2
Subeucalanus subcrassus	-	1.5	-	-	-	0.1	0.2	-	-
Subeucalanus subtenuis	1	-	1	0.1	1	0.7	-	3	1.4
Family: Paracalanidae									
Paracalanus indicus	-	0.2	-	-	-	-	-	3.7	0.2
Family: Clausocalanidae									
Clausocalanus arcuicornis	-	0.2	0.2	-	2	-	-	-	0.2
Family: Rhincalanidae									
Rhincalanus rostrifrons	-	-	0.1	-	1	-	-	2	0.7
Family: Scolecitrichidae									
Scolecithrix danae	-	-	0.2	0.6	2.3	-	-	0.2	1.4
Family: Euchaetidae									
Euchaeta concinna	-	1	-	1	0.5	-	1	2.7	1.2
Euchaeta longicornis	0.3	-	-	-	1.2	-	-	1	
Euchaeta marina	-	-	0.8	1	3	-	2	3.1	2.7
Family: Centropagidae									
Centopages calaninus	-	1.7	-	-	3	-	1	-	0.2
Centropages furcatus	-	-	-	2	-	-	-	2.5	-
Centropages orsini	-	-	-	-	-	-	-	0.1	3
Centropages gracilis	0.5	-	0.7	0.2	2.1	0.5	-	-	-
Family: Temoridae									
Temora discaudata	-	0.2	0.7	-	-	1	0.3	0.7	0.1
Temora turbinata	-	-	0.3	2	-	1.6	0.4	1	0.5
Family: Candacidae									
Candacia ethiopica	2	-	-	1	-	-	1.3	-	-
Candacia pachydactyla	-	-	-	1.6	-	-	-	0.2	0.4
Candacia simplex	-	-	0.5	-	-	-	-	-	-
Candacia truncata	-	5	-	1	-	-	3.1	0.3	0.3
Family: Pontellidae									
Labidocera acuta	-	-	1	2.1	1.1	-	3	-	1.6
Labidocera bataviae	-	-	-	-	-	0.3	0.6	0.4	-

Labidocera detruncata	-	-	-	-	-	0.2	0.2	-	0.7
Labidocera kroyeri	-	-	-	-	0.7	0.1	-	1	-
Labidocera madurae	-	-	-	0.1	-	-	0.4	2.7	0.4
Labidocera minuta	-	-	-	1	1	-	-	-	1.3
Labidocera pavo	-	-	-	-	1.5	-	0.9	2.7	0.6
Pontella denticauda	-	-	2.3	-	-	2.7	-	-	-
Pontella fera	-	-	2	-	-	1.8	-	-	-
Pontella sinica	-	-	1.7	-	-	3	-	-	-
Pontella spinipes	-	-	3.1	-	-	2	-	0.1	0.3
Pontellina plumata	6	3.7	1	1.4	-	-	2	0.3	-
Pontellopsis armata	-	2.8	-	-	-	-	2.7	1.7	2.4
Pontellopsis perspicax	-	-	-	2	2.3	0.7	0.2	0.2	-
Potellopsis regalis	0.5	0.9	-	1	-	0.1	0.6	0.7	2.6
Family: Acartidae									
Acartia erythraea	-	-	0.3	-	1	-	-	-	-
Acartia negligens	-	-	-	1.7	1.6	-	-	1	0.6
Order: Cyclopoida	**3**	**9**	**10**	**13**	**18**	**6**	**7**	**12**	**4**

5.8.3. Community structure of calanoid copepods

The diversity indices of calanoids collected from coastal waters of the Arabian Sea is represented in table 34. Highest Shannon index value was observed in S52 (4.21) and the lowest value observed was 2.49 in S2. Simpson's index was lowest in S2 (0.81), and highest were in stations S45, 46, 47 and S53 (0.97) Evenness values were ranged from 0.78(S2) to 0.96 (S47). Richness values were varied from 2.82 (S2) to 8.34 (S53) (Table 34).

Table 34. Diversity indices of calanoid copepods along coastal waters of Arabian Sea during spring intermonsoon 2015.

Stations	H'	J'	Lambda	d
S2	2.49	0.78	0.81	2.82
S39	3.23	0.87	0.91	3.83
S45	3.85	0.91	0.97	6.11
S46	4.00	0.93	0.97	6.06
S47	4.16	0.96	0.97	5.53
S48	3.54	0.87	0.95	5.43
S51	3.67	0.87	0.94	5.66
S52	4.21	0.89	0.96	7.39
S53	4.19	0.87	0.97	8.34
Average	3.70±0.56	0.88±0.05	0.94±0.05	5.69±1.66

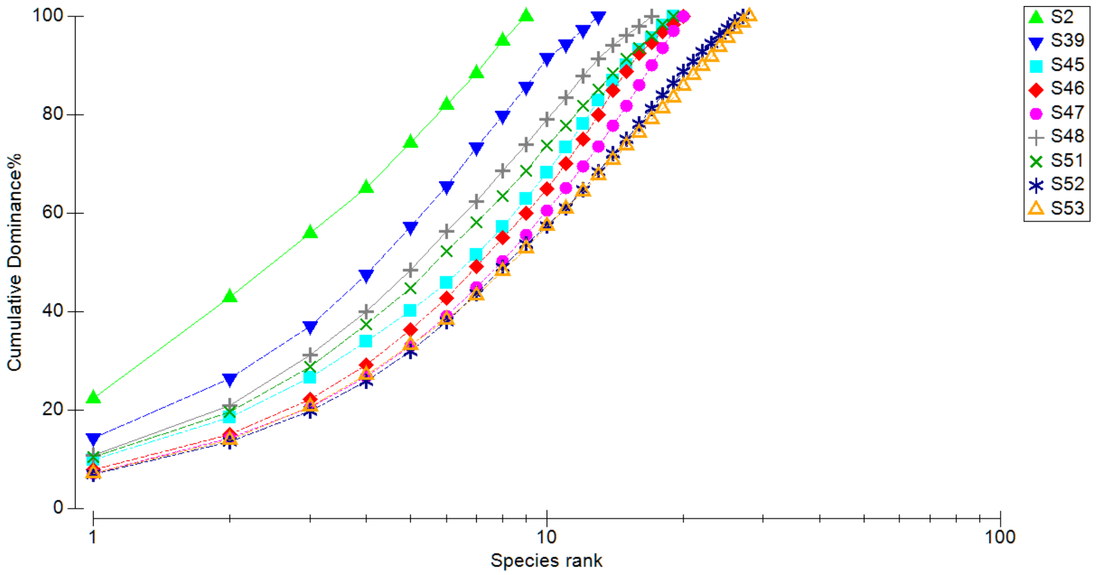

Figure 30. *K*-dominance curves of calanoids along coastal waters of the Arabian Sea during intermonsoon 2015.

The K-dominance curves of calanoids from 9 stations of coastal waters of the Arabian Sea revealed the highest dominance of the species in the stations S2 and S39 and lowest diversity (Fig. 30). The remaining stations with the lowest dominance and higher diversity.

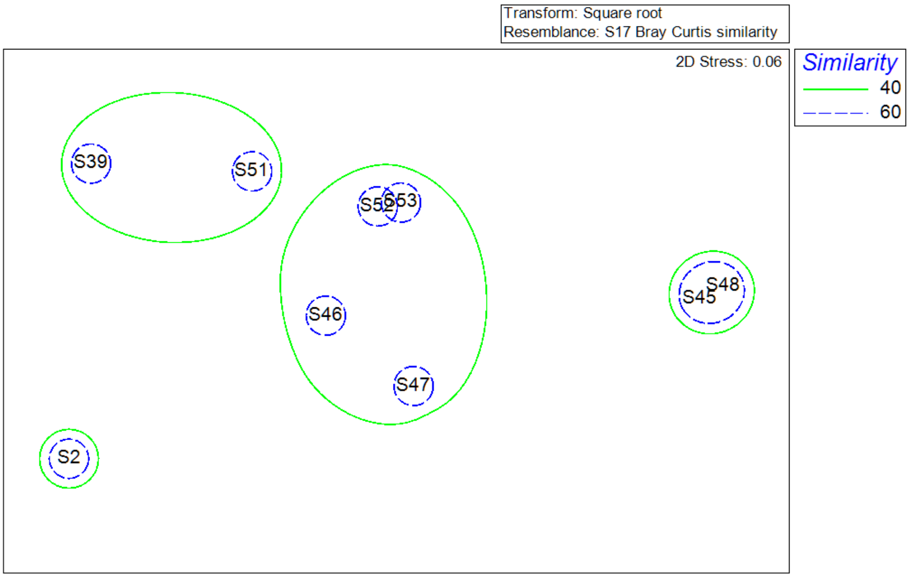

Figure 31. MDS orientation of Bray-Curtis similarity matrix of calanoid species abundance data (square root transformed) of nine stations in coastal waters of Arabia Sea during spring intermonsoon 2015.

Figure 32. MDS bubble plots of the species (A) *Subeucalanus mucronatus*, (B) *S.subcrassus*, (C) *Pontellopsis perspicax,* (D) *Centropages gracilis*, (E) *C.calaninus*, (F) *Euchaeta concinna* distributed along coastal waters of South West coast of India.

The MDS plot of the stations from the south-west coast of India (Fig. 31) showed a separation of three groups. The stations S39 & S51, S46, S47, S52 & S53, formed two groups with 40% similarity. The stations S45&S48 form a separate group with 60% similarity. The MDS bubble plots of the species *Subeucalanus mucronatus*, *S.subcrassus*, *Pontellopsis perspicax, Centropages gracilis*, C. *calaninus*, *Euchaeta concinna* (Figs. 32 A-F) indicates the contribution and distribution along with the stations.

5.9. ZOOPLANKTON COMMUNITY STRUCTURE DURING FALL INTERMONSOON 2015

The volume of water filtered ranged from 132 -167 m^3. Zooplankton abundance is ranging from 70 to 150 ind/m^3 and total biomass of 0.01 to 0.05 ml/m^3 (Table 35). Holoplankton composition was higher than that of meroplankton in all stations. Copepods contributed a significant share in the zooplankton composition. Chaetognaths were the second dominant group in most of the stations among holoplankton.

Table 35. Percentage composition of various taxonomical groups of holo and meroplankton to total zooplankton in the coastal waters of South West coast of India during fall intermonsoon 2015.

	S1	**S7**	**S9**	**S15**	**S18**	**S22**	**S23**
Total zooplankton (ind/m^3)	**113**	**97**	**132**	**97**	**90**	**70**	**150**
Biomass (ml/m^3)	0.03	0.02	0.02	0.04	0.04	0.01	0.05
Holoplankton							
Calanoid	39.8	49.5	47	53.6	64.4	47	34.0
Cyclopoids	21.2	26.8	28.8	33.0	28.9	19	16.7
Copepod Total	**61.1**	**76.3**	**75.8**	**86.6**	**93.3**	**66**	**50.7**
Radiolaria	2.7	-	-	3.1	-	5.7	1.3
Amphipoda	1.8	-	-	1	1.1	2.9	2.7
Ostracoda	0.9	1	-	1	-	2.9	0.7
Isopoda	1.8	-	-	2.1	-	-	-
Euphausiacea	1.9	1.0	3	-	-	5.7	5.3
Chaetognatha	12.4	15.5	7.6	2.1	1.1	4.3	10
Tunicata	1.8	-	2.2	-	-	1.4	0.7
Hydromedusae	-	-	-	2.1	-	4.3	3.3
Siphonophora	0.9	1	2.2	1	1.1	2.9	7.3
Pteropoda	4.4	2	-	4.1	-	-	-
Other groups (un identified)	1.8	1	0.7	2.1	1.1	2.9	6.7
Holoplankton total	**91.2**	**97.9**	**91.7**	**105.2**	**97.8**	**99**	**88.7**
Meroplankton							
Decapoda larvae	7.	5.15	3.7	-	-	1.4	2
Fish eggs & larvae	0.8	-	-	-	7.7	2.9	8.67
Mollusca (Veligers)	-	3.1	4.5	-	-	-	-
Echinoderm larvae	-	-	-	1	-	4.3	3.3
Polychaete larvae	0.8	-	-	-	-	1.4	0.7
Meroplankton total	**8.8**	**8.25**	**8.3**	**1**	**7.7**	**10**	**14.7**

5.9.1. Diversity of zooplankton

The diversity indices of zooplankton collected from coastal waters of the Arabian Sea is represented in table 34. All indices were lowest in station 18 (S18) and highest in station 22 (S22). Highest Shannon index was observed was 3.69 and the lowest value observed was 2.31. Evenness values were ranged from 0.82 to 0.95. Simpson's dominance index was varied from 0.79 to 0.94, and the richness value ranged from 2.02 to 4.17.

Table 36. Diversity indices of zooplankton along coastal waters of Arabian Sea during fall intermonsoon 2015.

Stations	H'	J'	Lambda	d
S1	3.59	0.92	0.93	4.00
S7	2.94	0.88	0.87	2.79
S9	2.87	0.91	0.87	2.39
S15	3.16	0.88	0.88	3.37
S18	2.31	0.82	0.79	2.02
S22	3.69	0.95	0.94	4.17
S23	3.68	0.94	0.93	3.76
Average	3.18±0.51	0.90±0.04	0.89±0.05	3.21±0.83

5.9.2. The composition of calanoid copepods

A total of 27 calanoid species belonging to 11 families and 15 genera were identified along coastal waters of the south-west coast of India during fall intermonsoon 2015. The most abundant calanoid copepod family along the southwestern coast of India during the study period was Pontellidae (27%) having nine species, followed by Candacidae (10%) represented by four species (Table 37 and Figure 33). In all stations, representatives of 15 species of calanoid copepods on average were observed. The species *Canthocalanus pauper* (S7, S9), *Paracalanus indicus* (S7, S18 & S23), *Rhincalanus rostrifrons* (S9), *Centropages calaninus* (S8, S9 & S23), *C.gracilis* (S7, S9), *Candacia ethiopica* (S1, S18 & S22), *C.simplex* (S7, S9 & S23), *C.truncata* (S2, S9 & S23), *Pontella spinipes*, (S7 & S18), shows clear spatial occurrence (Table 37).

Table 37. Variation in abundance (Ind./m^3) of calanoid copepod species in the coastal waters of South West coast of India during fall intermonsoon 2015.

	S1	S7	S9	S15	S18	S22	S23
Total copepoda (No/ m^3)	**69**	**74**	**101**	**84**	**84**	**46**	**75**
Order: Calanoida							
Family: Calanidae							
Canthocalanus pauper	-	0.9	0.9	-	-	-	-
Undinula vulgaris	5.8	10	9.7	6.5	15	10.4	5.6
Family: Eucalanidae							
Subeucalanus subcrassus	8.7	5.43	3	6.5	-	3.17	2.8
Family: Paracalanidae							
Paracalanus indicus	-	0.3	-	-	0.3	-	2
Family: Clausocalanidae							
Clausocalanus arcuicornis	12	8.7	1.2	8.6	3	1.59	8
Family: Rhincalanidae							
Rhincalanus rostrifrons	-	-	0.7	-	-	-	-
Family: Euchaetidae							
Euchaeta concinna	-	1.09	0.7	3.2	-	-	0.4
Euchaeta marina	3.8	3.26	0.7	4.3	-	-	0.4
Euchaeta indica	7.7	-	4.48	-	4.4	1.59	-
Family: Centropagidae							
Centopages calaninus	-	-	1.75	-	2.2	-	1.2
Centropages gracilis	-	2	2.4	-	-	-	-
Family: Temoridae							
Temora discaudata	-	-	1.49	-	1.1	1.59	2.4
Temora turbinata	-	-	1.75	-	1.1	1.59	1.6
Family: Candacidae							
Candacia ethiopica	1.9	-	-	-	1.1	1.59	-
Candacia pachydactyla	-	-	1.5	-	2.2	1.59	6.8
Candacia simplex	-	5.43	0.6	-	-	-	2.4
Candacia truncata	-	-	5.97	-	-	0.5	1.6
Family: Pontellidae							
Labidocera acuta	-	1.09	3.7	2.2	5.5	0.7	-
Labidocera detruncata	-	1.09	-	2.1	1.1	1.6	5.6
Labidocera madurae	-	-	0.8	1.1	-	0.8	-
Labidocera minuta	-	-	2.2	2.2	1.1	0.6	3.2
Pontella fera	-	-	5.9	5.4	8.8	2.4	1.2
Pontella spinipes	-	1.09	-	-	2.2	-	-
Pontellina plumata	1.9	2.17	5.9	-	1.1	1.6	2.4
Pontellopsis armata	-	1.09	-	4.3	4.4	1.8	-
Potellopsis herdmani	1.7	-	0.6	3.2	-	-	1.2
Family: Acartidae							
Acartia negligens	-	3.3	4.5	-	1.1	-	1.2
Unidentified	1.9	1.1	2.3	2.2	2.2	-	0.4
Order: Cyclopoida	**24**	**26**	**38**	**32**	**26**	**13**	**25**

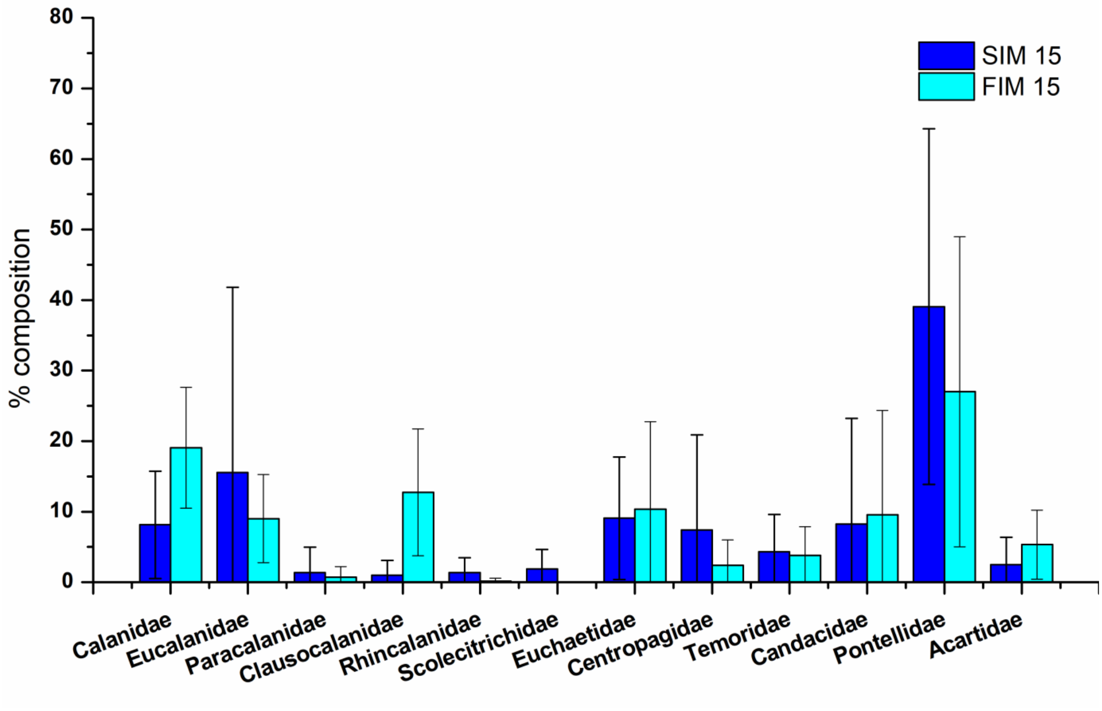

Figure 33. Average Percentage composition of calanoid families along the south-west coast of India during spring intermonsoon and fall intermonsoon 2015.

5.9.3. Community structure of calanoid copepods

The diversity indices of calanoids collected from 7 coastal stations of Arabian Sea is represented in Table 36. Highest Shannon index was observed in S9 (4.4) and the lowest value observed was 3.08 in station 1 (S1). Evenness values were ranged from 0.96(S7, S18) to 0.99 (S15). Simpson's dominance index was lowest in S1 (0.92) and highest in station S9 (0.98), and the richness value ranged from 2.72 (S1) to 6.19 (S9) (Table 38).

Table 38. Diversity indices of calanoid copepods along coastal waters of Arabian Sea during fall intermonsoon 2015.

Stations	H'	J'	Lambda	d
S1	3.08	0.97	0.92	2.72
S7	3.85	0.96	0.96	4.66
S9	4.40	0.97	0.98	6.19
S15	3.65	0.99	0.96	3.73
S18	4.01	0.96	0.96	5.05
S22	3.89	0.97	0.97	4.91
S23	4.12	0.97	0.97	5.37
Average	**3.86±0.42**	**0.97±0.01**	**0.96±0.02**	**4.66±1.13**

The K-dominance curves of calanoids from 7 stations of coastal waters of Arabian Sea revealed the highest dominance of the species in the station S1 and lowest diversity and the station S9 with the highest diversity of the species with the lowest dominance (Fig. 34).

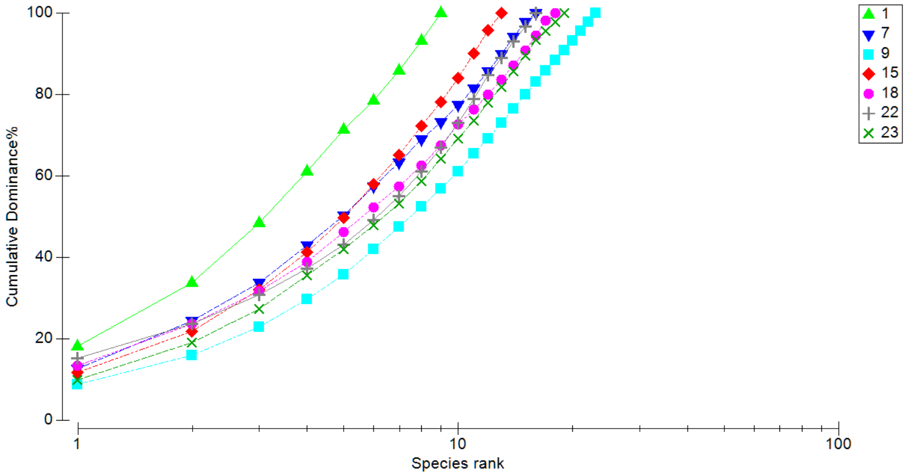

Figure 34. *K*-dominance curves of calanoids along coastal waters of the Arabian Sea during intermonsoon 2015.

The MDS plot of 7 stations along the coastal waters of Arabia Sea (Fig.35) formed with 40% similarity. The stations S9 & S23 and S18 & S22 form an inner group with 60% similarity. The MDS bubble plots of the species *Undinula vulgaris, Clausocalanus arcuicornis*, *labidocera acuta,* and *pontellina plumata* (Fig. 36 A-D), indicates the contribution and distribution along the stations.

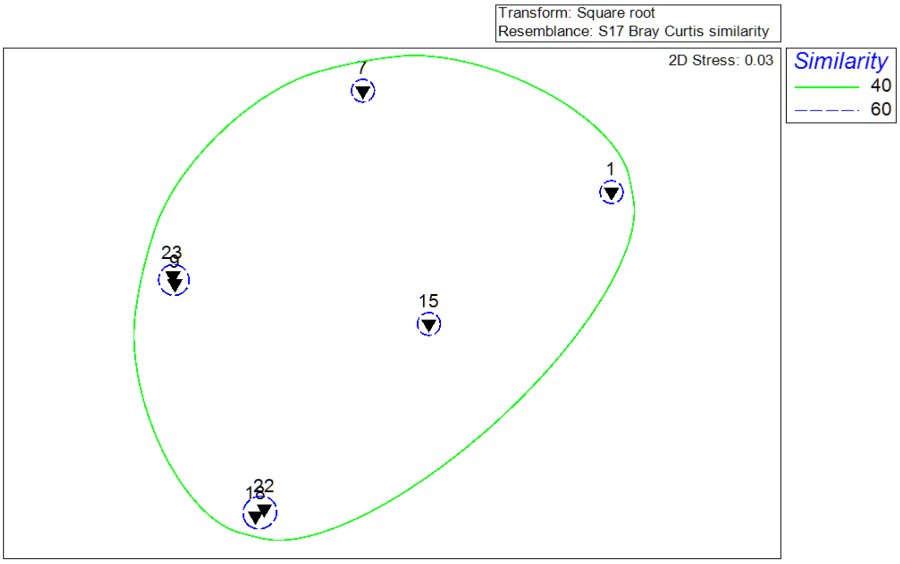

Figure 35. MDS orientation of Bray-Curtis similarity matrix of calanoid species abundance data (square root transformed) of seven stations in coastal waters of Arabia Sea during fall intermonsoon 2015.

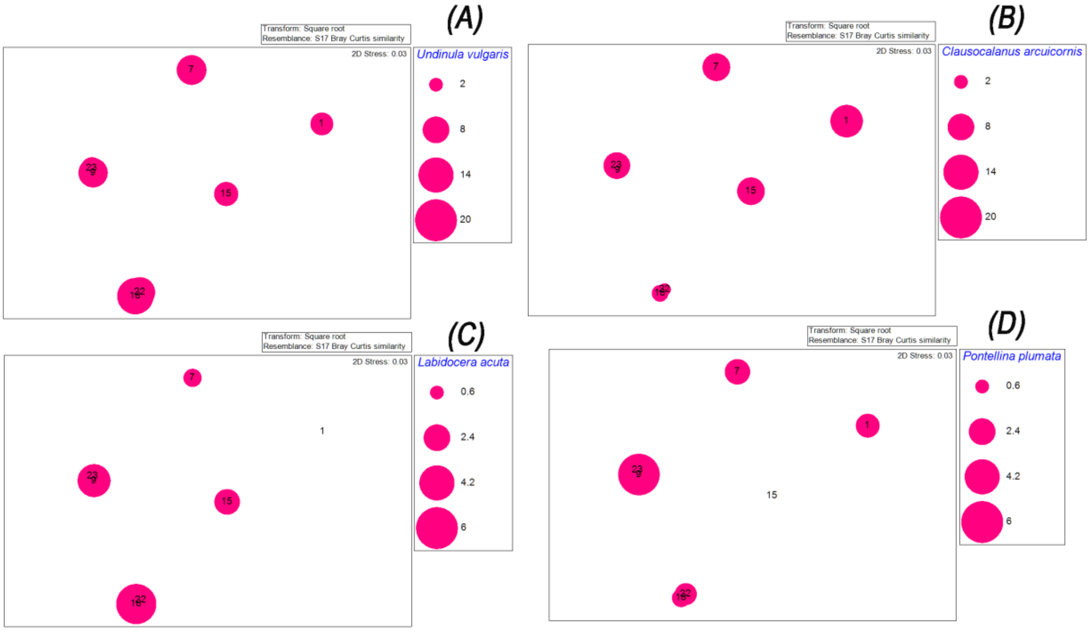

Fig. 36. MDS bubble plots of the species (A) *Undinula vulgaris* (B) *Clausocalanus arcuicornis,* (C) *Labidocera acuta*, (D) *Pontellina plumata*.

Table 39. Comparison of the occurrence of calanoid copepods in the lagoon and coastal waters of the south-west coast of India during 2013 - 2016. (*presence, - absence)

Species	AGT	BAN	KLPNY	KVT	MNY	MNY 338	SWC
Cosmocalanus darwini	-	-	*	*	-	-	-
Canthocalanus pauper	-	-	-	-	-	-	*
Undinula vulgaris	*	*	*	*	*	*	*
Acrocalanus longicornis	*	*	*	-	*	-	-
Calocalanus pavo	-	-	-	*	-	-	-
Calocalanus plumulosus	-	-	-	-	*	-	-
Paracalanus indicus	-	-	*	-	-	*	*
Bestiolina sp.	-	-	-	*	-	-	-
Pareucalanus attenuatus	*	-	-	-	-	*	*
P. sewelli	-	-	-	-	-	*	*
Subeucalanus subcrassus	*	-	-	*	*	-	*
S.mucronatus	-	-	-	*	-	*	*
S. subtenuis	-	-	-	-	-	*	*
S.elongatus	*	*	-	-	-	*	*
Clausocalanus arcuicornis	*	-	-	-	*	*	*
Rhincalanaus rostrifrons	-	*	-	-	-	*	*
Euchaeta marina	*	-	-	*	*	*	*
E. concinna	*	-	-	-	-	*	*
E. longicornis	-	-	-	*	*	*	*
E. indica	-	-	-	-	-	-	*

Euchirella sp.	-	-	-	-	-	*	-
Scolecithrix danae	*	*	-	-	-	*	*
Lucicutia flavicornis	-	-	-	*	-	-	-
Centropages calaninus	-	-	-	-	-	*	*
C. furcatus	*	-	*	*	-	*	*
C.gracilis	-	-	-	*	*	*	*
C.orisinii	-	-	-	*	*	-	*
Pseudodiaptomus serricaudatus	-	-	*	*	-	-	-
Temora discaudata	*	-	-	*	-	*	*
T.turbinata	*	*	-	*	-	*	*
Candacia aethiopica	-	-	-	-	-	*	*
C.bradyi	-	-	-	*	*	-	-
C.catula	*	-	*	*	*	-	-
C.pachydactyla	-	-	-	-	-	*	*
C.simplex	-	-	-	*	-	*	*
C.truncata	*	-	-	-	-	-	*
Calanopia minor	*	-	-	*	-	-	-
C. thompsoni	-	-	*	-	*	-	-
Labidocera acuta	*	*	-	*	*	*	*
L. detruncata	-	-	-	-	*	*	*
L. kroyeri	-	-	*	-	-	*	*
L.minuta	-	-	-	*	-	*	*
L. pavo	-	-	*	-	-	*	*
L. bataviae	-	-	-	-	-	*	*
L. madurae	-	-	-	*	*	*	*
Pontella denticauda	-	-	-	-	-	*	*
P. fera	-	-	-	-	-	*	*
P. sinica	-	-	-	-	-	*	*
P. spinipes	-	-	-	-	-	*	*
Pontellina plumata	*	*	*	*	*	*	*
Pontellopsis armata	*	-	-	-	-	*	*
P. perspicax	*	-	*	-	-	*	*
P.herdmani	-	-	-	-	-	-	*
P.regalis	*	-	-	-	-	*	*
Acartia (Acartia) negligens	*	-	*	*	*	*	*
A. (Odontacartia) centrura	-	-	-	*	-	-	-
A. (Odontacartia) erythraea	-	-	*	*	*	-	*
A. (Odontacartia) bispinosa	-	-	-	-	*	-	-
A. amboinensis	-	-	*	*	-	-	-
A.(Acanthacartia) fossae	*	-	-	-	-	-	-
Tortanus minicoyensis sp.nov.	-	-	-	-	*	-	-
Tortanus sp.	-	-	-	-	*	-	-

5.10. DISCUSSION

5.10.1. Lagoon waters of Lakshadweep

This study provides a comprehensive understanding of the mesozooplankton distribution and community composition from lagoon waters of Lakshadweep and coastal waters of the south-west coast of India. The zooplankton density of different islands ranged from 6 to 56 ind./m^3 during various seasons. Zooplankton density in Agatti atoll ranged from 37 to 56 ind./m^{3,} and biomass ranged from 0.02 to 0.04ml/m^3. The zooplankton groups recorded during the present study were higher in Agatti lagoon waters (Twenty three groups) compared to the recent studies by Varghese et al., (2018). In their studies during March 2013, sixteen groups of zooplankters were observed. Twenty three species of calanoid copepods were identified from Agatti atoll during the investigation. The number of species and density of zooplankton was higher compared to the previous studies by Pratap et al., (1977) and Achuthankutty et al., (1989), In the present study, the copepod density ranged from 10 to 17 ind. /m^3 during winter monsoon 2015 and 18 to 28 ind./m^3 during spring intermonsoon 2016. In the previous study, copepod density was 14 ind. / m^3 (Achuthankutty et al., 1989). A comparison of the present observations with the earlier studies in the Agatti lagoon, *Undinula vulgaris*, *Paraeucalanus attenuates, Centropages furcatus, Temora discaudata, Temora turbinate, Acartia negligens* and *Pontellina plumata* were observed in the present and previous studies. The calanoid species *Acartia fossae* found in the present study is the first report of the species from lagoon waters of Lakshadweep.

Zooplankton density in lagoon waters of Bangaram ranged from 37 to 52 ind./m^{3,} and the biomass ranged from 0.06 to 0.09 ml/m^3. Girijavallabhavan et al., (1989) and Varghese et al., (2018) noted that among zooplankton, decapod larvae dominated followed by gastropod larvae inside the Bangaram lagoon. The present study also validates the previous observations with higher dominance (66 to 79%) of decapod larvae in Bangaram. The second dominant groups were the copepods (15 to 26%). Eight species of calanoid copepods were identified from

Bangaram and the species *Undinula vulgaris* is the significant share to the total calanoid copepods.

In lagoon waters of Kalpeni, zooplankton density ranged from 10 to 37 ind./$m^{3,}$ and biomass ranged from 0.01 to 0.02ml/m^3. During the fall intermonsoon sampling, holoplankton composition was higher than that of meroplankton (63.5% in station 1 and 76.9% in station 2). While during the winter monsoon, meroplankton becomes the primary composition (72 and 56.3%). During fall intermonsoon 2013, calanoid copepod formed the dominant component (16.22 and 25.64%). Achuthankutty et al., 1989 reported larval decapod crustaceans (71.1 and 68.2% respectively) dominated inside the lagoon during spring intermonsoon 1985. In their study period, also noted that the dominance of meroplankton in the lagoon. Among the meroplankton, Fish eggs and larvae (14.85 and 10.26%) dominated during fall intermonsoon 2013. Decapod crustacean larvae dominated (41.31 and 42.05%) during winter monsoon 2014. In this period, Euphausiacea dominated among the holoplankton (19.14 and 30.11%) and copepods were only the fourth abundant group (5.29 and 6.25%). A total of 16 species belonging to 8 families and 13 genera were identified during the study period. The average abundance of calanoid copepod was higher during the fall intermonsoon period. In both the seasons, the highest abundance of copepods and other zooplankton was observed in station 1 (S1). It could be due to the lack of shelter such as seagrass foliage which provides more accommodation to the zooplankton groups (Sanu et al., 2014). The highest number of copepod species was found in fall intermonsoon (10 species) and the lowest in winter monsoon (7 species). The number of recorded species and density was higher compared to the previous study by Achuthankutty et al. (1989). Comparison between the present observations and the earlier studies in the Kalpeni lagoon indicated that many calanoid species that were reported in the previous study were not found to occur in the present study except the species *Pontellina plumata*, *Labidocera pavo* and *Acartia amboiensis*.

Zooplankton density in Kavaratti atoll ranged from 6 to 29 ind./m^3, which is lower than that of Suresh et al. (1997), who reported zooplankton density ranging from 122 to 722 ind/m^3 in daytime samples. Pratap et al., (1977) reported that compared to Agatti and Suhelipar lagoon in Lakshadweep, zooplankton density was lower in Kavaratti as former lagoons were broader and more in-depth with higher carrying capacity. A total of 24 mesozooplankton taxa were observed in the present study. The number of the taxa was higher to that of Stephen, (2001), but reported a sharp decline from 1982, when about 23 zooplankton taxa were recorded. Vineetha et al., (2018) recorded 21 zooplankton taxa from the lagoon. Copepods dominated in all stations and seasons as in most tropical and subtropical waters (Cornils et al., 2010). The results also agree with other findings in Kavaratti atoll (Nasser et al., 1998; Madhupratap et al., 1991). On the contrary, Madhupratap et al., (1977) observed domination of molluscan larvae in the zooplankton, while Suresh et al., (1997) reported the dominance of fish eggs and larvae in daytime samples from Kavaratti. The dominance of cyclopoid copepods during spring intermonsoon 2013 may be due to the change in food availability by change of phytoplankton composition from micro phytoplankters to pico, and nanoflagellates which are proposed as an essential factor for the increase in the abundance of small species as they are unable to feed diatoms (Doi et al., 2008). In Kavaratti atoll 28 calanoid species were recorded. The total number of species reported in the present study was comparatively higher than other reports from the same area by Madhupratap et al., (1977; 1991) Jean et al., (2010), Robin et al., (2012). Vineetha et al., (2018) recorded 33 calanoid species from Kavaratti atoll. Among the calanoids, the families Candacidae, Calanidae, Pontellidae, Temoridae, Psuedodiaptomidae, Centropagidae and Oithonidae were dominated. Goswami and Usha, (1990) reported the same families in addition to Paracalanidae, Acartidae, Euchaetidae, Scolecithridae, and Pseudocalanidae also displayed higher abundance. Generally, among copepods the genera Candacia, Calanopia, and Temora were dominated during the study period. In contrast, Madhupratap et al., (1977) reported that the genera, *Paracalanus* and *Acrocalanus* contributed significantly to the calanoid copepod composition, while Goswami et al., (1973) reported the dominance of harpacticoid copepod species inside the lagoon. Many species that were reported to be abundant in previous studies were not found to be occurring in the present study (Madhupratap et al., 1977; 1991; Jean et al., 2010; Robin et al., 2012).

Among the 28 identified calanoid species, 20 species have already been reported from the Kavaratti atoll (Madhupratap et al., 1977; 1991; Jean et al., 2010, Robin et al.,2012, Vineetha et al., 2018).

Zooplankton density in Minicoy lagoon ranged from 11 to 27 ind./$m^{3,}$ and the biomass ranged from 0.05 to 0.2ml/m^3 which is lower compared to the previous studies by Nasser et al., (1998). In their research, zooplankton density ranged from 28 to 40 ind./m^3. Twenty-one zooplankton taxa were identified from the lagoon waters of Minicoy during the study period. Holoplankton composition was higher than meroplankton in the three sampling seasons. There was no much spatial variation of zooplankton composition in the present study that confirms with the previous research by Nasser et al., (1998). The highest meroplankton composition (60.6%) in station two during fall intermonsoon 2013 was due to the abundance of live corals in station 2 (Nasser et al., 1998). A total of 21 calanoid species were observed from the Minicoy lagoon in which a new species *Tortanus minicoyensis* of the genus *Tortanus* subgenus *Atortus* is described during winter monsoon 2014. Among the identified species, *Acrocalanus longicornis* and *Calanopia thompsoni* were found exclusively during summer monsoon 2014.

5.10.2. Oceanic stations around Minicoy Island

In the oceanic stations around Minicoy Island, zooplankton density and biomass was higher compared to the lagoon samples. Zooplankton abundance ranged from 16 to 42ind./$m^{3,}$ and biomass from 0.08 to 0.18ml/m^3. The present result reconfirms the findings of the earlier results by Achuthankutty et al., (1989) that zooplankton density in the lagoon waters of Lakshadweep archipelago is lower compared to the oceanic waters around the island, which is the characteristic feature of shallow coral lagoons (Pratap et al., 1977). There are 19 zooplankton taxa that were observed in the oceanic stations of Minicoy. Pagano et al., (2017) noted that some zooplankton taxa were higher in the adjacent oceanic station than the lagoon waters. Calanoid copepods were the significant group in all stations. The chaetognaths were the second dominant group, and their abundance is higher in the windward side than leeward stations. A total of 39 calanoid species belonging to 13 families were identified from the oceanic stations. Spatial variation of copepod occurrence was in this study, the species *Labidocera pavo*, *Pontella spinipes*, *Pontellopsis perpicax* and *Pontella regalis* observed only in the leeward side, and *Labidocera madurae* and *Pontella denticauda* were observed only in the windward side. The pontellid copepod *Calanopia thompsoni* was observed inside the Minicoy lagoon was not observed in the adjacent oceanic waters of Minicoy. The genera *Calanopia* Dana, 1853 are known to live within the coral reef ecosystem (Smith et al., 2017). Most other pontellid genera are considered either oceanic or neritic and also neustonic (Silas and Pillai, 1973, and Smith et al., 2017).

5.10.3. Coastal waters of South West coast of India

In coastal waters of the south-west coast of India, during spring intermonsoon 2015, zooplankton density ranged from 81 to 197 ind./m^3 while during fall intermonsoon 2015, it ranged from 70 to 150 ind./m^3. The biomass ranged from 0.03 to 0.22ml/m^3 and 0.01 to 0.05 ml/m^3 respectively. During spring intermonsoon, 20 zooplankton taxa were observed, while during fall intermonsoon, 17 taxa were present. Forty-two calanoid species 12 families were observed during spring intermonsoon, 27 species under 11 families were observed during fall intermonsoon. From the lagoon waters of Lakshadweep, a total of 27 species under 11 families and 15 genera has been identified from lagoon waters during the present study. From oceanic waters around Minicoy Island, 39 calanoid species under 13 families and 18 genera were identified. During the entire study period, 62 calanoid species under 16 families and 26 genera were observed. The species *Paracalanus attenuatus*, *P. sewelli*, *Subeucalanus mucronatus*, *S. elongatus*, *S. subtenuis* , *Euchaeta longicornis Centropages furcatus, C. orsini, Pontella denticauda, P.sinica, Pontellopsis perspicax, P. regalis,* and *Acartia erythraea* were observed only during spring intermonsoon along the coastal waters, and *Pontellopsis herdmani* and *Euchaeta indica* were observed only during fall intermonsoon.

5.10.4. Comparison of lagoon waters of Lakshadweep and coastal waters of South West coast of India.

Identification of all calanoid copepods in a sample may often be difficult but at times rare species may, on occasion, be overlooked and also the identification of species sometimes gets confused. Numbers of species that determines the sample or geographical region are often minimum numbers. Diversity generally decreases from neritic coastal waters to the inner areas such as enclosed bays, fjords and inlets while the corresponding biomass decreases (Achuthankutty et al., 1989; Pagano et al., 2017). Species diversity value was high, typical of open ocean conditions (Madhupratap and Haridas 1990). McGowan and Walker (1979) suggested that predation as the significant factor controlling diversity. In the present study, the species diversity inside the lagoon waters was highest observed during fall intermonsoon in Kalpeni (3.23±0.16), and the lowest was observed in Minicoy during winter monsoon 2014 (1.56±26). In coastal and oceanic waters it ranged from 1.92 to 3.78 during spring intermonsoon 2015 and 2.31 to 3.69 during fall intermonsoon 2015. Tranter, (1973) found that diversity is generally higher in winter than in summer in tropical and subtropical regions of the eastern Indian Ocean. Achuthankutty et al., 1989 observed that the species diversity was high in the sea compared to the lagoon waters. In their observations, diversity was 4 at Kalpeni oceanic waters and 3.4 at the oceanic stations of Agatti. The diversity was 2 inside the lagoon water of Kalpeni and 1.6 at Agatti.

Copepods dominate the zooplankton community of the Arabian Sea, where over 50 species of copepods occur in the surface waters with nearly 11 species co-dominant during any particular season. (Madhupratap et al., 1992). In lagoon waters, the co-occurrence of copepod species was observed from 8 to 17 species during different seasons and islands. In oceanic and coastal waters, the presence of 12 to 19 species was observed. The lowest number of species observed in lagoon waters from Kalpeni during winter monsoon 2014 (7 species) and the highest number of calanoid species was observed from Kavaratti during fall intermonsoon 2013, winter monsoon 2014 and 2015 (18 species). In oceanic waters around Minicoy, the co-occurrence of calanoid species ranged from 6 to

28, and 9 to 29 species were found along coastal waters of the south-west coast of India. A large number of species of copepods occurring in the oceanic water column, coupled with the occurrence of as many as 10-16 congeneric species, raises the question as to how so many species exist together. Brainbridge, (1972) suggested that two attributes permitted the co-existence of congeneric species, viz. different patterns of vertical migration between highly stratified water masses and size differences between species. It is likely, however, that the situations are more complicated than this and additional factors must be involved. The co-existence of multiple congeneric species have often been collected together in same stations and plankton-net tows (Brady, 1883; Sewell, 1912; Sherman, 1964; Silas and Pillai, 1973; Mulyadi, 2000) which increases the chance of misidentification (Sanu et al., 2018). The evidence for niche separation of pelagic copepods in the open ocean is feeble. Coastal species of copepods belong to a wide variety of genera. There are neritic species close to the shore that form populations within bays and the outer parts of estuaries. The presence of mechanisms for co-existence of multiple congeneric species in relatively small areas and the two dimensional habitat in their neustonic life, either by differentiating their habitat water, as defined by various physicochemical and/or biotic factors (Sherman 1964), and/or food resources (Ohtsuka, 1985), inviting further research on their microhabitats and feeding ecology (Sanu et al., 2018).

Considering the total calanoid species identified during the present study, the species *Subeucalanus subtenuis*, *Centropages calaninus*, *Euchirella sp*. *Euchaeta indica*, *Labidocera bataviae*, *L.detruncata*, *Pontella denticauda*, *P.fera*, *P.sinica*, *P. spinipes, Canthocalanus pauper, Candacia aaethiopica, Candacia pachydactyla* and *Pontellopsis herdmani* were not observed in the lagoon waters and dominant only in the oceanic waters of Minicoy and coastal waters of the south-west coast of India (Table 39). A similar observation was made by Achuthankutty et al., (1989) from Agatti and Kalpeni atolls. In their observations species belonging to the family Centropagidae, Candacidae, Calocalanidae and Euchaetidae were absent in the collections from the lagoons as compared to the surrounding sea. The poor abundance of oceanic copepods in the lagoon waters could be due to the predators in the reef community while on transport from Sea to the lagoon

(Achuthankutty et al., 1989). The species *Cosmocalanus darwinii, Pseudodiaptomous serricaudatus* and *Acartia amboiensis* were observed only in lagoon waters of Kalpeni and Kavaratti. The species *Candacia bradyi* was found only in Kavaratti and Minicoy, *Calanopia minor* in Agatti and Kavaratti, *Calanopia thompsoni* in Kalpeni and Minicoy. Few species were observed only in particular islands, the species *Calocalanus pavo*, *Lucicutia falavicornis* and *Acartia centrura* were found only in Kavaratti atoll, while *Calocalanus plumulosus, Acartia bispinosa* and *Tortanus sp.* were observed only from Minicoy lagoon (Table 39). Among the identified species, Centropages orsinii, *Acartia spinicauda, Centropeges furcatus, Calausocalanus arcuicornis* were observed both in Arabian Sea and Bay of Bengal by previous studies (Suchismitha et al., 2018). The species reported from the present study, *Euchaeta marina*, *Euchaeta longicornis* , *Cosmocalanus darwini*, *Subeucalanus mucronatus*, *Subeucalanus subcrassus*, *Temora discaudata*, *Centropages furcatus*, *Candacia bradyi*, *Candacia catula*, *Candacia simplex, Acartia negligens* and *Acartia amboinensis*, were restricted to Indian and Pacific oceans (Madhuprathap and Haridas, 1986, Sanu et al., 2014). The present study attempted to provide baseline data on mesozooplankton community composition based on seasonal sampling. It is evident that the mesozooplankton community in the study area was more susceptible to a variation on the temporal scale rather than the spatial extent.

* * *

Chapter - 6

MORPHO-TAXONOMY OF CALANOID COPEPODS

Contents

6.1. INTRODUCTION

Knowledge on the taxonomy and distribution of calanoid copepods of the coastal waters of the Arabian Sea and lagoon waters of Lakshadweep archipelago are very limited. Pioneering studies since last three decades on distribution, abundance, diversity with some preliminary taxonomic information from the Arabian Sea have been documented (International Indian Ocean Expedition IIOE, 1962-65 and few notable works by Pillai, 1975; Silas and Pillai ,1973; Saraswathy, 1982 and 1988; Rosamma, 1988; Saraswathy, 1986; Jayalakshmi, 1991). Lakshadweep islands (coral) are notable hotspots of marine biodiversity occupying a significant part of the Western Arabian Sea that has been least investigated regarding the copepod ecology and their community structure. Most of the studies from India have insufficient taxonomic descriptions rather than detailing the distribution, abundance and diversity pattern of copepods in different ecosystems of India.

Previous studies in the Arabian Sea and Lagoon waters of Lakshadweep are focused on aspects related to ecology and diversity of planktonic copepods thus having a severe dearth on the morpho-taxonomy and systematics of calanoid copepods from this region. So this study from 2013-16 has explored and conducted detailed investigations on the taxonomy and occurrence of pelagic copepods from South West coast of the Arabian Sea and the lagoon waters of Lakshadweep islands to delineate the morpho-taxonomy and systematics of pelagic copepods using classical as well as molecular methods. The study also fulfils the goals enshrined in UN convention in Biodiversity (CBD) where India is a signatory under the Aichi Biodiversity Targets (2011-2020) that stresses the need for reducing biodiversity loss, strengthen capacity building (taxonomists) and make available scientific data and knowledge on biodiversity and its application. In this chapter, identified calanoid copepods were described and illustrated. For each presented species a short description, original line drawings of important identifying characters and distribution of the female and male (In some species, either female or male specimens only described due to the absence of the specimen in the collected samples) are given.

6.2. RESULTS

6.2.1. Systematics:

Kingdom	**: Animalia**
Phylum	**: Arthropoda**
Subphylum	**: Crustacea** Brunnich, 1772
Class	**: Maxillopoda** Milne - Edwards, 1840
Infraclass	**: Neocopepoda** Huys & Boxshall, 1991
Superorder	**: Gynoplea** Giesbrecht, 1882
Order	**: Calanoida** G.O. Sars, 1902

*Order **Calanoida** G.O. Sars, 1902*

The order Calanoida are defined by the combination of the gymnoplean tagmosis, the presence of only one spine on the outer margin of P2-P5 Exp1, the presence of a coxal epipodite (Le1), but not a lobate basal exite on mx1, and the presence of a seta on the inner margin of A2 coxa. The presence of a maximum of 2 setae on the terminal segment of Mx2 (Enp4) is an apomorphy (derived character) of the Calanoida. (Huys and Boxshall, 1991).

Table 1. List of calanoid copepod species identified in the present study.

Family	Genus	Species
Calanidae Dana, 1849		
	Cosmocalanus Bradford & Jillet, 1974	
		C. darwinii (Lubbock,1860)
	Canthocalanus A.Scott, 1909	
		C. pauper (Giesbrecht, 1888)
	Undinula A.Scott, 1909	
		U. vulgaris (Dana,1849)

Paracalanidae Giesbrecht, 1893

- *Acrocalanus* Giesbrecht, 1888
  - *A. longicornis* (Giesbrecht 1888)
- *Calocalanus* Giesbrecht,1888
  - *C. pavo* (Dana,1849)
  - *C. plumulosus* (Claus, 1863)
- *Paracalanus* Boeck, 1864
  - *P. indicus* (Wolfenden,1905)
- *Bestiolina* Andronov, 1972
  - *Bestiolina sp.*

Eucalanidae Giesbrecht, 1893

- *Eucalanus* Dana,1852
  - *E. elongatus* (Dana, 1849)
- *Pareucalanus* Geletin,1976
  - *P. attenuatus* (Dana, 1849)
  - *P. sewelli* (Fleminger,1973)
- *Subeucalanus* Geletin,1976
  - *S. subcrassus* (Giesbrecht, 1888)
  - *S. mucronatus* (Giesbrecht,1888)
  - *S. subtenuis* (Giesbrecht, 1888)

Clausocalanidae Giesbrecht,1893

- *Clausocalanus* Giesbrecht, 1888
  - *C. arcuicornis* (Dana, 1849)

Rhincalanidae Geletin, 1976

- Rhincalanus Dana, 1852
  - *R. rostrifrons* (Dana, 1849)

Euchaetidae Giesbrecht,1893

- *Euchaeta* Philippi,1843
  - *E. marina* (Prestandrea, 1833)
  - *E. concinna* Dana, 1849
  - *E. longicornis* Giesbrecht, 1888
  - *E. indica* Wolfenden,1905

Aetideidae Giesbrecht, 1892

- *Euchirella sp.*

Scolecitrichidae Giesbrecht, 1893

- *Scolecithrix* Brady, 1883
  - *S. danae* (Lubbock, 1856)

Lucicutidae Sars,1902

- *Lucicutia* Giesbrecht & Schmeil, 1898
  - *L. flavicornis* (Claus, 1863)

Centropagidae Giesbrecht,1893

- *Centropages* Kröyer, 1849
  - *C. calaninus* (Dana, 1849)
  - *C. furcatus* (Dana, 1849)
  - *C. gracilis* (Dana,1849)

C. orisinii Giesbrecht,1889

Pseudodiaptomidae Sars,1902

Pseudodiaptomus Herrick,1884

P. serricaudatus (T.Scott,1894)

Temoridae Giesbrecht,1893

Temora Baird,1850

T. discaudata Giesbrecht,1889

T. turbinata (Dana,1849)

Candacidae Giesbrecht, 1893

Candacia Dana, 1846

C. ethiopica (Dana, 1849)

C. bradyi A.scott,1902

C. catula (Giesbrecht, 1889)

C. pachydactyla (Dana,1849)

C. simplex (Giesbrecht, 1889)

C. truncata (Dana,1849)

Pontellidae Dana,1853

Calanoipa Dana, 1853 (Part.)

C. minor A.Scott,1902

C. thompsoni A. Scott, 1909

Labidocera Lubbock,1853

L. acuta (Dana,1849)

L. detruncata (Dana, 1849)

L. kroyeri (Brady, 1883)

L. minuta Giesbrecht,1889

L. pavo Giesbrecht,1889

L. bataviae A. Scott, 1909

L. madurae A. Scott, 1909

Pontella Dana, 1846

P. denticauda (A. Scott, 1909)

P. fera Dana, 1849

P. sinica Chen & Zhang, 1965

P. spinipes Giesbrecht, 1889

Pontellina Dana, 1852

P. plumata (Dana, 1849)

Pontellopsis Brady, 1883

P. armata (Giesbrecht, 1889)

P. perspicax (Dana, 1849)

P. regalis (Dana, 1849)

P. herdmani Thompson & Scott, 1903

Acartidae Sars,1846

Acartia Dana 1846

A. (Acartia) negligens Dana, 1849

A. (Odontacartia) spinicauda Giesbrecht, 1889

A. (Odontacartia) erythraea Giesbrecht, 1889

A. (Odontacartia) bispinosa Carl, 1907
A. amboinensis Carl,1907
A. (Acanthacartia) fossae Gurney, 1927

Tortanidae Sars, 1902

Tortanus Giesbrecht,1898
T. minicoyensis sp.nov.
Tortanus sp.

6.2.2. Family **Calanidae** Dana, 1849

1. *Cosmocalanus darwinii* (Lubbock, 1860)

Female. TL: 1.72-2.3mm (n=5). Head and pd1 fused. Postero-lateral corners of Pd5 slightly asymmetrical (Fig. 1 A, C). A1 reaches up to the terminal portion of urosome (Fig.1 B). Postero-lateral and posterodorsal margins of Ur-1 and Ur-2 with spinules (Fig. 1 C). Inner margin of P5 coxa bearing small teeth, Enp with seven setae (Fig. 1 D).

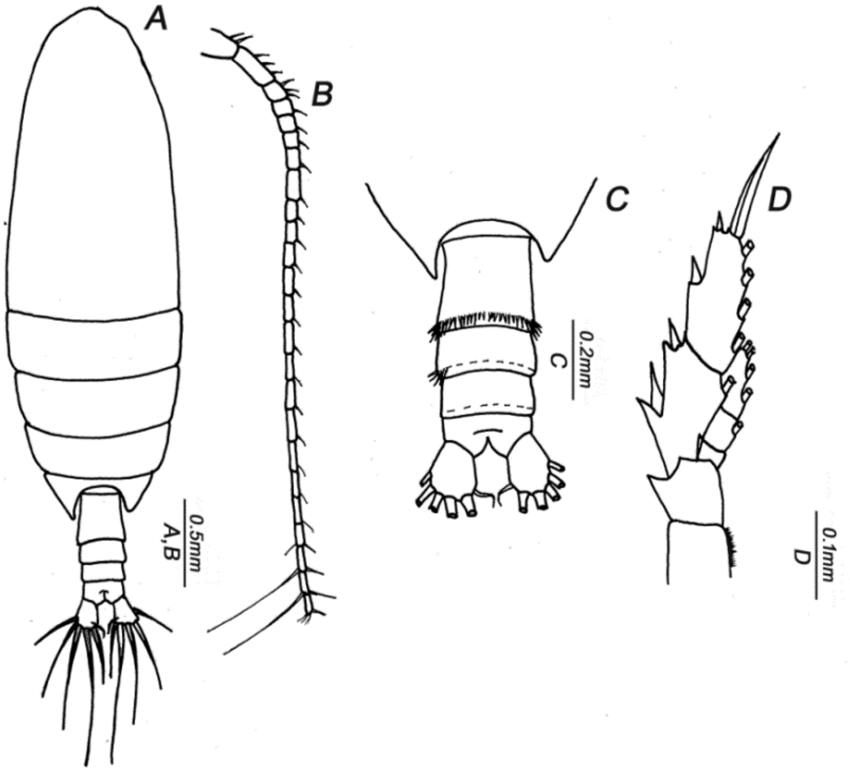

Figure 1. *Cosmocalanus darwinii* female. A- Habitus dorsal; B- right antennule; C- Ur, lateral; D- P5, anterior.

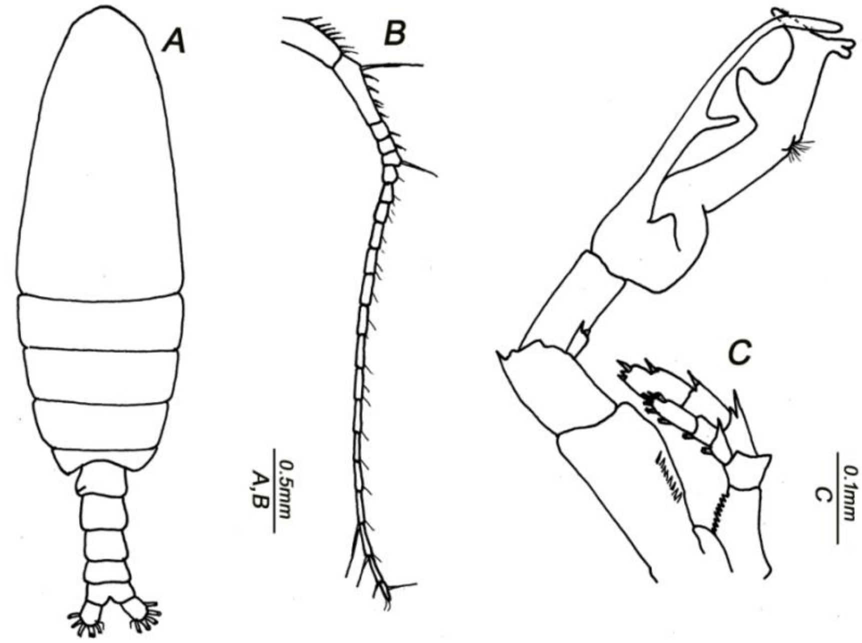

Figure 2. *Cosmocalanus darwinii* male. A- dorsal; B- right antennule; C-P5, anterior.

Male. TL: 1.62-1.9mm (n=5). Ur 5 segmented (Fig 2-A), Right A1 geniculate (Fig.2-B). Asymmetrical large P5, projecting from the side of the body (Fig.2-C). Right leg similar to female. Highly modified left leg. Coxa inner border with teeth right and left rami. Highly modified left leg; Enp– 1 segmented and rudimentary. Exp2 and Exp 3 constituting pincers like construction.

Distribution: The species was recorded in the tropical regions of Atlantic, Indian, and North Pacific Ocean. (Razouls et al., 2005-2018). In the present study, it was observed from the lagoon waters of Kalpeni and Kavaratti.

2. *Canthocalanus pauper* (Giesbrecht, 1888)

Female: TL: 1.38 – 1.6mm (n=3). Head and Pd1 fused (Fig. 3 A). P1 anterior margin of coxa ending in a sharp projection; basis with a distal seta on the anterior surface modified into a proximally thickened spine (Fig. 3B). P5 without teeth on the inner border of coxa; Enp with seven setae.

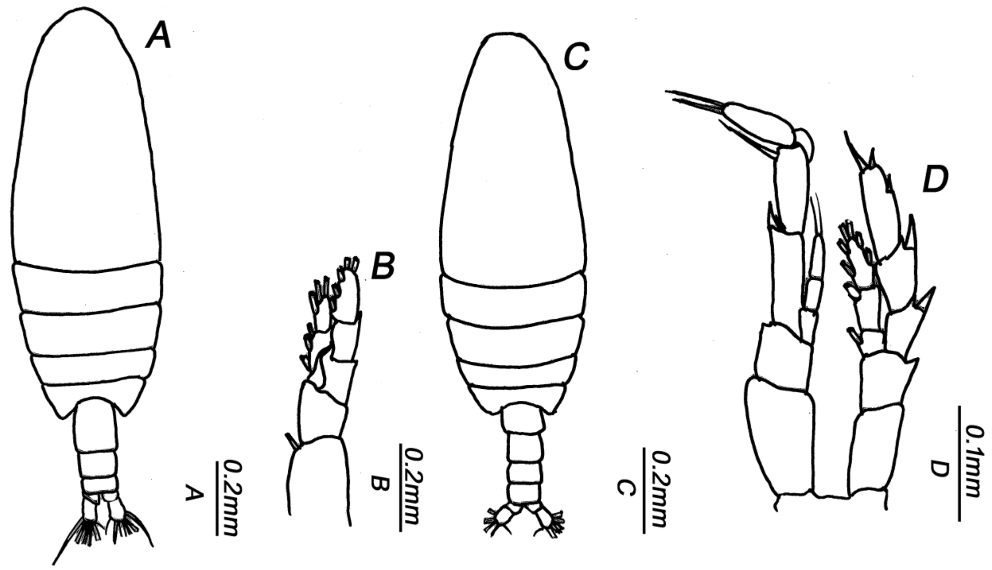

Figure 3. *Canthocalanus pauper* female. A- Habitus dorsal; B- right P1. Male. C- Habitus dorsal; D- P5.

Male. TL: 1.2-1.4mm (n=3). Head and Pd1 fused (Fig.3C). P5 with both rami three segmented, hardly modified on the left. Right Enp with eight setae, right Exp without inner setae. Left Exp elongated with elongated outer distal setae on segments 2 and 3 (Fig.3D).

Distribution: The species was recorded in tropical regions of the Atlantic, Indian and Pacific oceans (Razouls et al., 2005-2018). In the present study, the species was observed from coastal waters of south-west coast India.

3. *Undinula vulgaris* (Dana, 1849)

Female: TL 2.32-3.3 (n=7). Head and Pd5 fused. Posterolateral corners of Pd5 extend into 1 or 2 points (Fig.4 C, D & E). A1 reached the end of Ur. P1-P5 same size and similar structure. P2 with a notch on the external margin of the second segment of the exopodite. (Fig.4 B) P5 coxa without any serrations on the internal edge. Enp with seven setae. Spine-like Enp1 and Enp2.

Male: TL 2.05-2.6mm (n=5). P5 coxa without serrations on the inner margin. Left P5 is highly modified; Enp absent (Fig.5 B). Outer edge spines of Exp1 & Exp2 very elongate and Exp3 highly modified. Right P5 with both rami three segmented, Exp2 with outer distal border elongate extending as far as the first outer spine of the Exp3.

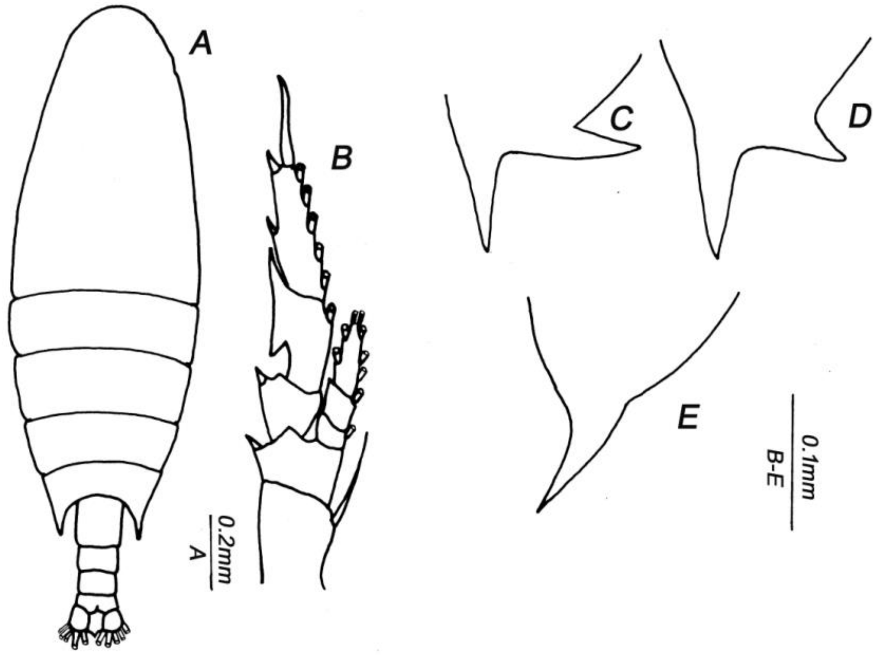

Figure 4. *Undinula vulgaris* Female A- Habitus dorsal, B- P2, C-E postero lateral corners of Pd5.

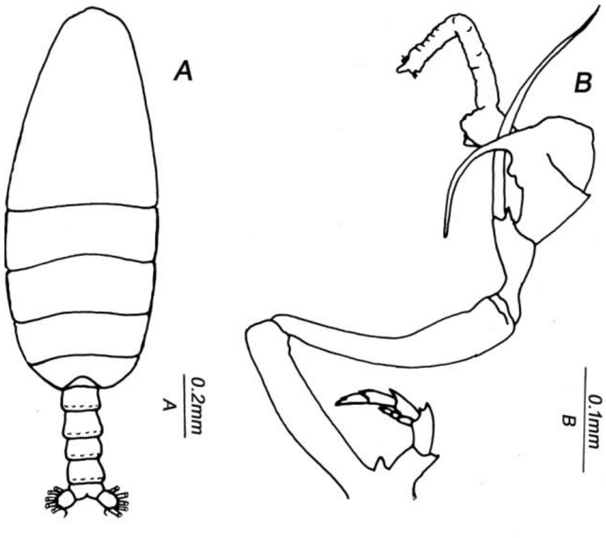

Figure 5. *Undinula vulgaris* Male A- dorsal, B- P5.

Remarks: There are three **forms** identified by the shape of the postero-lateral corners of Pr in the female. In males, postero-lateral corners of Pr uniformly rounded (Sewell, 1929). The form *typica* has symmetrical postero-lateral corners. The form *giesbrechti* has a single claw spine on the right and double spine on the left. The form *zeylanica* has a single claw spine on the right, and double spine on the left but the whole of the posterior margin is considerably thickened and dilated, and the spine on the right corner is thickened and projects straight backwards; In the present study, all three forms were found.

Distribution: The species was recorded in Newfoundland to the Gulf of Mexico, Central North Atlantic, East and western South Atlantic, Eastern Indian Ocean, eastern and western North Pacific (Walter and Boxshall 2018). In the present study, it was observed from the lagoon waters of Agatti, Bangaram, Kalpeni, Kavaratti, Minicoy, Oceanic waters of Minicoy Island and coastal waters of the south-west coast of India.

6.2.3. Family: *Paracalanidae* Giesbrecht, 1893

1. *Acrocalanus longicornis* (Giesbrecht 1888)

Female. TL: 0.8-1.2mm (n=4). A1 extends beyond CR by 6 terminal segments. Partial segmentation between the Ce and Pd1. P2 and P3 coxa with several proximal, medial and distal spines on the posterior surface along the outer edge .P4 Exp3 outer distal border with 28 tiny teeth (Fig.6 B).

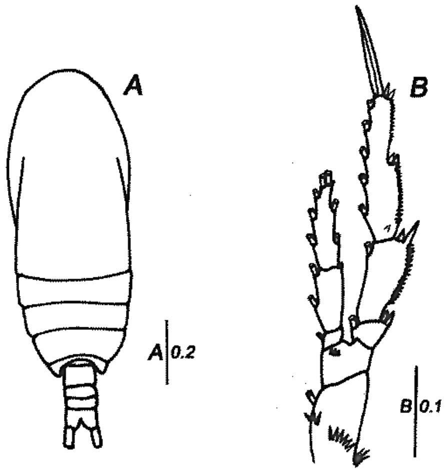

Figure 6. *Acrocalanus longicornis* Female A- habitus dorsal, B- P4

Distribution: The species was recorded in Central South Atlantic, Indian Ocean, Central and Eastern tropical Pacific and China seas (Razouls et al., 2005-2018). In the present study, the species was observed from the lagoon waters of Agatti, Bangaram, Kalpeni and Minicoy.

2. *Calocalanus pavo* (Dana, 1849)

Female. TL: 0.72-1.2mm (n=3) Transparent body, Pr stout, Head and Pd1 fused (Fig.7 A). Ur two segmented, onion-shaped genital segment, symmetrical furca, elongate and typically divergent, arranged almost at right angles to the Ur. Uniramous and symmetrical P5 (Fig.7B), four-segmented, the terminal segment with five plumose setae and one spine on the outer distal border and two rows of tiny spinules.

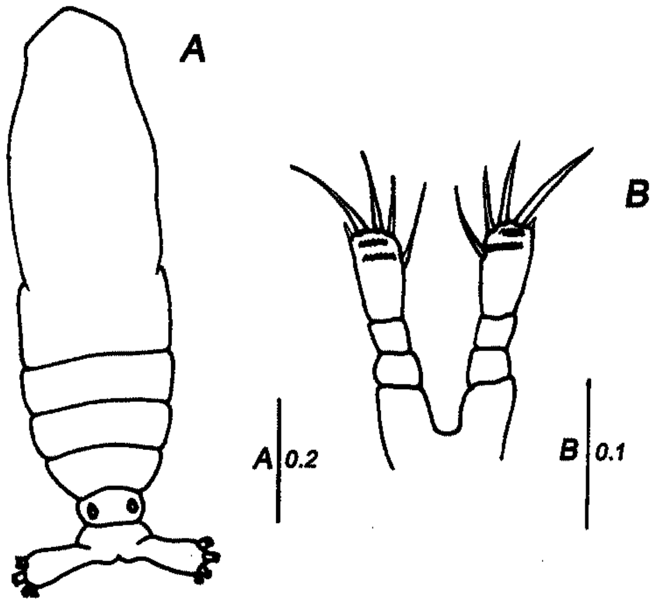

Figure 7. *Calocalanus pavo* Female A- habitus. B-P5.

Remarks: This species prefers waters of high salinities (>36 psu) and high temperatures (>25°C). It did not occur in deep waters.

Distribution: The species was recorded in Caribbean sea, Iceland waters, Eastern tropical Pacific, Central South Atlantic, Sub Antarctic, Indian Ocean, Central tropical Pacific, China Seas (Razouls et al., 2005-2018). In the present study, this species was observed from Kavaratti atoll.

3. *Calocalanus plumulosus* (Claus, 1863)

Female: TL 0.92-1.3mm. Body slender, head and Pd1 fused (Fig.8A). Three segmented Ur; cuboidal shaped genital segment. Posterior border of the genital segment and second urosomal segment lined with fine spinules (Fig.8B) P5 slightly asymmetrical, hirsute terminally, terminal segments with one plumose seta between 2 sharp setae, one external spine and a horizontal row of fine spinules (Fig.8C).

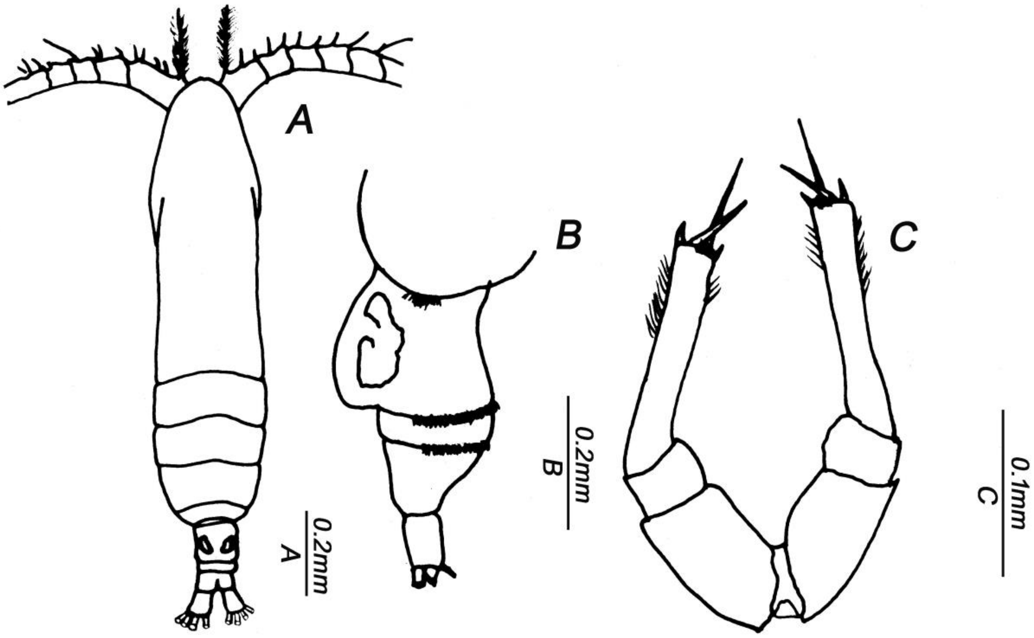

Figure 8. *Calocalanus plumulosus.* female A- habitus dorsal, B- genital segment lateral, C- P5.

Remarks: This species prefers Oceanic waters and cooler temperature (<25°C).

Distribution: The species was recorded in Caribbean sea, Iceland waters, Eastern tropical Pacific, Central South Atlantic, Sub Antarctic, Indian Ocean, Central tropical Pacific, China Seas (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Minicoy.

4. *Paracalanus indicus* (Wolfenden, 1905)

Female. TL: 0.76-0.85mm (n=5). Head fused with Pd1 (Fig.9 A). Genital segment widest interiorly in dorsal view. Pr is about three times longer than Ur. A1 extends beyond Pd5, all segments separate. CR twice as long as wide with its inner sea short. P5 small and symmetrical; 2 segmented and uniramous. Distal segment cylindrical, with the terminal spine longer than it’s joint. Outer distal spine small (Fig.9 B).

Male. TL: 0.82mm. CR twice as long as wide, Ans longer than Ur-4. A1 extends to about the distal border of Ur-2. P5 asymmetrical and uniramous and extends beyond the posterior border of Ur-3, Left leg five-segmented, right leg two-segmented; extends well beyond the distal border of left segment 2. (Fig. 9D).

Remarks: *Paracalanus indicus* possibly may misidentify as *Paracalanus parvus* and *Paracalanus quasimodo*, hence the locality records to confirm in the Atlantic Ocean.

Distribution: The species was recorded in the Caribbean sea, Iceland waters, Eastern tropical Pacific, Sub Antarctic, Indian Ocean, China Seas (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kalpeni, Oceanic stations around Minicoy and coastal waters of the south-west coast of India.

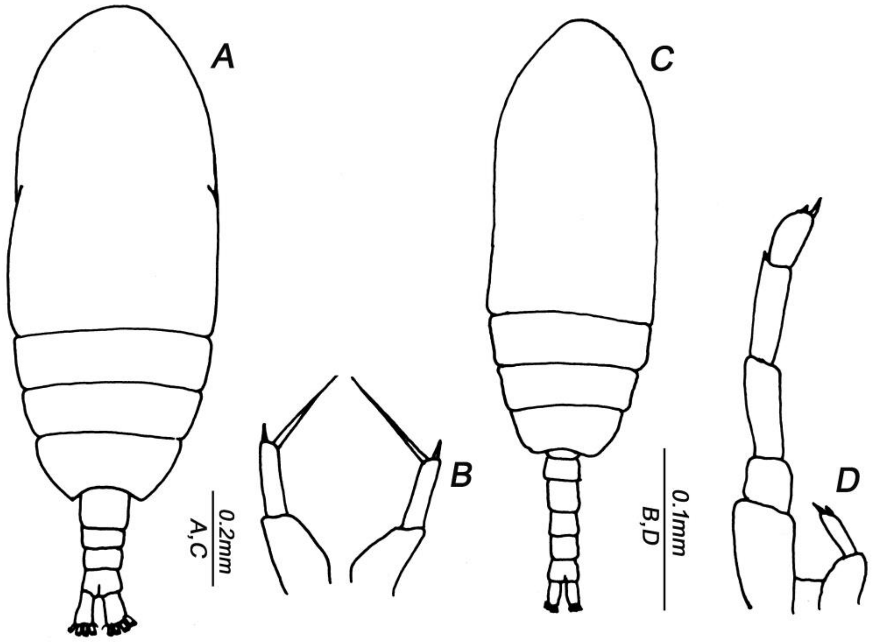

Figure 9. *Pararcalanus indicus* female A- dorsal; B-P5; male C- dorsal; D- P5.

5. ***Bestiolina sp.***

Female. TL: 0.85mm. Rostrum shortened, rostral filaments long and slender (Fig.10 A), Leg 5 is rudimentary and knob-like (Fig.10 B), pedigerous segment five without spinules, Antenna 1 extends as far as caudal rami, terminal segment elongate.

Male. TL: 0.75mm. Rostrum shortened with a dorsal cephalic hump, Leg 5 consists of a swollen basal segment and four free segments (Fig. 10 C).

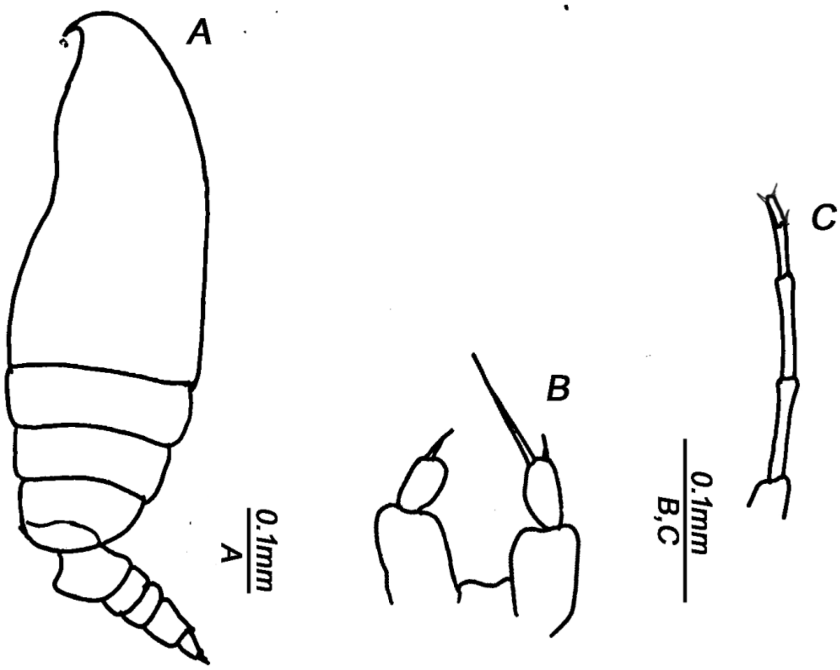

Figure 10. *Bestiolina sp.* A- female habitus lateral, B-P5. C- male P5.

Remarks: The species similar to *Bestiolina similis.*

Distribution: In the present study, this species was observed from lagoon waters of Kavaratti.

6.2.3. Family: Eucalanidae (Giesbrecht, 1893)

1. *Eucalanus elongatus* (Dana, 1849)

Male. TL: 3.3-3.95mm (n=5). Transparent body. Pd5 has lateral points (Fig. 11-A). A1 is extending beyond the furca by around the last four segments. Anterior Ce is triangular with a rounded tip. Ur 5 segmented. P5 4 segmented, both legs terminating with the spine. Right leg shorter than left (Fig. 11 B).

Distribution: The species was recorded in the Eastern tropical Pacific, the Indian Ocean, China Seas, North West Pacific, Central tropical Pacific, and the Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kalpeni, Oceanic waters of Minicoy and Coastal waters of the south-west coast of India.

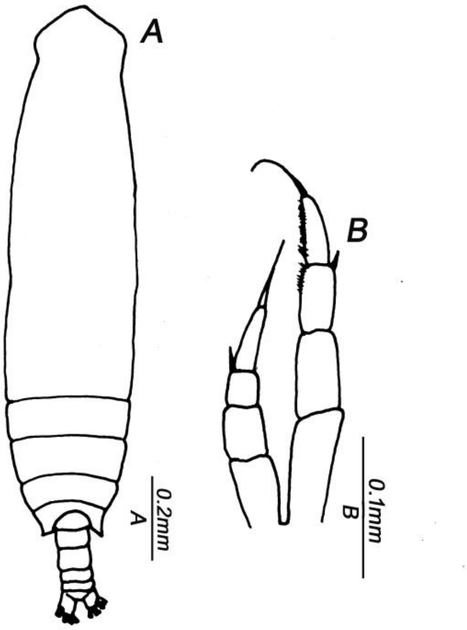

Figure 11. *Eucalanus elongatus* Male A-dorsal, B-P5.

Genus *Pareucalanus*

***2. Pareucalanus attenuatus* (Dana, 1849)**

Male. TL: 3.2-4.1mm (n=5). Anterior Ce triangular (Fig. 12-A) A1 extends beyond furca by the last 6-7 joints. Genital segment asymmetrical P5 simple, left leg longer than right. Both legs 4 segmented and terminated with the spine. Exp2 is of left leg hirsute (Fig. 12-B). Furca fused to the anal segment. One of the left furcal setae longer than the others.

Remarks: This species has been confused with *Eucalanus parki* of greater dimension and with *E. sewelli* of which it only differs slightly by the form of the head (cf. in Bradford-Grieve, 1994: fig.44: B).

Distribution: The species was recorded in Eastern tropical Pacific, Indian Ocean, Red Sea, China Seas, Gulf of Thailand and Central tropical Pacific (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti oceanic waters of Minicoy and Coastal waters of south west coast of India.

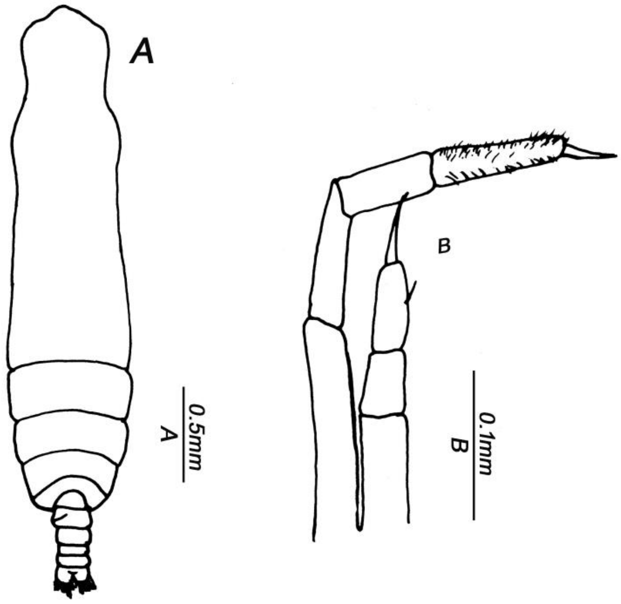

Figure 12. *Pareucalanu attenuatus.* Male A- dorsal, B- P5.

3. ***Pareucalanus sewelli*** **(Fleminger, 1973)**

Female. TL: 3.63- 4.5mm (n=3) Anterior Ce triangular (Fig.13 A,B), apex scute in lateral view. CR slightly asymmetrical (Fig.13C).

Remarks: *P.sewelli* and *P. attenuatus* are morphologically similar characteristics especially juveniles of the two species cannot be distinguished because of their very close morphological similarity. Quantitative data of the two species the present study were combined and represented in some stations to *P.attenuatus. P.sewelli* can be distinguished from *P.attenuatus* from the shape of the anterior head; the adult female of *P.sewelli* has a more strongly attenuated and longer forehead than in *P.attenuatus*.

Distribution: The species was recorded in Eastern tropical Pacific, Central South Atlantic, Indian Ocean, Gulf of Thailand, Great Barrier Reef, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from oceanic waters of Minicoy and coastal waters of the south-west coast of India.

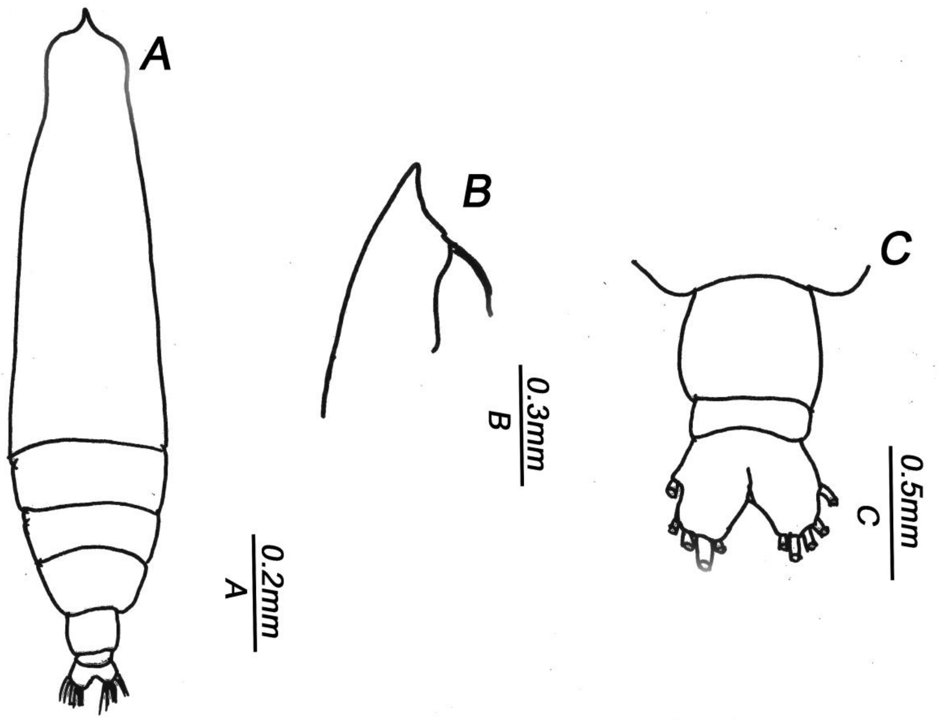

Figure 13. *Pareucalanus sewelli* female A- Habitus dorsal; B-Head lateral view; C-CR.

Genus: *Subeucalanus* Geletin, 1976

4. *Subeucalanus subcrassus* (Giesbrecht, 1888)

Female. TL: 1.7-2.5mm (n=4). Anterior of Ce rounded (Fig.13A); A1 extends beyond the furca by around four segments. Ur 3 segmented, genital segment broader than long, with a widest part in dorsal view on the posterior half of the segment, furca fused with an anal segment (Fig.13B).

Male. TL: 1.9 mm. (Fig.13 C) A1 reaches around the end of furca, Right P5 absent, terminal seta on left P5 longer than the terminal segment (Fig.13D).

Remarks: Female specimen similar to *Subeucalanus crassus* but slimmer, head more pointed and extends further forward in lateral view, the second terminal seta on the left furca is much longer than the right seta, and the genital segment is narrower. The species has close similarity with *Subeucalanus pileatus*. In *S.pileatus*, there are four setae by the mandible.

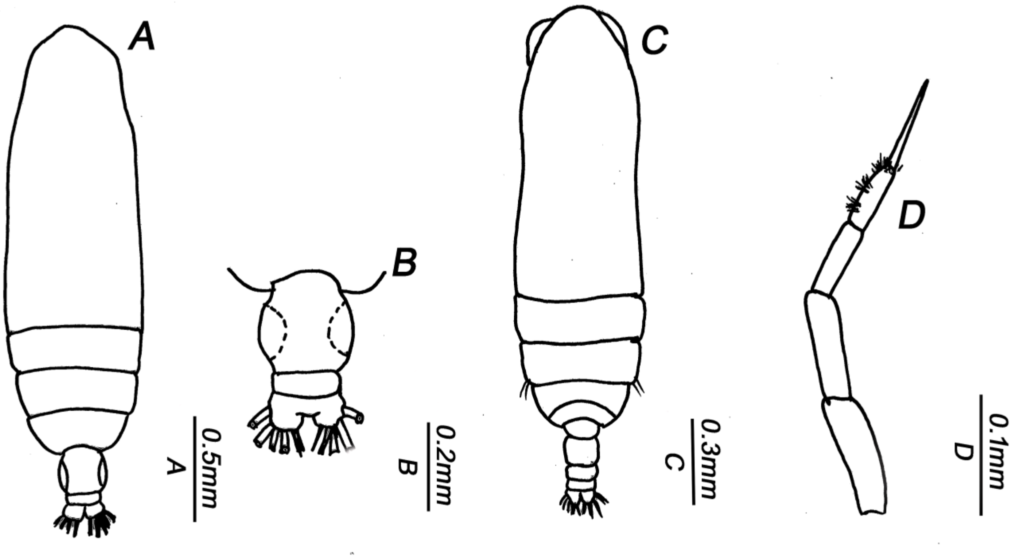

Figure 13. *Subeucalanus subcrassus* female A- Habitus dorsal; B-Ur; male C-Habitus dorsal; D-P5.

Distribution: The species was recorded in Eastern tropical Pacific, Red Sea, Indian Ocean, Gulf of Thailand, Great Barrier Reef, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kavaratti, Oceanic waters of Minicoy and coastal waters of South West coast of India.

5. ***Subeucalanus mucronatus*** **(Giesbrecht, 1888)**

Male. TL: 2.6, 3mm (n=2). Rounded anterior Ce, (Fig.14 A) Right P5 absent. Terminal spine is shorter than the Exp2, which separates it from *S. subtenuis* (Fig.14 B). Second inner seta on the right furca thicker and longer than other setae, if not broken.

Distribution: The species was recorded in Eastern tropical Pacific, Sub Antartic, Mediterranean Sea, Red Sea, Indian Ocean, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Kavaratti, Minicoy and coastal waters of the south-west coast of India.

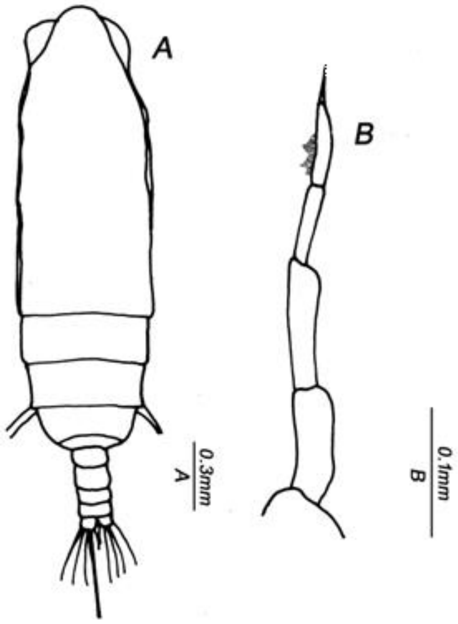

Figure 14. *Subeucalanus mucronatus* male A- Habitus dorsal; B-P5.

6. *Subeucalanus subtenuis* (Giesbrecht, 1888)

Female. TL: 2.6-3.24 (n=5). Body is similar to *S.mucronatus* (Fig.15 A)*.* Triangular anterior Ce, apical portion is less sharply pointed. Furca asymmetrical.

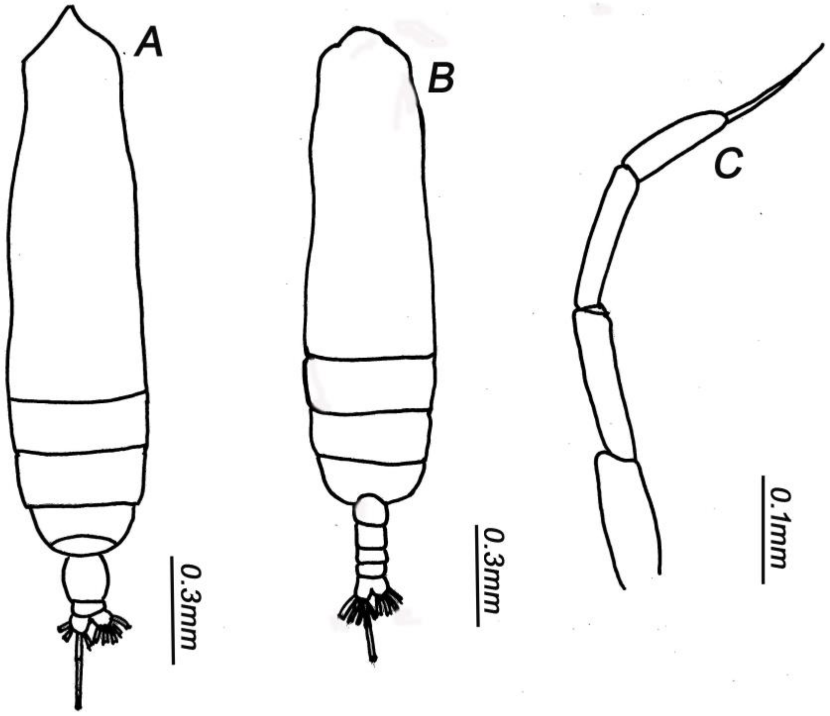

Figure 15. *Subeucalanus subtenuis* female A-Habitus dorsal; male B-Habitus dorsal; C-P5.

Male. TL: 2.8mm Anterior Ce rounded (Fig.15B). Body resembles S. *S.mucronatus* but the terminal spine on the left P5 is longer than the terminal segment. Also similar to *S. crassus* but has more developed asymmetry of the setae of the furca, the terminal spine of left P5 longer than Exp2 (Fig. 15C).

Remarks: It is tough to delineate the differences in between the three species; *S.subcrassus, S.mucronatus* and *S.subtenuis*, the quantitative data of the three species observed from some stations in the present study were combined and represented to *Subeucalans subcrassus.*

Distribution: The species was recorded in Eastern tropical Pacific, Red Sea, Gulf of guinea, Indian Ocean, Gulf of Thailand, China Seas, Gulf of Thailand, Great Barrier Reef, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from oceanic waters of Minicoy and coastal waters of the south-west coast of India.

6.2.4. Family: Clausocalanidae Giesbrecht, 1893

Genus: *Clausocalanus*

1. ***Clausocalanus arcuicornis* (Dana, 1849)**

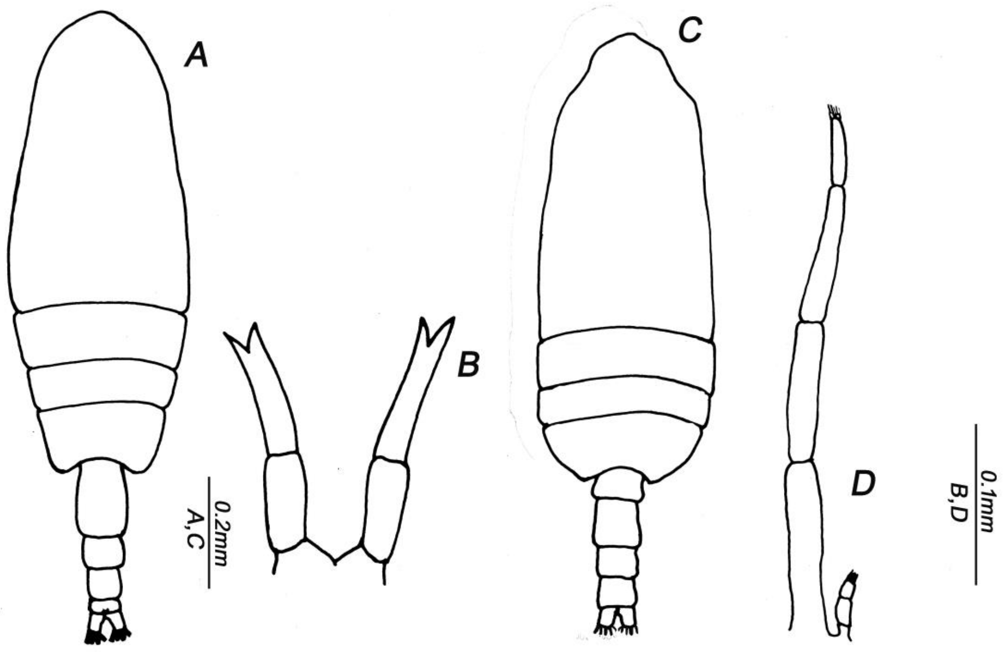

Figure 16. *Clausocalanus arcuicornis*: Female A-habitus dorsal, B-P5; Male C-habitus dorsal, D- P5.

Female TL: 1.25-1.7mm (n=5). Rostrum bifurcated, Genital segment 1.5 times as long as urosome segment3. (Fig.16 A) P5 symmetrical, Exp of the legs as long as the Cox and Bas together. Terminal segment bifurcated (Fig16 B).

Male. TL: 0.95mm. Ur2 long as to Ur3 and Ur4 together (Fig.16 C). Rostrum in lateral view knoblike and protruding ventrally. P5 uniramous and asymmetrical, right leg short and three-segmented. Left leg is longer than Ur, distal segment armed with slender setae (Fig.16 D).

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, North East Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Bangaram, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

6.2.5. Family: Aetideidae Giesbrecht, 1892

1. *Euchirella sp.*

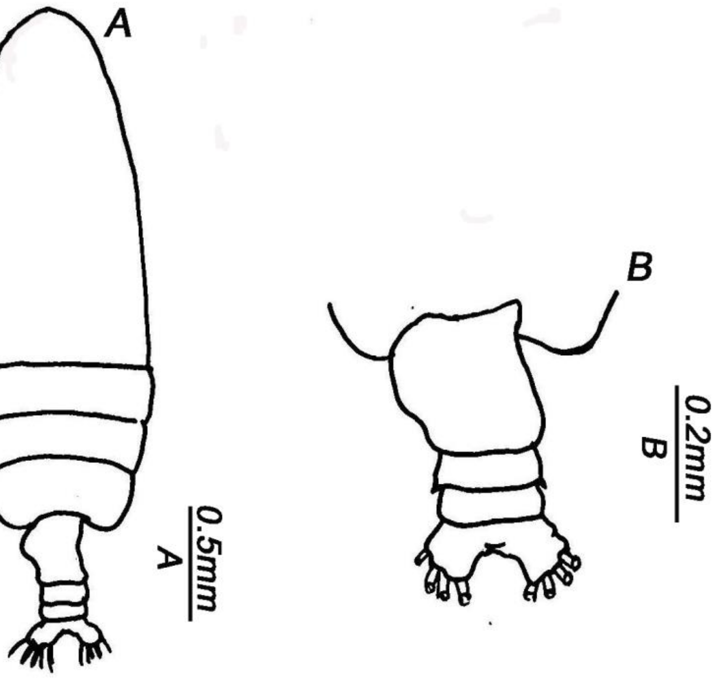

Figure 17. *Euchirella sp.* Female A- habitus dorsal, B-Ur.

Female. TL: 2.7mm. No crest on anterior Ce. Well-developed rostrum, Genital segment asymmetrical with a sizeable ear-like protrusion on the left and a small depression on the right. Anterior metasome segment rounded and symmetrical (Fig.17 A). P5 absent.

Remarks: The species resembles *Euchirella pulchra* Lubbock, 1856.

Distribution: In the present study, this species was observed from oceanic waters of Minicoy.

6.2.6. Family: Rhincalanidae Geletin, 1976

Genus: *Rhincalanus* Dana, 1852

1. *Rhincalanus rostrifrons* (Dana, 1849)

Female. TL: 2.94-3.25mm (n=5). Narrow anterior head, with rostral filaments laterally. A1 extends Cr. lateral and dorsal spines present in Pd2, Pd3and Pd4 (Fig.18 A). A pair is of dorsal spines present in Gns. P5 symmetrical, uniramous and three-segmented. Terminal segment extends into a point, inner distal margin with a stout denticulated seta (Fig.18 B).

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, North East Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Minicoy, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

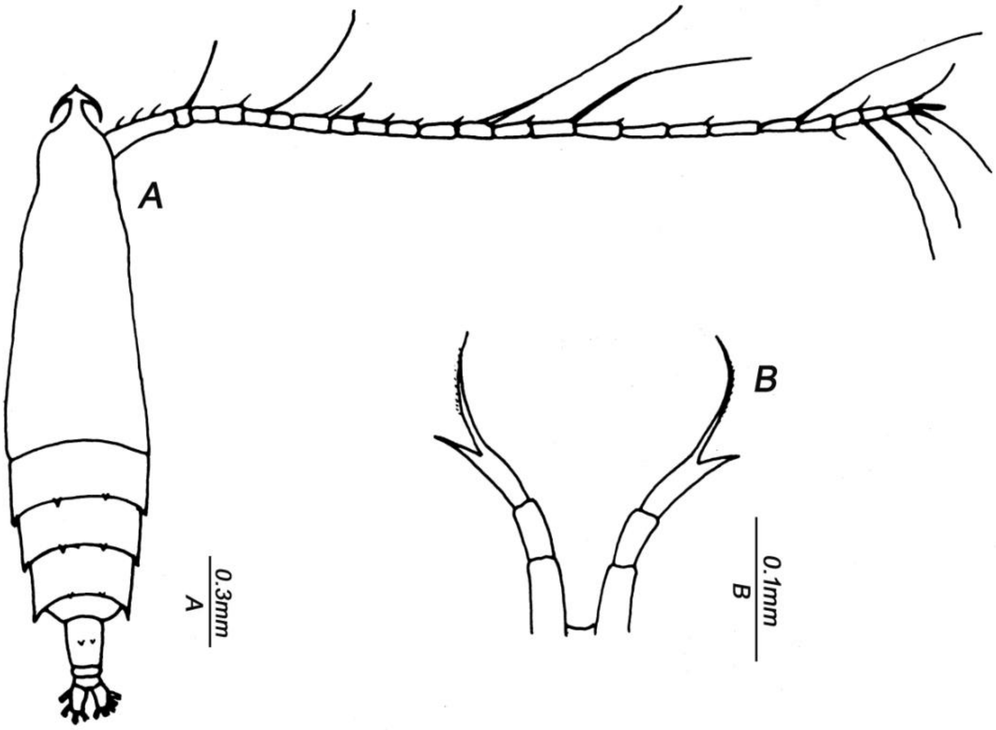

Figure 18. *Rhincalanus rostrifrons*. Female A- Dorsal, B- P5.

6.2.7. Family: Euchaetidae Giesbrecht, 1893

Genus: *Euchaeta* Philippi, 1843

1. *Euchaeta marina* (Prestandrea, 1833)

Female.TL:3.35-3.5mm (n=5). Head anteriorly into the large conical process (Fig.19A). Anteroventrally directed rostrum slightly curved backward (Fig.18B). Genital somite in dorsal view strongly asymmetrical, with a large lobular outgrowth on the right side and a small notch on the left side. P4 (Fig.19-D) marginal lobe is bearing second and third outer spines separated from respective segments by a relatively deep cleft.

Male. TL: 2.7-3mm (n=5). Rostrum elongated, slightly curved backward pointing downward (Fig.20 A). Posterolateral corners of prosome nearly symmetrical.P5 left exopod digitiform process spiniform, the second segment with a poorly sclerotised lobe (Fig.20 B). Third poorly sclerotised lobe, which is relatively large and fingerlike, is located just distal to tufts of stiff hairs.

Remarks: This species belongs to 'marina' Group, characterised by Two endopodal setae of Mx2 armed with long spinules in addition to short spinules. The basis of Mxp with long spinules in addition to short spinules along proximal half of medial margin. Exopod of male left P5 with three poorly sclerotised lobes: 1/- next to digitiform process of the 2nd segment; 2/- on hairy tubercle; 3/- next to tufts of stiff hairs on the 3rd segment. In exopod of male left P5, digitiform process spiniform and serrated lamella long, extending beyond tufts of stiff hairs.

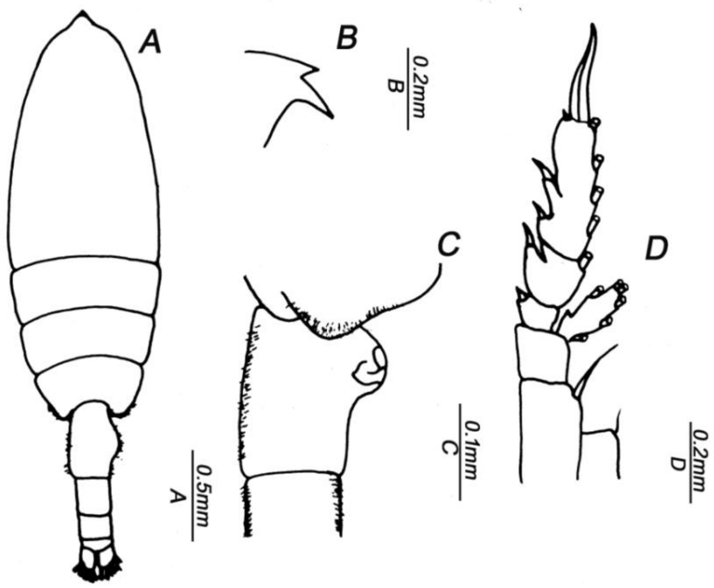

Figure 19. *Euchaeta marina*. Female A- dorsal, B- rostrum right lateral view, C- genital segment right lateral view, D-P5.

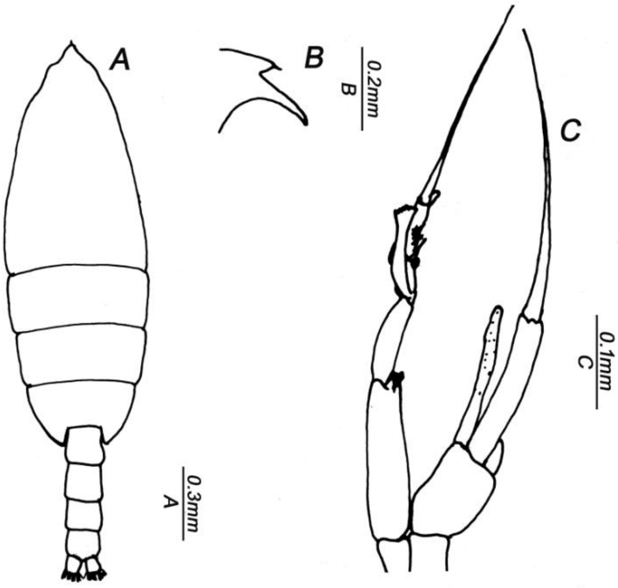

Figure 20. *Euchaeta marina* Male. A-dorsal, B-rostrum right lateral view, C-P5.

Distribution: The species was recorded in Carribean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Central tropical Pacific, China Seas, North West Pacific, North East Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Kavaratti, Minicoy, oceanic waters of Minicoy and coastal waters of south-west coast of India.

2. *Euchaeta concinna* Dana, 1849

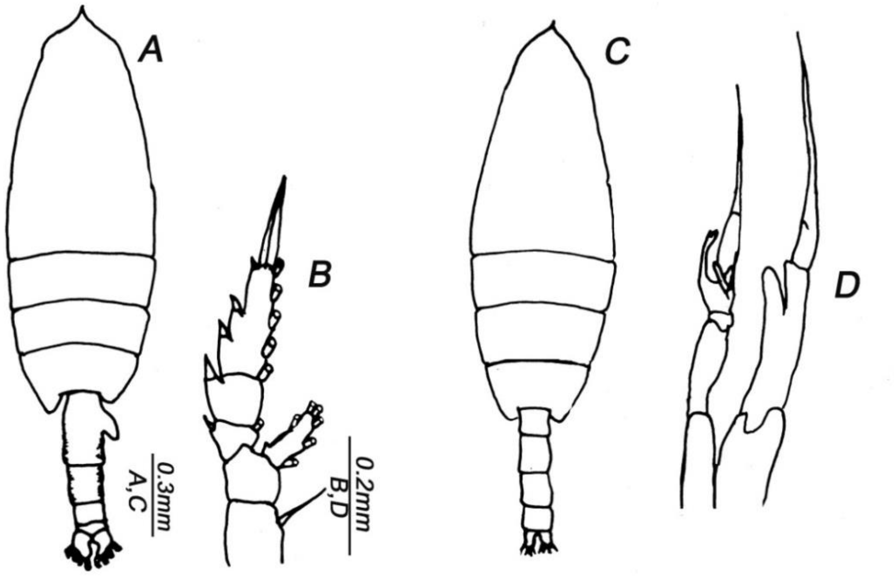

Figure 21. *Euchaeta concinna* Dana, 1849 Female. A-dorsal, B-P5, Male C-dorsal, D-P5.

Female.TL:2.6-3.2mm (n=5). Posterolateral corners of Pr angular, asymmetrical, left side slightly longer (Fig.21 A). P2 (Fig.21 B) exp2 outer spine large, overreaching following outer spine; marginal lobe bearing outer spine also large, separated from segment by deep incision; all other outer spines of similarly small size.

Male. TL: 2.25-2.3mm (n=5). Rostrum relatively short, pointing straight downward. Pr posterolateral corners in lateral view produced into a rounded lappet (Fig.21 C); serrated lamella of left P5 Exp elongate, hollow, with uniformly small teeth on medial-lateral margins and long teeth on distal margin (Fig.21 D).

Remarks: The species belongs to "concinna" Group, characterised by a 1st inner lobe of Mx1 with 1 or 2 proximal marginal setae. Only one endopodal seta of Mx2 armed with long spinules in addition to rows of small spinules. A 3rd exopodal segment of male left P5 without a poorly sclerotised lobe next to tufts of stiff hairs.

Distribution: The species was recorded in Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

3. *Euchaeta longicornis* Giesbrecht, 1888

Female.TL: 2.6-3.2mm (n=6). Body plan of the species is similar to *E. concinna*. High frontal eminence on the forehead and long slender rostrum (Fig.22 B). In both lateral and dorsal view, the distal end of metasome on each side broadly rounded (Fig.22 A). Dorsally and ventrally, genital segment strongly asymmetrical with a large swelling on half of the left side and a large wing-like outgrowth on distal half of right side. The lateral side of wing-like outgrowth bearing a small process.

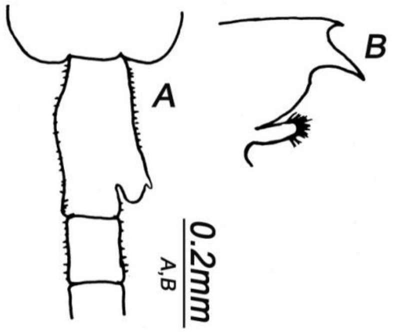

Figure 22. *Euchaeta longicornis.* Female A- Urosome genital segment, B-Rostrum right lateral view.

Remarks: The species belongs to "*concinna*" Group. This species resembles *P. concinna*, but the female of the latter species has the posterolateral corners of the metasome posteriorly produced and an incision on the left side of the genital segment when viewing in dorsal view.

Distribution: The species was recorded in Eastern tropical Pacific, Indian Ocean, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kavaratti, Minicoy, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

4. *Euchaeta indica* Wolfenden, 1905.

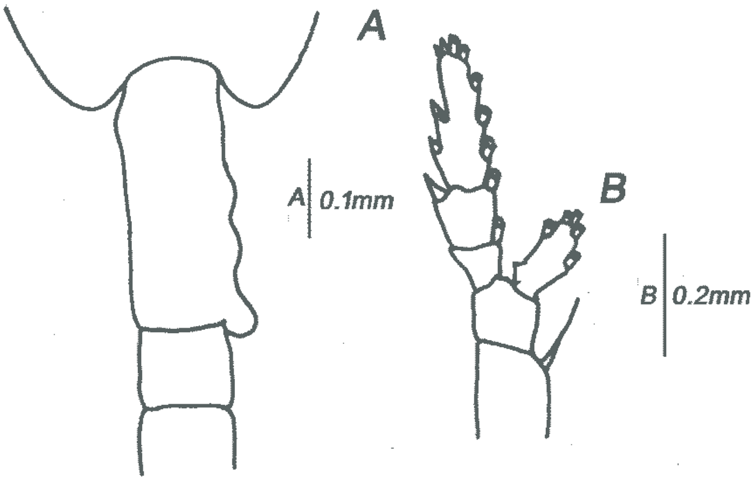

Figure 23. *Euchaeta indica*. Female. A- Genital segment. B-P5.

Female. TL: 2.4-2.5mm. (n=5). Body plan of the species similar to *E. marina*.A1 extends to the end of urosome segment 2. Frontal eminence on forehead developed. In lateral view, the genital segment is about twice as long as the broadest part (Fig.23 A). Genital segment is irregular in outline when viewed from dorsal and ventral sides. P5 (Fig.23 B) like *E.marina* in general appearance.

Remarks: This species belongs to '*marina*' Group. This species, originally described from the Maldive and Laccadive archipelagos, was demonstrated by Bradford (1974) to be a senior synonym of *E. wolfendeni*. Park found the species throughout the tropical waters of the Pacific from the American coast, to the Malay Archipelago, and the eastern Indian Ocean (Razouls et al., 2005-2018).

Distribution: The species was recorded in Eastern tropical Pacific, Indian Ocean, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from coastal waters of the south-west coast of India.

6.2.8. Family: Scolecitrichidae Giesbrecht, 1893

1. *Scolecithrix danae* (Lubbock, 1856)

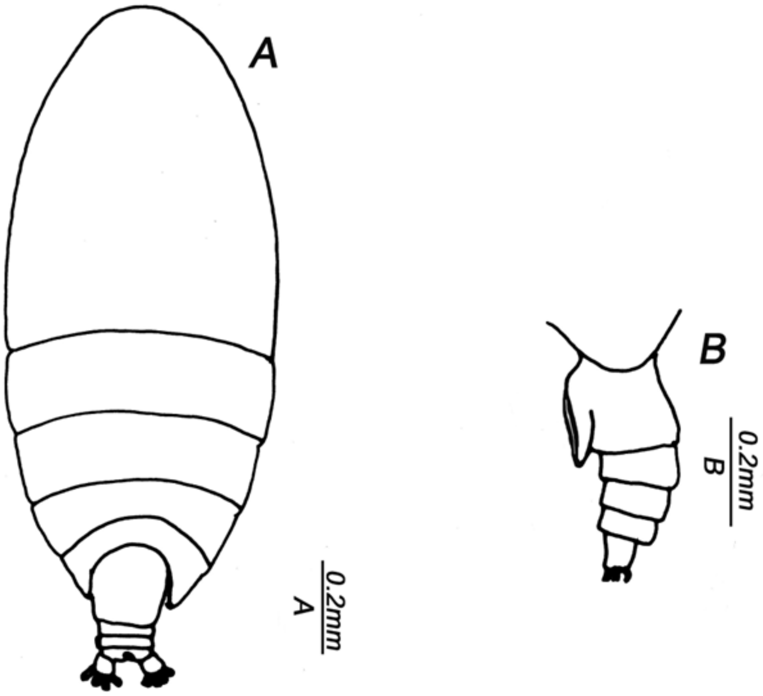

Figure 24. *Scolecithrix danae*. Female. A-dorsal, B-Ur left lateral view.

Female. TL: 1.7-2.2mm. The A1 extends beyond the prosome. Prosome has a very characteristic shape, being very broad at the midpoint (Fig.24 A). The anterior metasome segments are produced into points which extend close to the urosome, reaching halfway down the genital segment — Ur of 4 segments. The genital segment has a downward pointing projection when viewed from the side (Fig.24 B). P5 absent.

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, North East Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Bangaram, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

6.2.9. Family *Lucicutidae* Sars, 1902

1. *Lucicutia flavicornis* (Claus, 1863)

Female. TL:1.8mm. Cephalosome without lateral protrusions. Furca slightly more than five times as long as wide (Fig.25 A); A1 reaches the middle of furca (Fig.25 B). P5 endopodite with three segments; inner spine on exopodite segment 2 is long and straight, except for a slight bend at the tip, reaching beyond base of first inner seta on exopodite segment 3; a terminal segment on exopodite segment three less than half the length of the segment. Outer margin of exp 3 with several teeth (Fig.25 C).

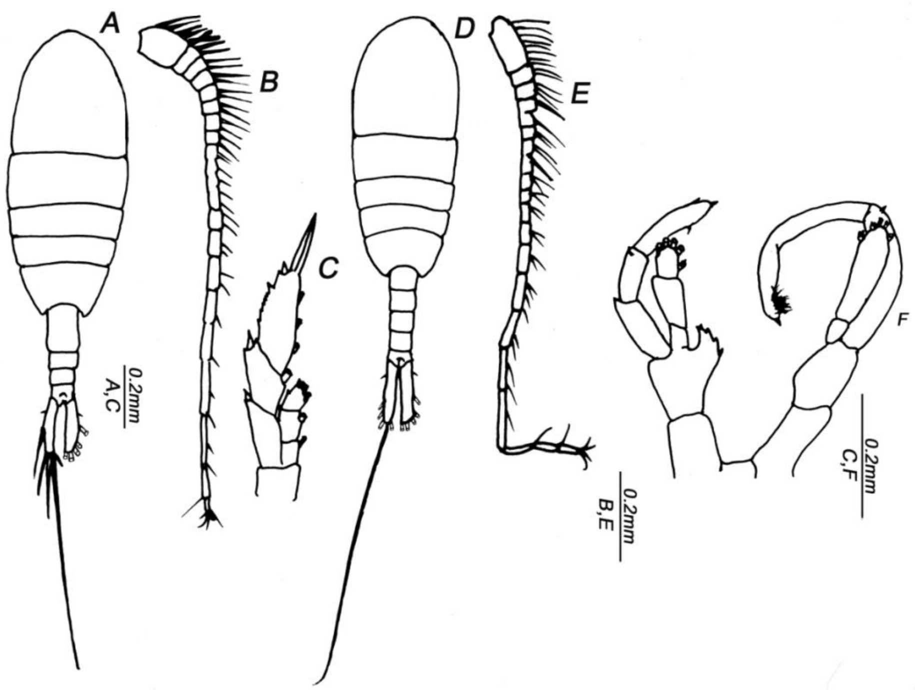

Figure 25. *Lucicutia flavicornis* Female. A-dorsal, B- Right A1, C-P5. Male D-dorsal, E-right A1, F-P5.

Male. TL:1.5mm. Ce without lateral protrusions (Fig.25 D). Furca slightly more than 5 times as long as wide; A1 reaches middle of furca (Fig.25 E).P5 right coxa inner margin with a conspicuous rounded protrusion, right basis with a triangular inner border bearing hairs distally; left coxa with a ridge on the inner margin, left basis inner distal corner protruding and ending in a point and with 3-5 extra teeth and sometimes a proximal spinule. Inner margins of both basis segments without pointed projections (Fig.25 F).

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, North East Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from Kavaratti atoll.

6.2.10. Family: Centropagidae Giesbrecht, 1893

1. *Centropages calaninus* (Dana, 1849)

Female.TL: 1.65-2mm. (n=5) The last metasome segment is rounded (Fig.26 A). Both the female genital segment and furca are slightly asymmetric. The genital segment swells laterally. The anal segment is slightly asymmetric. The genital segment swells laterally in dorsal view. The anal segment is almost twice as long as urosome segment 2. P5 exopodite segment two inner edge spine is straight and longer than exopodite segment 3 (Fig.26 B).

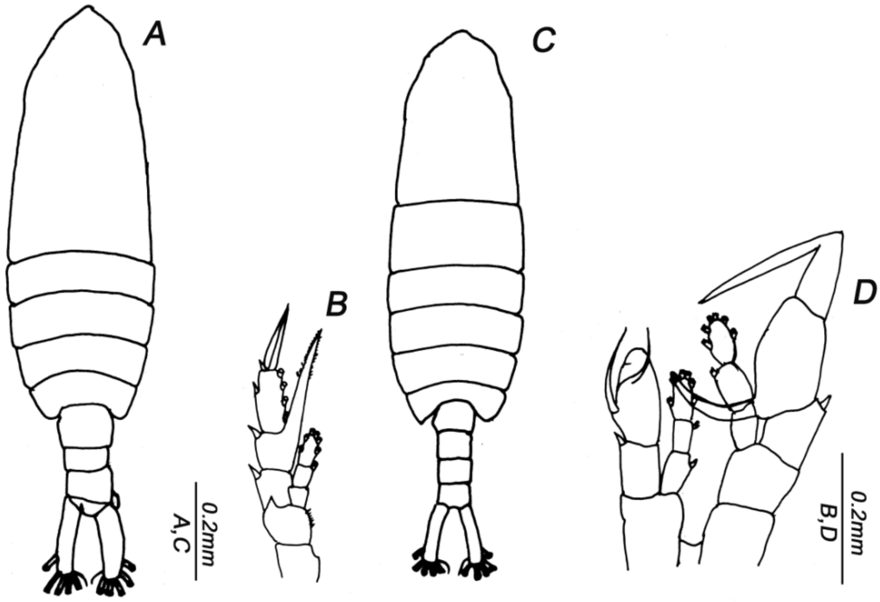

Figure 26. *Centropages calaninus* Female. A-dorsal, B-P5 male C-dorsal, D-P5.

Male. TL: 1.85 mm. The last metasome segment rounded (Fig.26 C). Right P5 exopodite segment three claws are longer than the inner extension of exopodite segment 2 (Fig.26 D).

Distribution: The species was recorded in Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, North East Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from oceanic waters of Minicoy and coastal waters of the south-west coast of India.

2. *Centropages furcatus* (Dana, 1849)

Female. TL: 1.5-1.63mm. Cephalosome has a conspicuous ventral ball-like eye, prominent second spines between the lateral spines on the last metasome segment and the urosome (Fig. 27 A). P5 exopodite segment two inner edge spine does not reach the distal border of Exp3. The anal segment is slightly asymmetrical (Fig.27 B).

Distribution: The species was recorded in Caribean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, North East Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Kalpeni, Kavaratti, oceanic waters of Minicoy and coastal waters of South West coast of India.

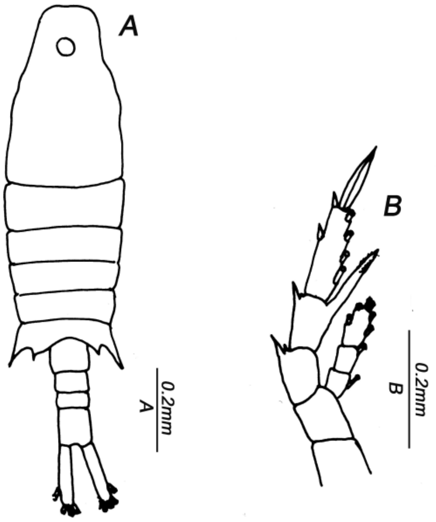

Figure 27. *Centropages furcatus* female A-dorsal, B-P5.

3.*Centropages gracilis* (Dana,1849)

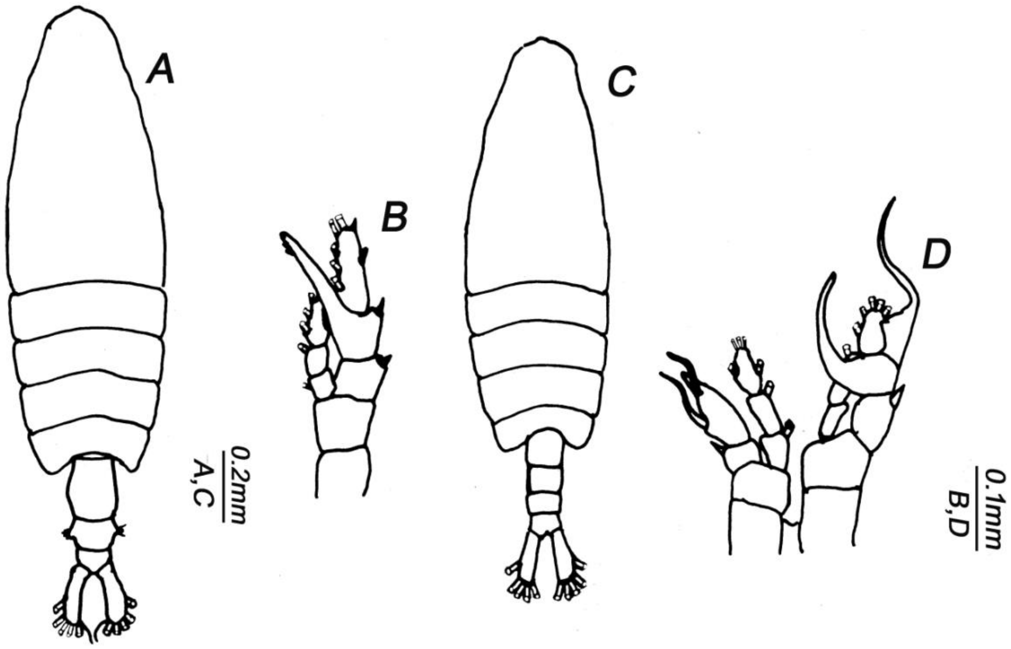

Figure 28. Female A- habitus dorsal, B-P5. Male C- habitus dorsal, D-P5.

Female.TL: 1.75-2mm (n=5). The lateral angles of the last metasome segment are rounded (Fig.28 A). The second urosome segment has lateral knobs covered in short spines. Inner marginal spine on exopodite 2 of the P5 does not reach the end of segment 3 (Fig.28 B).

Male. TL: 1.7mm. (Fig.28 C) The terminal claw of the grasping right P5is longer than the thumb and has a pronounced triangular protrusion, absent in other species of the genus (Fig.28 D).

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kavaratti, Minicoy, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

4. *Centropages orsinii* Giesbrecht, 1889

Female. TL: 1.5-1.6mm (n=7). The last metasome segment corners are pointed, but not sharply (Fig.29 A). The genital segment is symmetrical and has as offset spine on the ventral surface, which points backwards. P5 are nearly symmetrical and the inner marginal spine on exopodite two curved, is usually covered in small spines and does not reach the end of segment 3 (Fig 29 B,C).

Male. TL: 1.3-1.6mm. The last metasome corners are weakly pointed (Fig. 29 D). The terminal claw of the grasping right P5 is longer than the thumb. The terminal portion of exopodite segment 3 of the left P5 projects into a spine (Fig. 29 E).

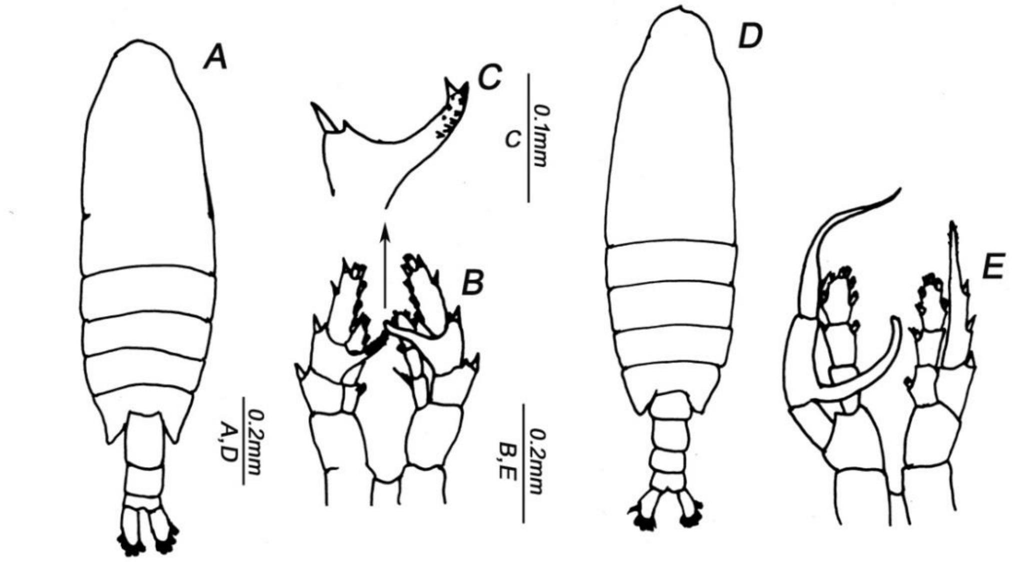

Figure 29.*Centropages orsinii* Female, A-dorsal, B-P5, C-Exp2 of P5. Male, D-dorsal, E-P5.

Remarks: *C. orsinii* constitutes with *C. halinus* and a ''*orsinii*'' species-group, members of which share the following features: 1- posterior corners of both sexes weakly pointed; 2- P1 to P3 with 2-segmented endopods, whilst 3-segmented endopods are retained on legs P4 and P5; 3- female P5 possess a relatively short medial process on the 2nd exopodal segment with bilateral serration along the distal part of the lateral margin; 4- male left P5 consists of 2-segmented exopod (ancestral segments 2 and 3 fused), with the 2nd segment being fused to a relatively long bilaterally serrated distal spine; 5 - male right P5 with 2nd exopodal segment has short seta at the distolateral corner and relatively short medial process slightly increasing the length of the 2nd exopodal segment; 6-male right P5 with 2nd exopodal segment curved and armed with a slender seta medially close to the basal articulation (El-Sherbiny & Al-Aidaroos, 2015; Razouls et al., 2005-2018).

Distribution: The species was recorded in the Indian Ocean, the Red Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kavaratti, Minicoy, and coastal waters of the south-west coast of India.

6.2.11. Family Pseudodiaptomidae Sars, 1902

1. *Pseudodiaptomus serricaudatus* (T.Scott, 1894)

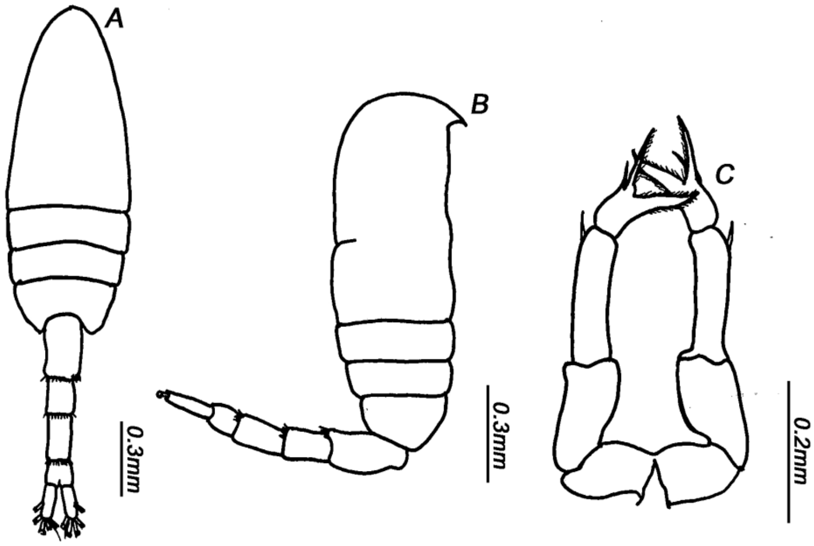

Figure 30. *Pseudodiaptomus serricaudatus* female. A-Habitus dorsal, B lateral view, C-P5.

Female. TL:0.8-1.2mm (n=5) Body slender and elongate. (Fig.30 A, B) Genital segment without laterally pointing spines, slightly asymmetrical, the posterior margin produced more backwards on the right than on the left; all urosome segments with a regular row of triangular teeth on posterior margin. P5 uniramous; 4-segmented; the terminal spine is shorter than the spiniform process of the 4th segment, and bears a slender plumose seta in place of the short, stout, serrate spine(Fig.30 C).

Distribution: The species was recorded in Cape of good hope, Red Sea, Indian Ocean, and Gulf of Thailand (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kalpeni and Kavaratti.

6.2.12. Family Temoridae Giesbrecht, 1893

1. *Temora discaudata* Giesbrecht, 1889

Female. TL: 1.6-1.9mm (n=5). Posterior metasome segments produced into spines (Fig.31 A). In *T.discaudata,* the anal segment and long slender furca are symmetrical. P5 uniramous and symmetrical, the inner spine of segment three longer than the 2 terminal spines, which are almost equal in length (Fig.31 B).

Male.TL: 1.8mm lateral angles of last metasome segment pointed and slightly asymmetrical (Fig.31 C); right A1 geniculate. Urosome of 5 segments, asymmetrical, with long slender furca. The thumb-like process by the left P5 is wide, the terminal segment is flattened and has four marginal spines. The terminal segment of the right P5 is hook-like and sharply bent backwards (Fig.31 D).

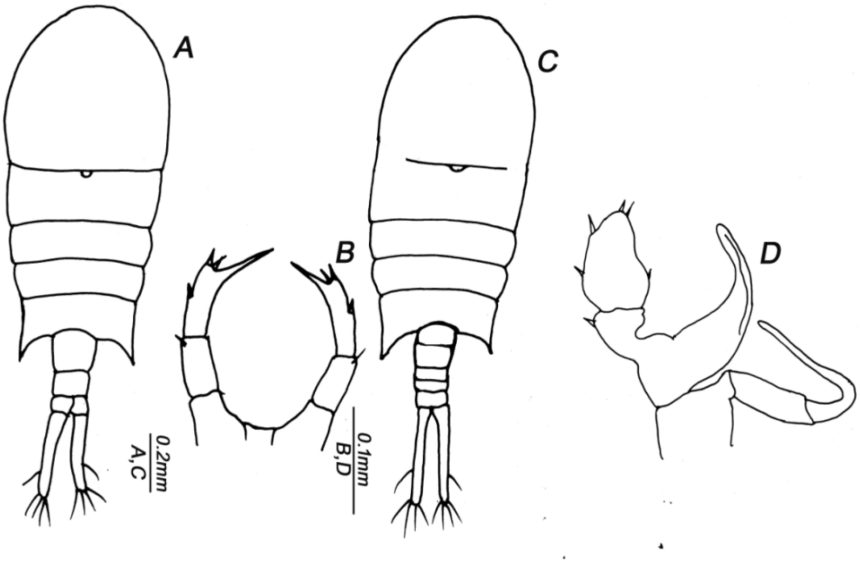

Figure 31. *Temora discaudata* Female. A-dorsal, B-P5. Male. C-dorsal, D-P5.

Remarks: This species bears some resemblance to *T.stylifera*, and several authors have recorded this latter species a being present in the Indian Ocean.

Distribution: The species was recorded in Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Kavaratti, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

2. Temora turbinata (Dana, 1849)

Female.TL: 95-1.35mm (n=6). Body widest at Cephalosome, tapering anteriorly to urosome; last metasome segment rounded (Fig.32 A). Urosome 3 segmented; anal segment symmetrical, shorter in length than the previous segment; P5 symmetrical, the inner marginal spine of the 3 terminal spines shorter than the other two (Fig.32 B).

Male.TL: 0.6-1.2 mm (n=5) body shape similar to female; Urosome quite symmetrical; furca long and slender (Fig.32 C); P5 asymmetrical, the left with a claw; thumb of the claw is slender and gradually curved (Fig. 32 D).

Distribution: The species was recorded in Caribean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, China Seas, Gulf of California and Sub-Antartic (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Bangaram Kavaratti, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

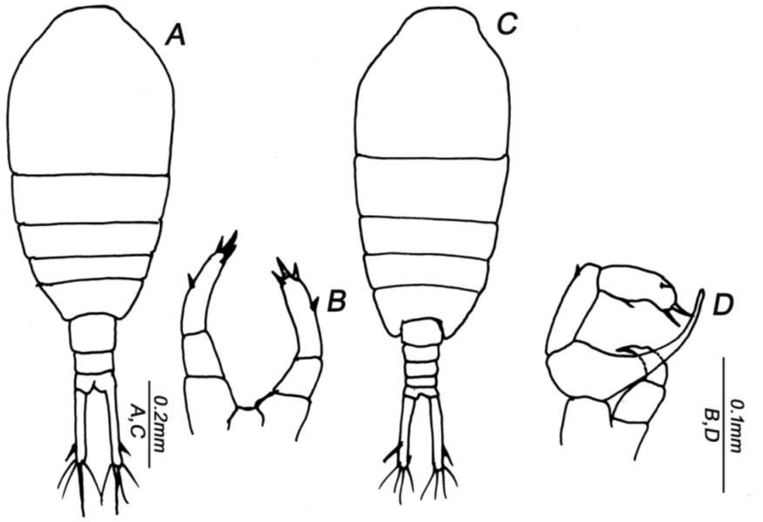

Figure 32. *Temora turbinata* Female.A-dorsal, B-P5. Male C-dorsal, D-P5.

6.2.13. Family Candacidae Giesbrecht, 1893

1. *Candacia ethiopica* (Dana, 1849)

Female. TL 1.9-2.3mm (n=5) The prosome is often very darkly pigmented (Fig.33 A). Last cephalosome segment rises to a small crest on the back at the rear edge. The genital segment is slightly asymmetric, with protrusions on each side, one larger than the other. Terminal segment of P5 has seven spines (Fig.33 B).

Male. TL 1.8-2mm (n=5) Recognized by the curved, spiny projection of the right posterolateral corner of the metasome (Fig.33 C). The genital segment has two triangular processes on the right margin. There is also a small crest on the last cephalosome segment, which is also found in some other *Candacia* spp. P5 asymmetrical, The male is distinguishable by the right side of fifth metasomal somite with bifid apex and the urosomite 1 with two triangular processes on the right margin.

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from oceanic waters of Minicoy and coastal waters of the south-west coast of India.

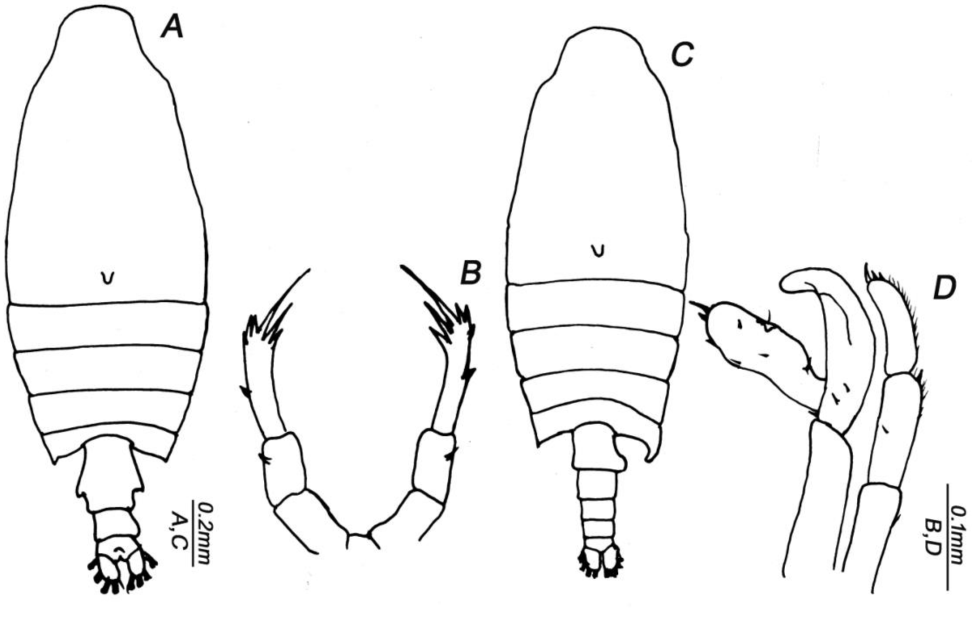

Figure 33. *Candacia ethiopica:* Female A-dorsal, B-P5. Male. C-dorsal, D-P5.

2. *Candacia bradyi* (A.Scott, 1902)

Female. TL. 1.5-1.9mm (n=5). Posterior metasome segment corners each end in a short spine (Fig.34 A). Genital segment broad and almost symmetrical in dorsal view, with a slight anterior protrusion on the right side. Urosome segment 2 has a pointed protrusion on the mid-ventral surface. P5 segment 3 curved slightly inwards with two setae on inner margin and three spines on the distally outer edge with an additional spine further back (Fig.34 B).

Distribution: The species was recorded in the Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific and China Seas (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kavaratti and Minicoy

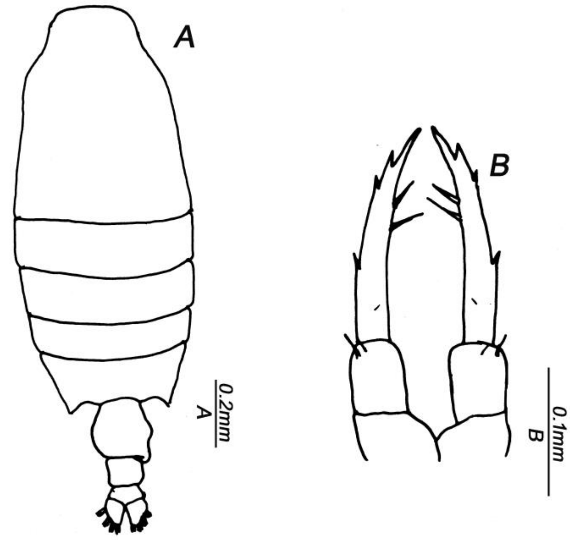

Figure 34. *Candacia bradyi* Female. A-dorsal, B-P5.

3. *Candacia catula* (Giesbrecht, 1889)

Female.TL: 1.35-1.6mm (n=7). Posterior metasome is symmetrical and pointed (Fig.35 A). Genital segment is symmetrical with both sides swollen. Segment 3 of P5 is long and has two outer marginal spines and three inner marginal setae and three teeth at the end (Fig.35 B).

Male. TL: 1.2-1.5mm (n=5). The last segment of the metasome pointed, but not prominently (Fig.35 C). Points are slightly asymmetric. Unusual among Candacia males in having no bumps on the genital segment.P5 asymmetrical. Right leg consists of a forceps. The claw-like third segment of left P5 with a terminal long and curved spine (Fig.35 D).

Distribution: The species was recorded in Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas and Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Kalpeni, Kavaratti, and Minicoy.

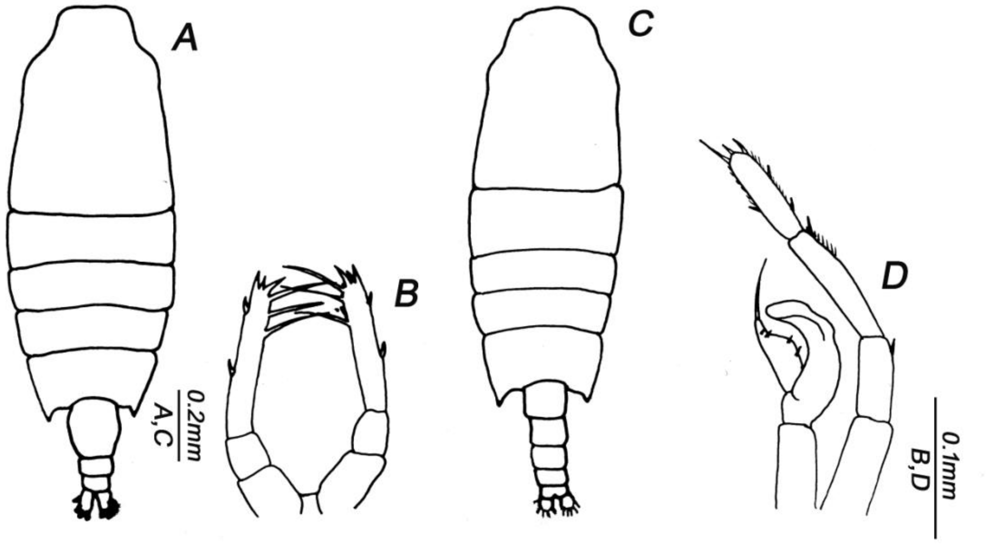

Figure 35. *Candacia catula* Female. A-Dorsal, B-P5, male C-dorsal, D-P5.

4. *Candacia pachydactyla* (Dana, 1849)

Female. TL: 2-2.8mm (n=5). Posterior metasome segment pointed and asymmetrical. A markedly asymmetric genital segment with characteristic large pointed protuberances extending obliquely (Fig.36 A). Segment 3 of P5 thickened with 3 strong terminal spines, 3 setae on the inner side and a strong spine on the outer edge (Fig.36 B).

Male. TL: 8-2.5mm (n=6). Posterior metasome is asymmetrical Fig.36 C). The genital segment with a large process on the right, consisting of a single, broad, rounded projection. Has a large characteristic protuberance on the genital segment. The thumb of the chela on the right P5 ends in a long spine as does the distal segment of the left P5 (Fig. 36 D).

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, and Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from oceanic waters of Minicoy and coastal waters of the south-west coast of India.

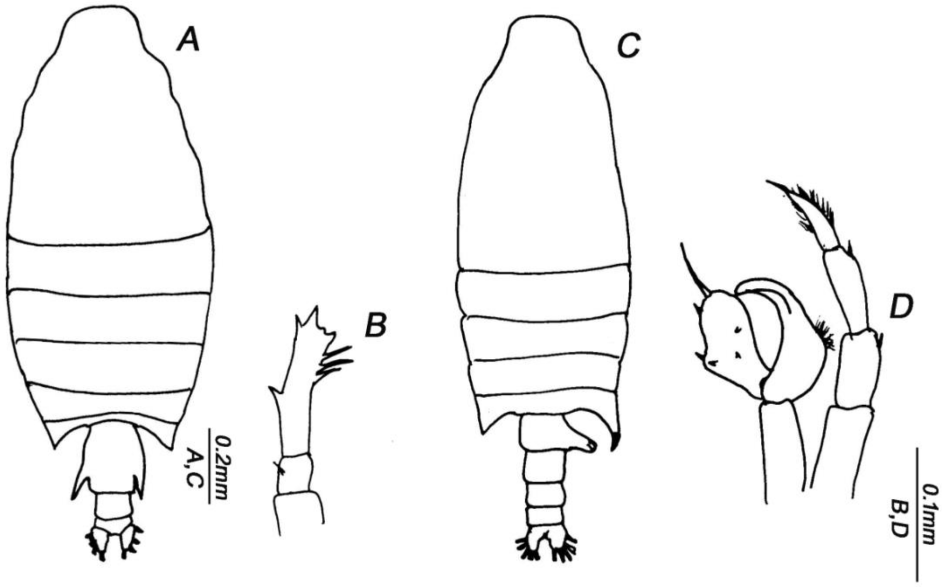

Figure 36. *Candacia pachydactyla* Female. A-dorsal, B-P5. Male. C-dorsal, D-P5.

5. *Candacia simplex* (Giesbrecht, 1889)

Female. TL: 1.6-1.9mm (n=5). Posterior corners of the metasome pointed and directed backwards. Genital segment is almost symmetrical and without lateral spine-like protrusions (Fig.37 A) P5 segment 3 with a thick finger-like terminal process finely serrated proximally. There are two inner edge spines, the distal one twice the length of the proximal one (Fig.37 B).

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, North East Pacific, Gulf of California and Sub-Antartic (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters Kavaratti, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

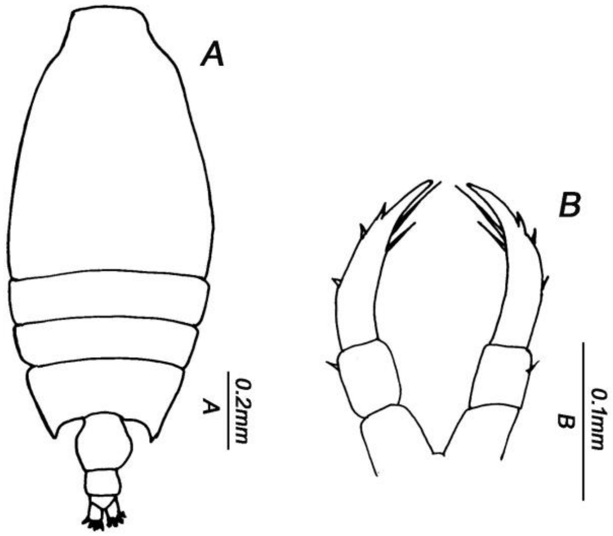

Figure 37. *Candacia simplex.* Female A-dorsal, B-P5.

6. *Candacia truncata* (Dana, 1849)

Female.TL: 1.8-2.1mm (n=8). The very characteristic square end to the last metasome segment when viewed laterally (Fig.38 A). The corners of the metasome are pointed and directed forwards; some points are not visible in dorsal view. The urosome is quite symmetrical, with no protuberances. P5 has a terminal finger-like process, finely serrated distally and 2 terminal setae of slightly different lengths (Fig.38 B).

Male. TL: Last metasome segment symmetrical, with sharp points (Fig.38 C). The urosome is symmetrical with no projections. Small spine on the external distal side of the left leg segment 2 of P5 (Fig.38 D). There is another spine on the external distal corner of segment 3, and four long spines of almost equal length on the end of segment 4.

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Eastern tropical Pacific, Indian Ocean, Red Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, and coastal waters of the south-west coast of India.

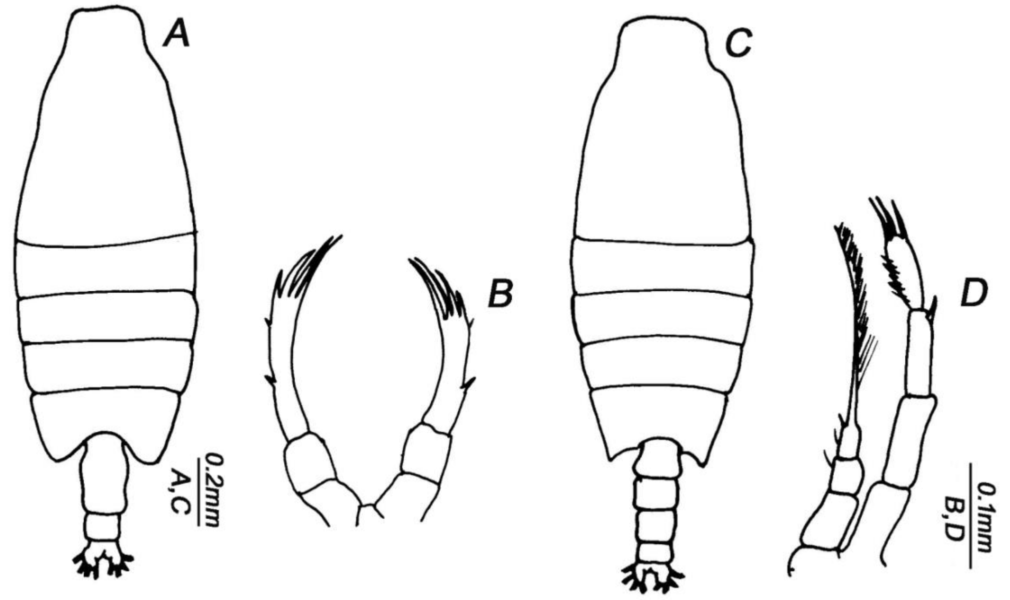

Figure 38. *Candacia truncata* Female. A-dorsal, B-P5 Male C-dorsal, D-P5.

6.2.14. Family Pontellidae Dana, 1853

Genus *Calanopia* Dana, 1853

1. *Calanopia minor* A.Scott, 1902

Female. TL: 1.2-1.5mm (n=4). The last metasome segment produced on each side into an acute spine (Fig.39 A); the rostrum pointed. Urosome 2 segment, the second segment distinctly longer than the genital segment. The P5 (Fig.39 B) quite symmetrical with four segments; the distal segment terminates in the longer inner spine and one short spine, with a further spine on outside mid-segment.

Male.TL: 1.2-1.3mm (n=5). The second urosome segment has no spiny process (Fig.39 C). A1 extends to the end of the third thoracic segment. The basis of left P5 (Fig.38 D) is swollen towards the proximal end of the inner margin; the swollen part produced into a small tooth-like a spine. The basis of the right exopodite is also swollen. Flattened joined of the first exopodite segment, with a seta on inner margin; outer thumb is short and naked. The claw-like the second segment is spoon-shaped and without any teeth, but with two inner marginal setae.

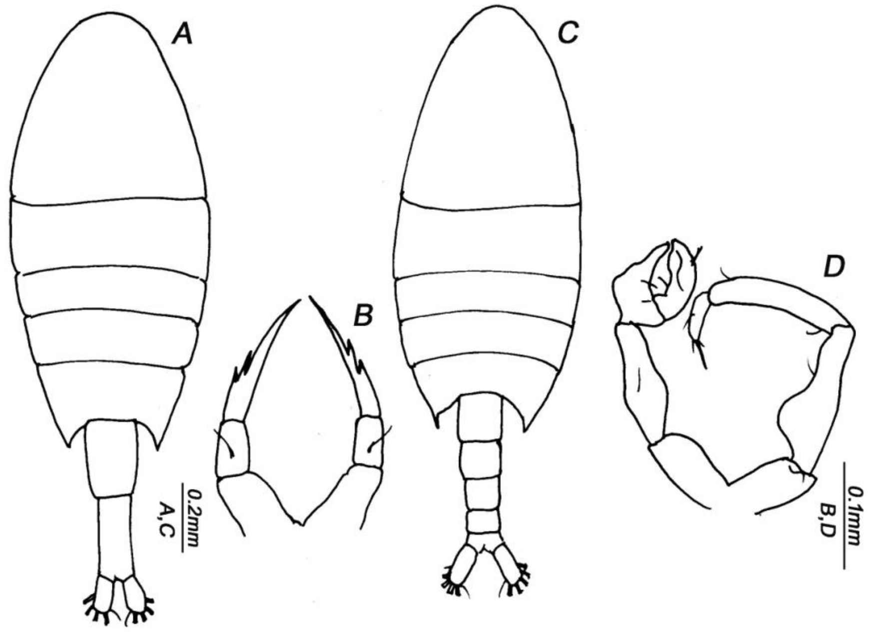

Figure 39. *Calanopia minor* Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

Distribution: The species was recorded in Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, and Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, and Kavaratti.

2. *Calanopia thompsoni* A.Scott, 1909

Female. TL: 2.5-2.65mm (n=5) Lateral hook on Ce. Strong spines onPd5, reaching halfway down genital segment. Genital segment is slightly longer than the second urosome segment. Genital segment ventrally is produced anteriorly and posteriorly into two blunt lobes. Furca is slightly asymmetrical (Fig.40 A). P5 symmetrical, endopodite of 2 segments, first one moderately long with a distal portion of outer margin with two very strong spines. Second segment narrow, terminating in a long, stout spine, serrated on both edges, the segment also with two outer marginal spines and a short inner one (Fig.40 B).

Male.TL:2.1-2.3mm (n=5). Lateral hooks on cephalosome, forehead angular in outline (Fig.40 C). Posterior metasome segment sharply pointed. No spine on urosome segment 2. Right A1 geniculate. Furca is symmetrical. P5 asymmetric, exopodite of the right leg claw-like (Fig.40 D).

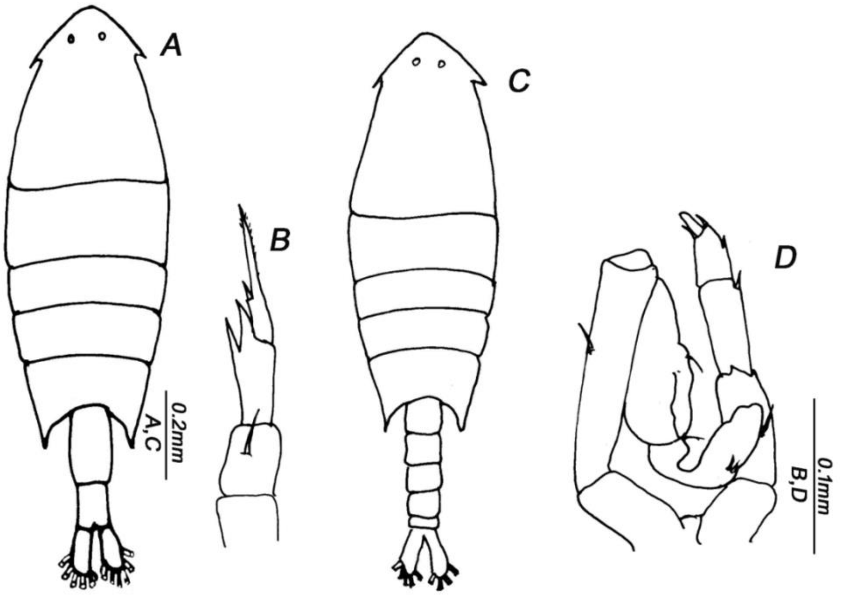

Figure 40. *Calanopia thompsoni* Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

Remarks: According to C.B. Wilson (1950, p.176) this is the most abundant species of the genus and is distinguished from any of the others by its size and by the lateral hooks on the sides of the head like those in the genus *Pontella*. For Al-Aidaroos & al. (2016, p.27) C. *thompsoni* from the Red Sea and *C. parathompsoni* Gaudy (1969) are conspecific.

Distribution: The species was recorded in the Indian Ocean, the Gulf of Thailand, Great Barrier Reef, China Seas, and Japan Sea (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kalpeni and Minicoy.

Genus *Labidocera* Lubbock, 1853

3. *Labidocera acuta* (Dana, 1849)

Female. TL: 2.9-3.3mm (n=5). Sharp spine on the front of cephalosome, directed slightly downwards (Fig.41 A). No lateral cephalic hooks; posterior metasome symmetrical with large lateral points. Urosome 3 segmented, genital segment asymmetrical, with a projection on the posterior right side which extends half way along the next segment, visible from the dorsal side. P5 with rather a variable exopodite, with relatively large spines on the outer border; endopodite claw-like (Fig. 41 B).

Male. TL: 2.8-3mm (n=5). Posterior metasome border symmetric, right side longest and bent outwards (Fig. 41 C). Urosome segment 1 with a small spine on the right. Left P5 with 3 terminal and one outer spine; right P5 without a thumb on the claw, but with a curved triangular flap (Fig. 41 D).

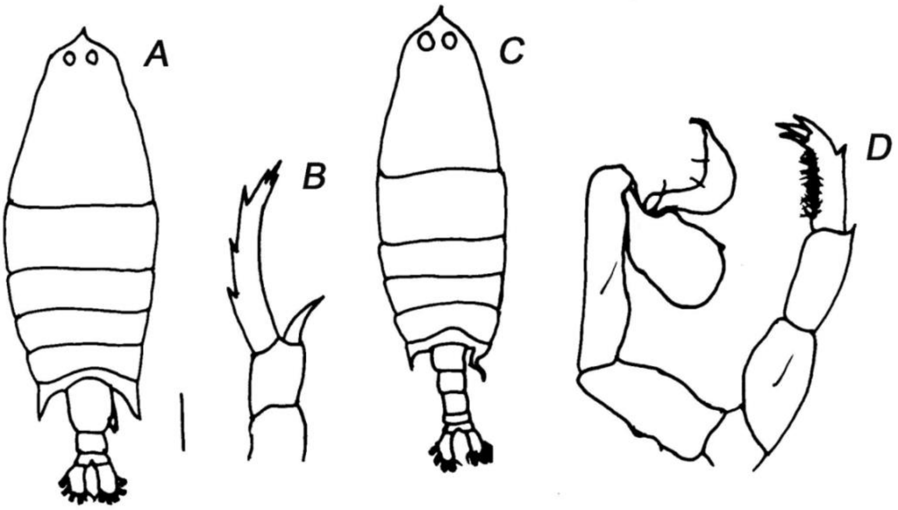

Figure 41. *Labidocera acuta* Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

Remarks: Giesbrecht (1892) described and illustrated two types of variants as *L. acuta* from the Indian Ocean, Arabian Sea, Red Sea, Hong Kong and the Philippines. To the 1st type (Giesbrecht: Pl.41, figs.10, 19, 28) may be referred the typical *L. acuta* described by Dana and Brady. The 2nd type (Giesbrecht: Pl.41, fig.29) obtained from the Arabian Sea and the Red Sea, shows marked differences like the urosome, especially genital segment, caudal rami and disposition of the caudal setae and the structure of the inner 2nd and 3rd setae, and P5. Giesbrecht did not give a name for this variant. Breemen (1908) has reproduced Giesbrecht's drawings of P5 of the variant and called it: '*L. acuta* var.' The present species included under the typical *L. acuta* described by Dana (1849).

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Bangaram, Kavaratti, Minicoy, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

4. *Labidocera detrucncata* (Dana, 1849)

Female. TL: 2.4-2.7mm (n=4) Forehead anterior prosome rounded, dorsal eyes spaced apart, no lateral cephalic hooks, last metasome segment asymmetric, extending further back on the left, with small lateral points; internal to the points the segment curves outwards to the level of the points (Fig.42 A). Urosome 3 segmented with left dorsal surface uneven, lined and notched, furca broad and almost symmetrical. P5 symmetrical, exopodite with three outer marginal spines, terminating in a bifurcated end, endopodite small (Fig. 42 B).

Male. 2.2-2.7mm (n=5) In dorsal view posterior metasome segment pointed, rounded in lateral view, Ur five segmented. Right A1 geniculate P5 asymmetrical, the right leg claw-like with a short triangular thumb on the first exopodite segment, terminating in a spine which is as long as the preceding segment (Fig.412 C). Left P5 terminal segment with four characteristic long spines, one of which is longer (Fig.42 D).

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from the lagoon and oceanic waters of Minicoy and coastal waters of the south-west coast of India.

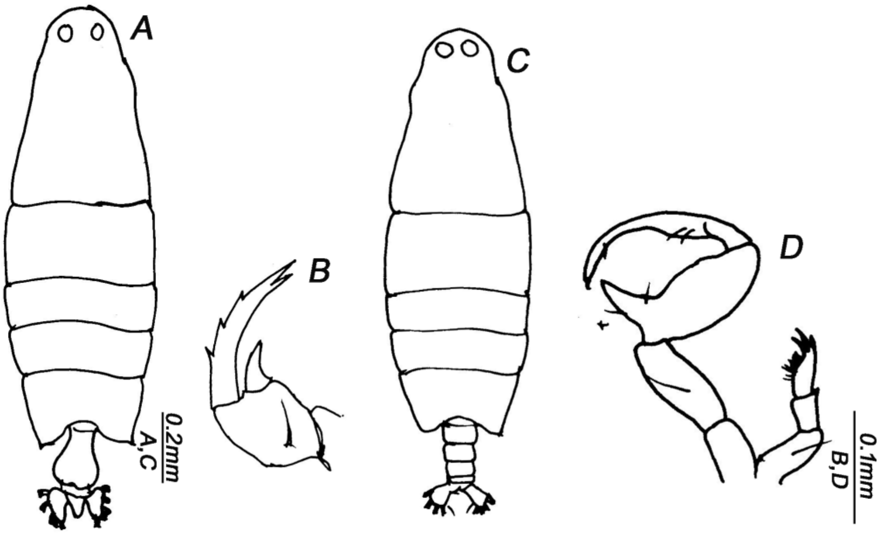

Figure 42. *Labidocera detruncata* Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

5. *Labidocera kroyeri* (Brady, 1883)

Male.TL.1.8-2.1mm (n=5) lateral cephalic hooks on Ce. Lateral corners of the last metasome segment asymmetrical, Left one pointed the right one bifurcated (Fig. 43 A). Five segmented urosome, genital segment swollen on the left side. Right A1 geniculate. Right P5 exopodite segment one claw-like with the curved thumb, the middle portion of the outer margin with two processes (Fig.43 B).

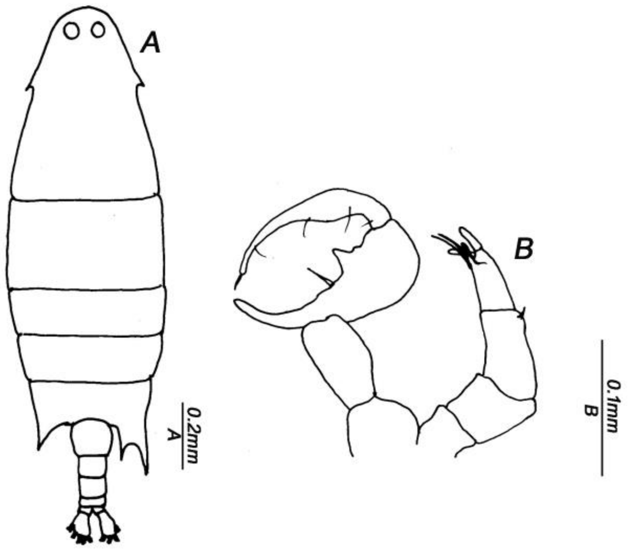

Figure 43. *Labidocera kroyeri* male. A-dorsal, B-P5.

Distribution: The species was recorded in the Indian Ocean, the Gulf of Thailand, the Great Barrier Reef, China Seas, and Japan Sea (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kalpeni oceanic waters of Minicoy and coastal waters of the south-west coast of India.

6. *Labidocera minuta* (Giesbrecht, 1889)

Female. TL: 1.6-2.2mm (n=5). Ce narrow and rounded, small dorsal eye lenses; small lateral hooks present (Fig. 44 A). Lateral posterior margin of metasome rounded, but extended on the right side with a ventrally pointing spine; left side without any spine; Ur 3-segmented, genital segment elongated, and half the length of urosome; right anterior and also posterior corner of genital segment with lateral swellings, in the proximal centre of the ventral surface is a small chitinous outgrowth. P5 symmetrical, exopodite, short, broad-based and ends in an apical spine plus a rather shorter spine on the inner margin (Fig.44 B).

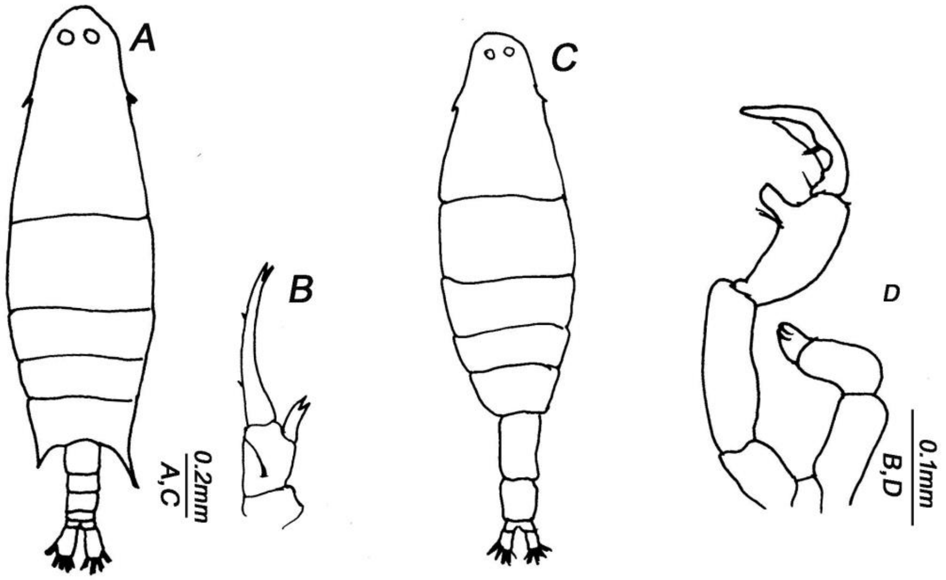

Figure 44. *Labidocera minuta* Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

Male. TL: 1.4-1.8mm (n=5). Ce similar to the female, but dorsal eye lenses are huge and close together (Fig.44 C). Last metasome segment asymmetrical, a shorter point on the left, extended into a long flat, curved tip on the right. Ur 5 segmented, genital segment broader than long, with a small lobe at the right posterior margin. Right A1 geniculate. Right P5 with a claw on the first exopod segment, thumb short with a seta at the base, terminal segment curved with three setae along the internal margin and two setae distally. Left leg terminal segment with at least three lobes like processes (Fig.44 D).

Remarks: For Jeong & al. (2009, p.518) this species is closely related to *L. bengalensis*, but can be distinguished by In females the genital double-somite is about 1.5 times longer than the 2nd urosomite (2.5 times longer in *L. bengalensis*), the 2nd urosomite has prominent chitinous tubercles (no tubercles in *L. bengalensis*), the caudal rami are asymmetrical (symmetrical in *L. bengalensis*, the P5 has a bifurcate endopod (conical endopod in *L. bengalensis*).

Distribution: The species was recorded in Eastern tropical Pacific, Indian Ocean, Red Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, and Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kavaratti, Minicoy, oceanic waters of Minicoy and coastal waters of south-west coast of India.

7. *Labidocera pavo* Giesbrecht, 1889.

Female. TL: 1.9-2.5mm. Body robust, no lateral hooks on Ce (Fig.45 A); dorsal eyes quite well developed; posterior metasome segment pointed and symmetrical; Ur short, two segmented; right side of the genital segment has a process with a spine on end, ventrally the posterior margin produced into a long lobe, second urosome segment short. Some specimens with a transparent elliptical plate on the ventral surface of urosome. P5 almost symmetrical, exopod with two outer marginal spines and terminates in 3 spines, endopod is simple and not bifurcated, left endopod quite rounded and right ending in a sharp point (Fig.45 B).

Male. TL: 1.7-1.9mm. Posterior metasome segment is symmetrical with lateral points. Urosome 5-segmented. Urosome and furca quite symmetrical (Fig.45 C). Right A1 geniculate. P5 asymmetrical (Fig.45 D); right endopod claw-like with well-developed thump, towards inner base of thumb is a robust seta; terminal segment elongated, curved, with a blunt conical projection on proximal inner margin, with 2 inner mid-marginal setae, terminates in a point with one terminal seta; left leg terminal segment with 1 outer marginal spine and 3 terminal sub-equal spines, all curving inwards.

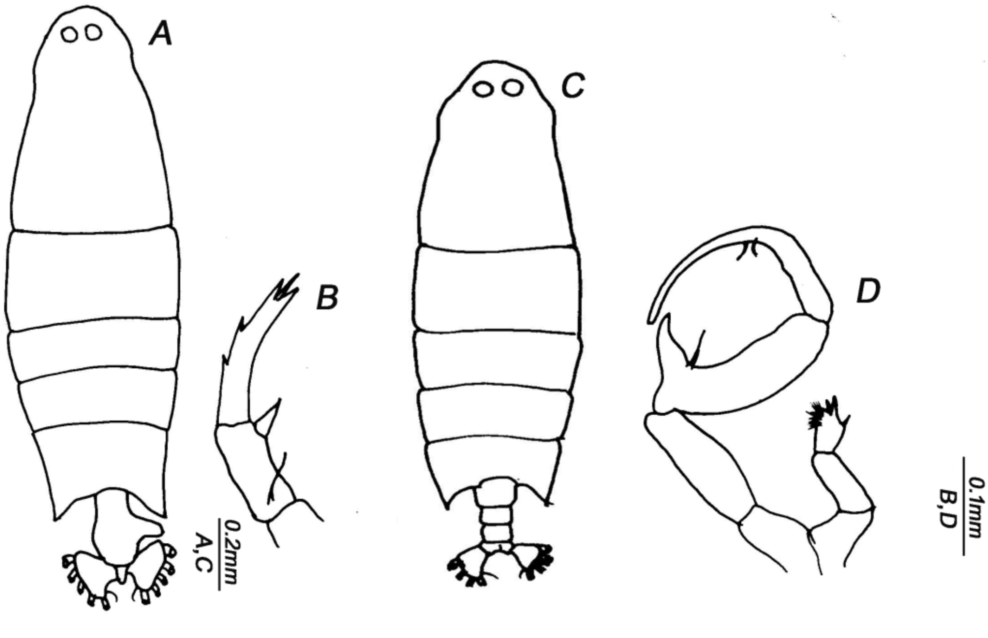

Figure 45. *Labidocera pavo* Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

Distribution: The species was recorded in Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, and North West Pacific (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kalpeni, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

8. *Labidocera bataviae* A.Scott.1909.

Female. TL: 1.9-2.3mm. No lateral cephalic hooks; rounded Ce, dorsal eye lenses spaced apart posterior metasome segment almost symmetrical and produced into two divergent points; urosome short with two segments, genital segment asymmetrical and large, produced on the right side; well-developed lamina on the anal segment (Fig.46 A). Furca very asymmetrical left ramus almost two times wider than long and arranged at right angles to the urosome. P5 asymmetrical, left leg longer, exopodite with two outer marginal spines and a minute spine on inner margin; terminating in unequal spines, middle spine longer and serrated along both the edges. Endopodite much reduced with bifurcated tip (Fig.46 B).

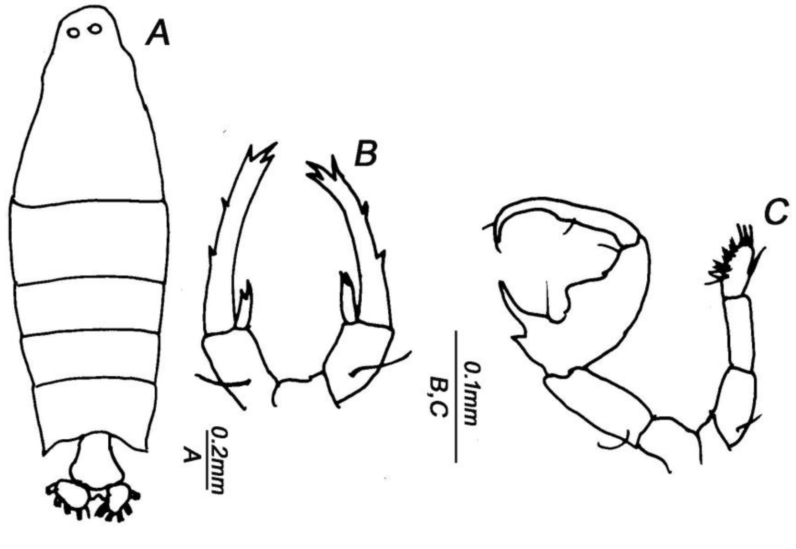

Figure 46. *Labidocera bataviae* .Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

Male. TL: 1.6-1.9mm (n=6). The body resembles female, but posterior metasome quite asymmetrical, right point longer than left; urosome five-segmented, the first segment with a notch on the left side (Fig.46 C). Furca slightly asymmetric, right ramus rounder than left. Right A1 geniculate. Right P5 claw-like, thumb at the proximal end of exopodite segment, long and robust, with a distinct spine and seta close to the base of thumb; terminal segment curved inwards, with a conical protrusion on its inner mid-margin. Left P5 terminal segment with 1outer mid-marginal spine and curved terminal spines of which the outermost is most extended (Fig.46 D).

Distribution: The species was recorded Indian Ocean, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, and China Seas (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of oceanic waters of Minicoy and coastal waters of the south-west coast of India.

9. ***Labidocera madurae*** **A.Scott, 1909.**

Female. TL: 2.11–2.80 mm. Body elongated, with one pair of circular dorsal eye lenses that are feeble, small, and placed apart (Fig. 47 a). Rostrum deeply bifurcated symmetrically produced posteriorly into pointed processes (Fig.47 d). The genital segment is moderately large and asymmetrical, with the middle of the right side considerably inflated. The Furcal rami are symmetrical and are longer than broad. The P5 is nearly symmetrical. The exopodite is furnished with two outer marginal spines. The apex terminates in three subequal spines. The apex of the endopodite is not bifurcated (Fig.47 f).

Male: TL: 1.62–1.96mm. Males resemble females except in the urosome that has five segments (Fig. 47 e). The right antennule is geniculate, short(Fig.47 c). Curved thumb-like process on the proximal outer margin of the first joint of the right exopodite of the P5. The claw-like joint long and narrow. The apical joint of the left exopodite is elongate and ovate and is twice as long as broad. The outer margin is furnished with one spine, and the apex bears three spines. The inner margin has a pad of fine hairs (Fig.47 g). The full description of the species is detailed in chapter 7.

Distribution: The species was recorded in the Indian Ocean, the Mediterranean Sea, Gulf of Thailand, Central tropical Pacific (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kavaratti, Minicoy, oceanic waters of Minicoy and coastal waters of the south west coast of India.

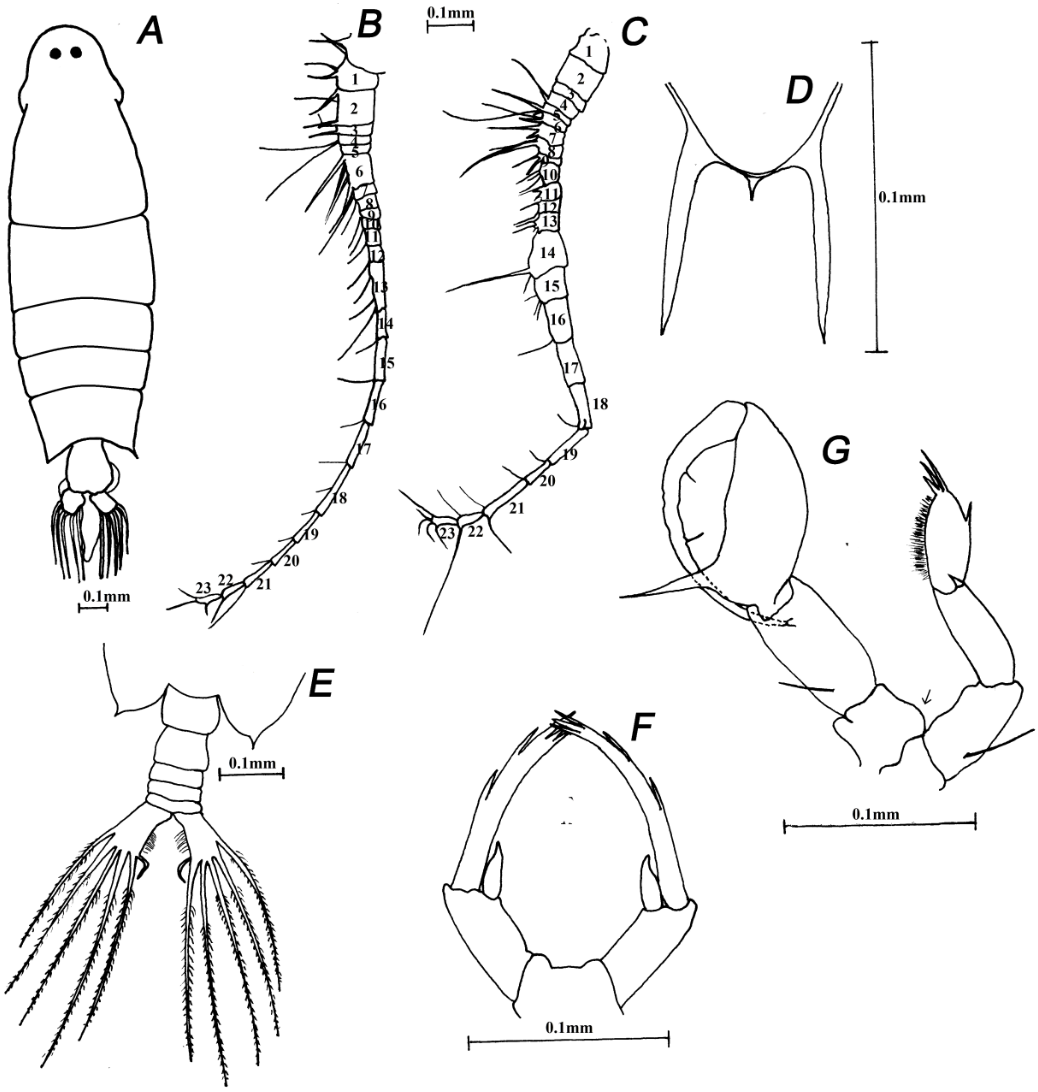

Figure 47. *Labidocera madurae* A- Female, dorsal view. B-Female, first antennae. C-Male, geniculate first antennae. D-Rostrum; E-Male urosome dorsal. F-female, fifth leg. G- Male, P5.

Genus: Pontella Dana, 1846.

10. *Pontella denticauda* (A. Scott, 1909)

Female. TL: 2.5-2.8mm (n=5) Posterolateral ends of Pd5 symmetrical, narrowly rounded (Fig.48 A). Ur composed of 2 somites, Url asymmetrical, proximo-lateral margin of left side produced into the large stipiform process, right side produced into two rounded processes; Ur2 very short, as long as spiniform process on Url; CR asymmetrical, left ramus distinctly broader than right. P5 symmetrical, similar to that of *P. fera* (Fig.48 B).

Male. TL: 1.9- 2.5mm (n=5) Body is robust with prominent cephalic hooks (Fig.48 C). Posterior corners of prosome symmetrical and sharply pointed. Urosome comprises five somites; genital somite slightly asymmetrical with a lobe-like projection; CR asymmetrical; right ramus slightly longer than the left. P5 asymmetrical (Fig.48 D) and right leg chelate, exopodal segment 2 of left P5 curved and slender, bifurcate at apex, and inner margin hirsute.

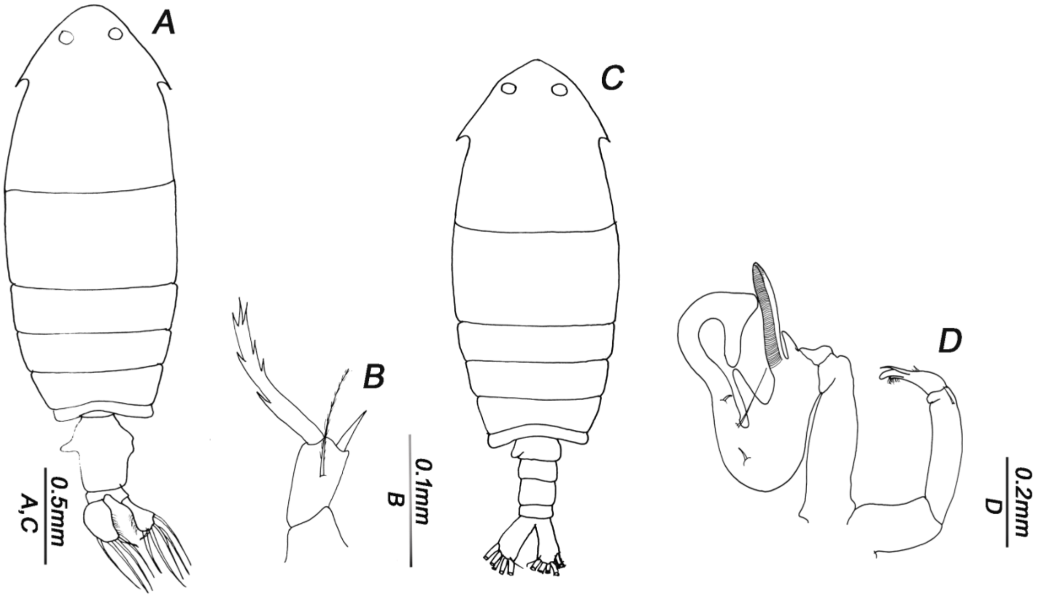

Figure 48. *Pontella denticauda* Female. A- habitus dorsal, B-P5. Male C- habitus dorsal, D-P5.

Remarks: This species belongs to "*P. fera*"-Group. Mulyadi (2011) included the species in the genus *Ivellopsis* Claus, 1893.

Distribution: The species was recorded in the Indian Ocean, the Gulf of Thailand, Central tropical Pacific, and China Seas (Razouls et al., 2005-2018). In the present study, this species was observed from oceanic waters of Minicoy and coastal waters of the south-west coast of India.

11. *Pontella sinica* Chen & Zhang, 1965

Female. TL: 5.2 mm. Ce is triangular with sharp hooks (Fig.49 A). Ur asymmetrical with three somites. CR is broad and asymmetrical, right ramus larger than left. P5 symmetrical; basis with plumose seta and small seta on the proximal posterior surface. Exopod with three-minute outer marginal spines, endopod reaching half length of exopod (Fig.49 B).

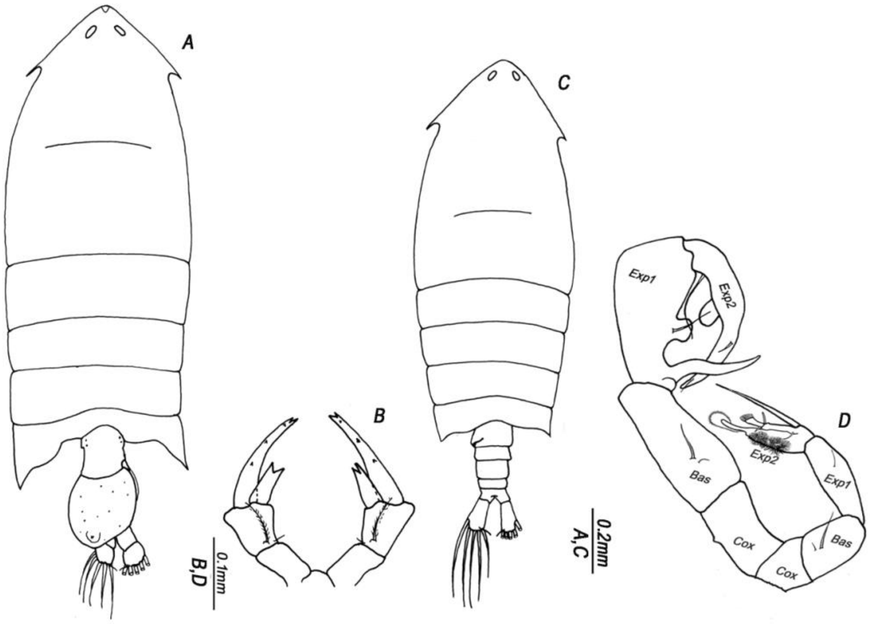

Figure 49. *Pontella sinica* Female. A A-dorsal, B-P5. Male C-dorsal, D-P5.

Male. TL: 4.35 -4.47 mm (n=5). Body is robust with prominent cephalic hooks. Posterior corners of prosome symmetrical and sharply pointed. Ur comprising five somites; genital somite slightly asymmetrical with a lobe-like projection; CR symmetrical.P5, Right leg chelate, the first exopodal segment with thumb-like process slightly curved in a sigmoid manner. Left leg ending in two unequal processes; longer process spatulate with crenulated margin and hirsute mediolaterally (Fig.49 D).

Remarks: Detailed description and female-male correspondence of the species discussed in Chapter 7.

Distribution: The species was recorded in **the** Indian Ocean, and China Seas (Razouls et al., 2005-2018; Francis et al. 2018). In the present study, this species was observed from oceanic waters of Minicoy and coastal waters of the south-west coast of India.

12. *Pontella spinipes* Giesbrecht, 1889

Female. TL:3.75–4.17 mm (n=5). Body robust (Fig.50 A). Three blue and rounded processes present mid-dorsally on first three pedigerous somites. Posterolateral corners of fifth pedigerous somite produced posteriorly into largely pointed lobes, of which left one larger than right and reaching near posterior margin of genital somite. Ur two-segmented. P5 asymmetrical, right leg slightly larger than left; exopod of each leg acuminate and curved with four lateral spinules; endopod about half length of exopod and bifid apically (Fig.50 B).

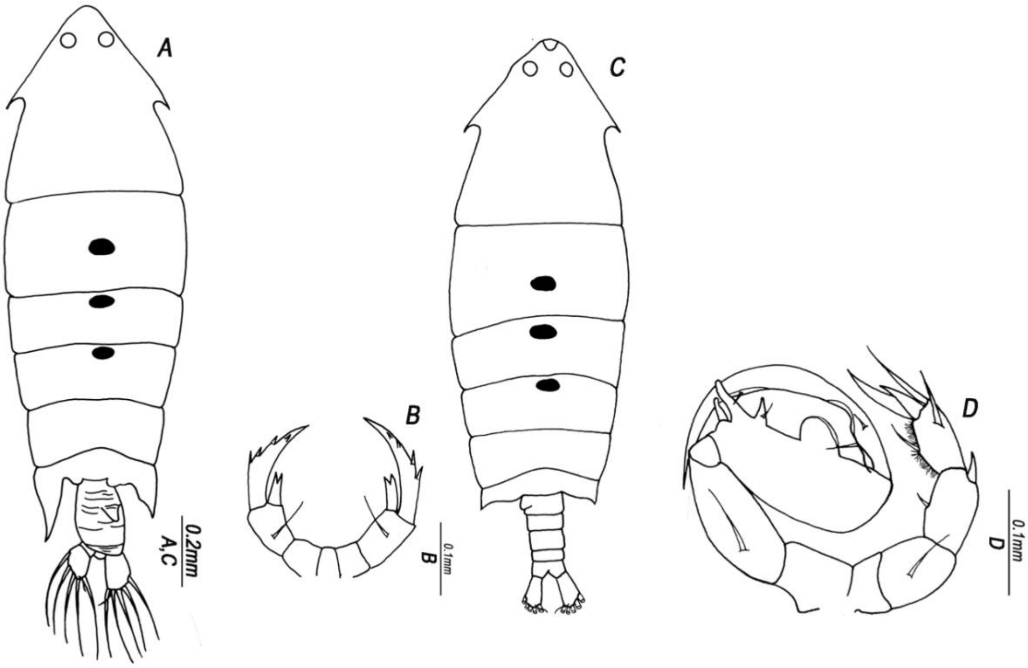

Figure 50. *Pontella spinipes* Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

Male. TL: 3.31–3.73 mm (n=5). Fourth and fifth pedigerous somites separate (Fig.50 C). Posterolateral ends of fifth pedigerous somite produced into symmetrical, acuminate lobes. Ur composed of five somites; genital somite asymmetrical with a lobe-like projection on the left side. P5 chela on right leg well developed. The left leg first exopodal segment with inner medial seta and outer distal spine; a second exopodal segment with inner seta near distal third, outer seta near distal third, outer distal seta, two unequal distal spines, of which inner one 1.5 times longer than medial, and two rows of setules along inner margin (Fig.50 D).

Remarks: Detailed description and female-male correspondence of the species discussed in chapter 7.

Distribution: The species was recorded in the Indian Ocean, Gulf of Thailand, and Central tropical Pacific, China Seas, (Razouls et al., 2005-2018). In the present study, this species was observed from oceanic waters of Minicoy and coastal waters of the south-west coast of India.

13. *Pontella fera* Dana, 1849

Female. TL 2.3-2.9mm. Ur two segmented, genital segment asymmetrical, bulging laterally on the left side; Ventrally the genital segment has two knobs like processes, varying in size and shape (Fig.51 A) P5 asymmetrical, endopodite short and bifurcated at the tip, variable in appearance. Exopodite elongated, with three spines on both inner and outer margins, terminating in another spine, outer marginal spines more widely spaced (Fig.51 B).

Male. TL: 2.33-2.67mm. Ce as in female, urosome five-segmented, the genital segment with a small lateral bulge on the right side, furca asymmetrical slightly broader than the right (Fig.51 C). Right P5 with a claw. The base of the claw with a large projecting thumb with a small process at its base and a short and a broad process between this and the terminal segment. Terminal segment initially almost straight, but the distal half curves backwards, the tip bearing a small seta. Left P5 is terminating in 3 different processes (Fig.51 D).

Distribution: The species was recorded in Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, and Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from oceanic waters of Minicoy and coastal waters of the south-west coast of India.

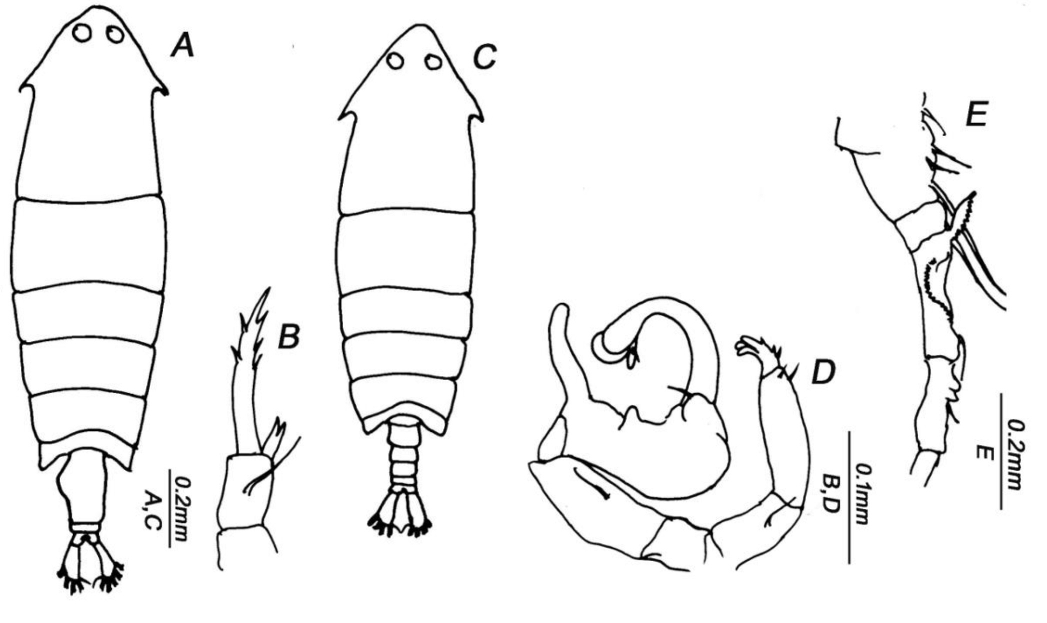

Figure 51. *Pontella fera* Female. A-dorsal, B-P5. Male C-dorsal, D-P, E-Right A1.

Genus: Pontellina Dana, 1852

14. *Pontellina plumata* (Dana, 1849)

Female. TL:1.3-1.9mm (n=5). Pr in dorsal, view quite oval; posterior metasome segments almost symmetrical and conspicuously pointed in lateral view; Ce without lateral hooks, without cuticular lenses, with inconspicuous ventral eye without a lens (Fig.52A). Urosome 2 segmented, right furca fused to the anal segment; P5 with 1-segmented exopodite, bearing one lateral and 3 terminal seta, as well as one medial seta; endopodite is bifurcated or may come to a single point (Fig.52 B).

Male. TL 1.35-1.89mm (n=5). Posterior metasome segments symmetrical, less pointed than in the female when viewed laterally; one pair of cuticular lenses (Fig.52 C). A1 geniculate. P5 is uniramous; right P5 ending in a claw, base of claw broad, with a conical tooth- like elevation on inner margin and seta. Left leg distal segment with prominent outer marginal spine and 3 terminal subequal spines, inner margin with tuft hair (Fig.52 D).

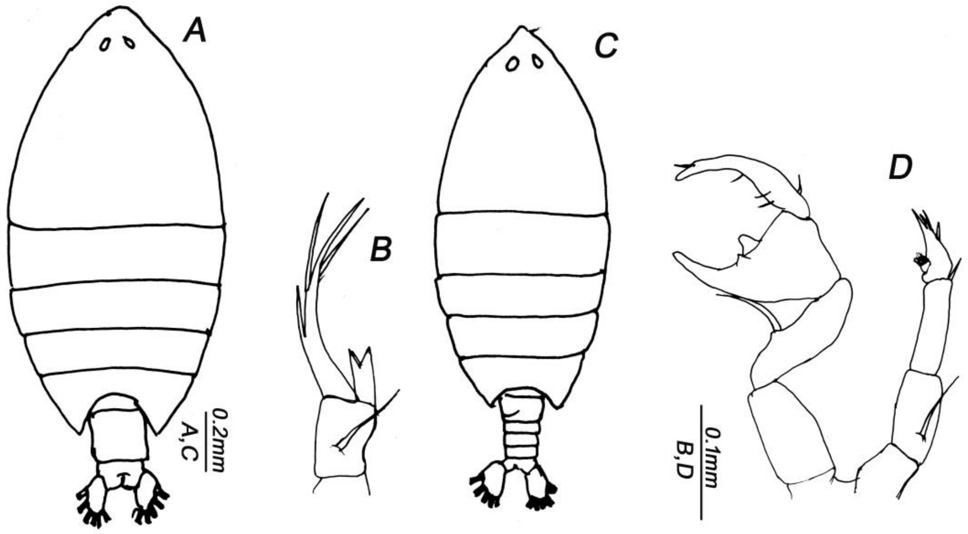

Figure 52. *Pontellina plumata.* Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, and Gulf of California (Razouls et al., 2005-

2018). In the present study, this species was observed from lagoon waters of Agatti, Bangaram, Kalpeni, Kavaratti, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

Genus: *Pontellopsis* Brady, 1883

15. *Pontellopsis armata* (Giesbrecht, 1849)

Female.TL: 2.24-2.5mm (n=5) Ce broadly rounded anteriorly; posterior metasome symmetrical, produced into long lateral, sharply pointed projections (Fig.53 A). Urosome 2- segmented, genital segment with a backwardly pointed spine above the genital opening and a dorsal swelling on the right side. Anal segment asymmetrical, dorsally overlapping the furca. P5 asymmetrical, exopodite stout and curved inwards, with 3 minutes external marginal spines and three apical spines, the middle the longest. Endopodite bifurcated apically (Fig.53 B).

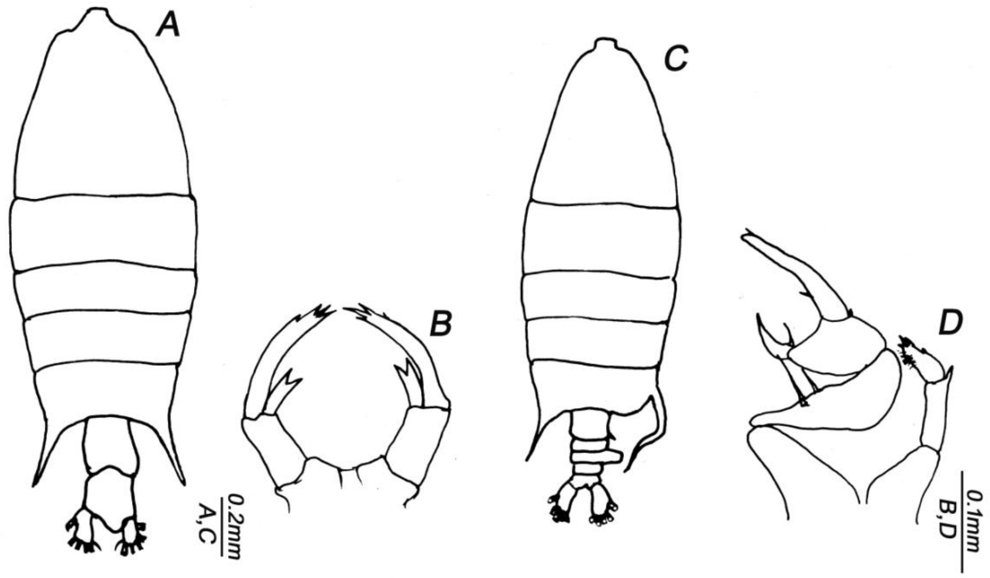

Figure 53. *Pontellopsis armata.* Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

Male.TL 1.87-2.1mm (n=5) Ce resembles female (Fig.53 C). Large angles of last metasome segment are asymmetrical; the left side produced into a pointed straight spine reaching the third urosome segment, the right side bluntly rounded, bearing a thin pointed curved process, longer than the spine on the left. Urosome 5 segmented, with the spine on the dorsal right genital segment; right side of segment 3 with large protuberance with spinules on the tip. P5 asymmetrical (Fig.53 D), the right leg with a claw, basis broad in the middle and with two sub-equal setae. Short thumb on claw segment, with a long seta at the base; terminal segment slightly bent, with two setae at the proximal inner end and one distal seta, a short spine at the outer base of the segment.

Distribution: The species was recorded in the Indian Ocean, the Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, and Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

16. *Pontellopsis perspicax* (Dana, 1849)

Male: TL: 1.7-1.9mm (n=3) Posterolateral corners of fifth pedigerous somite with strongly asymmetrical processes, with the long, slender, curved process on the right side. Left posterior prosome corner extending to the posterior border of urosomal segment 2; right corner exceeding to the posterior border of anal somite (Fig.54 A) Ur 5 segmented, urosomal segment 3 asymmetrically developed on right. Right P5 with a finger-like process of first exopodal segment longer than second. - Urosomal segment 3 with a large, naked protuberance on the right side (Fig.54 B).

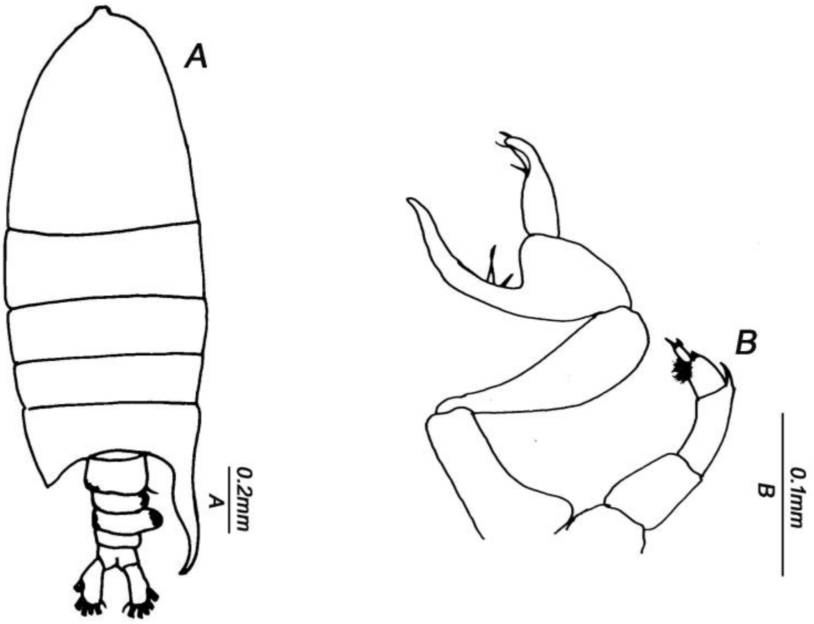

Figure 54. *Pontellopsis perspicax.* Male. A-dorsal, B-P5.

Distribution: The species was recorded in Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, North West Pacific, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Kalpeni, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

17. *Pontellopsis herdmani* Thompson & Scott, 1903

Female.TL: 1.7mm. Body stout, rostral base prominent on dorsal view (Fig.55 A). Ur asymmetrical and of two segments. Genital somite longer than segment 2 of urosome; segment dorsally towards mid-dorsal margin on the left side with a small spine and with a well-developed spine on its right distal corner; a slight indentation present on its left distal corner. CR slightly asymmetrical, right one broader than left. P5 symmetrical; exopod with two small outer marginal spines and with subequally bifid tip; endopod bifid at its tip, both rami curved inwards (Fig.55 B).

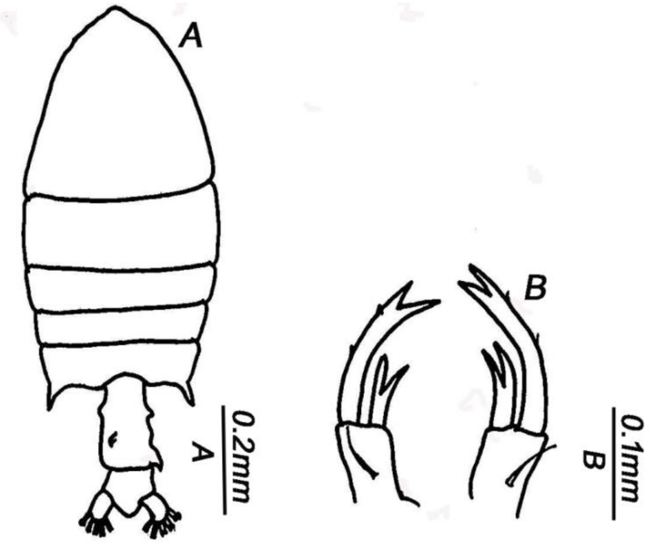

Figure 55. *Pontellopsis herdmani* Female.A- habitus dorsal, B-P5.

Distribution: The species was recorded in the Indian Ocean, the Gulf of Thailand, Great Barrier Reef, and China Seas (Razouls et al., 2005-2018). In the present study, this species was observed from coastal waters of the South West coast of India.

18. *Pontellopsis regalis* (Dana, 1849)

Female.TL: 2.9-3.1mm (n=3) Prosome broadly rounded anteriorly. Posterior corners of metasome drawn out into symmetrical acuminate lobes (Fig.56 A). Urosome two segmented; genital segment enlarged and asymmetrically produced on the left side into a distinct lobe; a pair of short spinules present at the base of the genital segment and with a few short setae along its lateral margin. P5 asymmetrical (Fig.56 B), Exopod long and curved. Endopod is short and apically bifid. Outer lateral margin of exopod with three-minute spines and inner margin with one long spine; apically it is bifid subsequently with the outer branch being smaller.

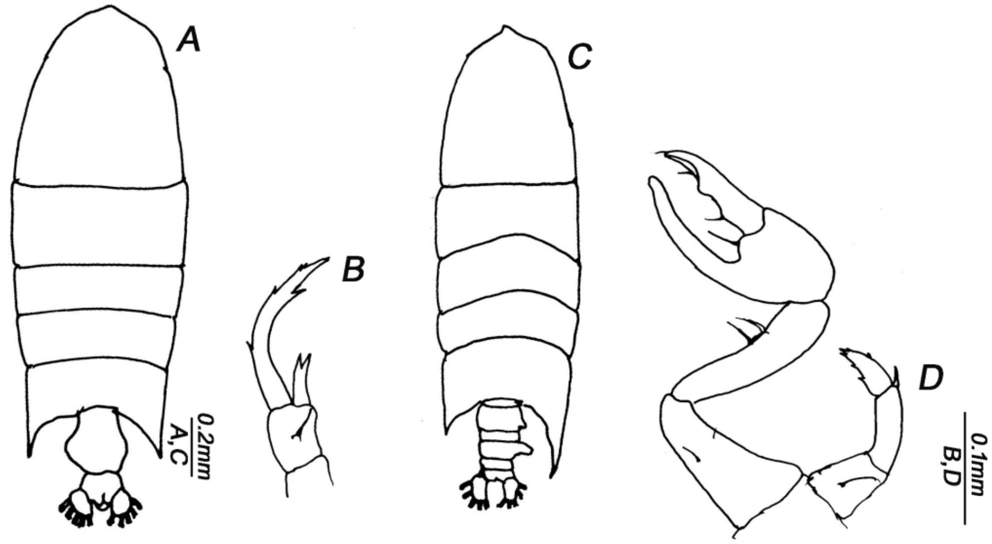

Figure 56. *Pontellopsis regalis.* Female. A-dorsal, B-P5. Male C-dorsal, D-P5.

Male. TL: 3.25-3.58mm (n=3). Posterior corners of metasome asymmetrical, with right lobe produced into an acuminate and elongated spine, which reaches the base of CR. Ur 5 segmented, genital segment broader than long and produced at its right distal corner into a short process bearing two setae (Fig.55 C). Right P5 chelate, with a broad hand and an elongated thumb, latter with a seta on its inner base; finger with bent tip and two marginal setae, it carries a conical process as its mid inner margin. Left leg distal segments with two outer lateral spines and two subequal spines apically of which outer one is most extended; the penultimate segment is drawn into a spine at outer distal margin; inner margin with a tuft of the seta (Fig.56 D).

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

6.2.15. Family: Acartidae Sars, 1846

Genus: Acartia Dana, 1846

1. *Acartia (Acartia) negligens* Dana, 1849

Female.TL: 0.98-1.3mm (n=4). Rostral filaments present. Small species, with one or sometimes more small spines on the posterior corners of the last metasome segment (Fig. 57 A). A row of tiny hairs may also present dorsally, although difficult to see except under high power. A1 reaches to furca. The first two urosome segments have a dorsal row of fine spinules on the posterior border. P5 is terminating in a very short, straight, spiny segment with serrated outer edges and a very long outer seta at least five times longer than the spine (Fig.57 B).

Male.TL: 0.8-1.5mm (n=4) A1 is shorter than the body. The male is also reported to have a tuft of hairs on either side of the last body segment (Fig.57 C). Ur segments 1 and two hairy laterally, segments 2, 3 and 4 with little dorso-posterior spinules (Fig.57 D). Male P5 uniramous, asymmetrical, larger on the right, exopod segment 2 with large inner lobe, segment 3 in the form of clasper (Fig.57 E)

Distribution: The species was recorded in the Caribbean Sea, Gulf of Mexico, Sargasso Sea, North Sea, Baltic Sea, Central South Atlantic, Eastern tropical Pacific, Indian Ocean, Red Sea, Mediterranean Sea, Gulf of Thailand, Great Barrier Reef, Central tropical Pacific, China Seas, and Gulf of California (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti, Kalpeni, Kavaratti, Minicoy, oceanic waters of Minicoy and coastal waters of the south-west coast of India.

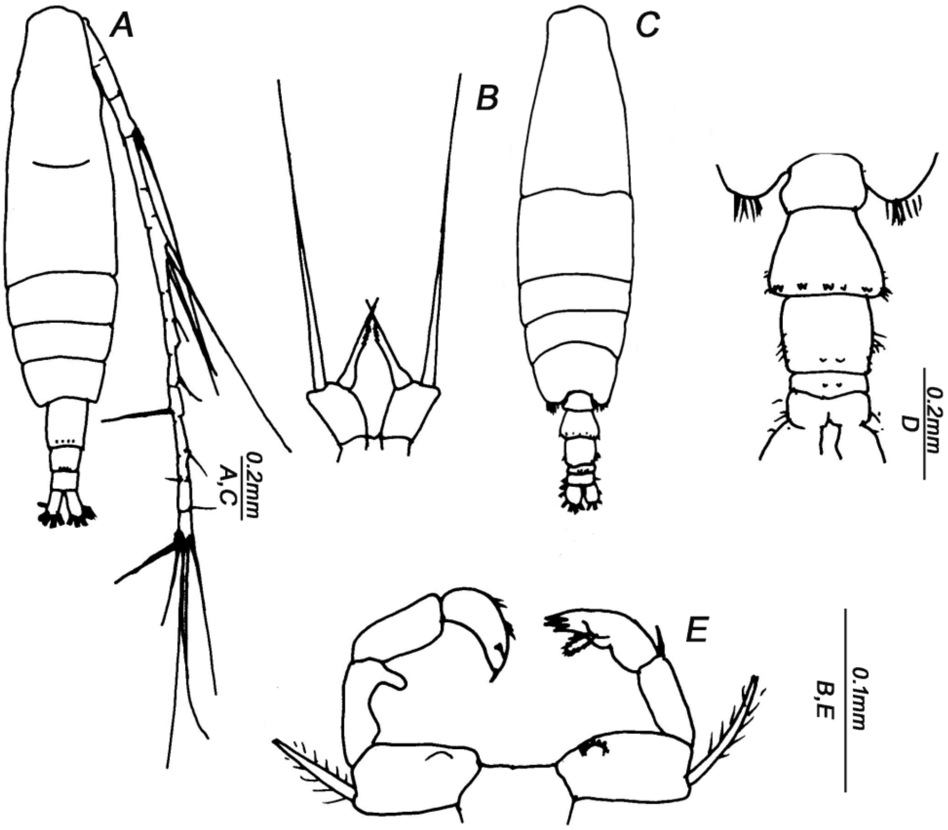

Figure 57. *Acartia (Acartia) negligens* Female. A-dorsal, B-P5. Male C-dorsal, D-Ur, E-P5.

2. ***Acartia (Odontacartia) spinicauda*** **Giesbrecht, 1889.**

Female. TL: 0.9mm. The genital segment with 2 spines which are smaller than those of the following segment. Caudal rami about 3 times as long as wide (Fig.58 A). A1 with spinules on the proximal segments. Terminal segment of P5 filamentous, and swelling at the base (Fig.58 B).

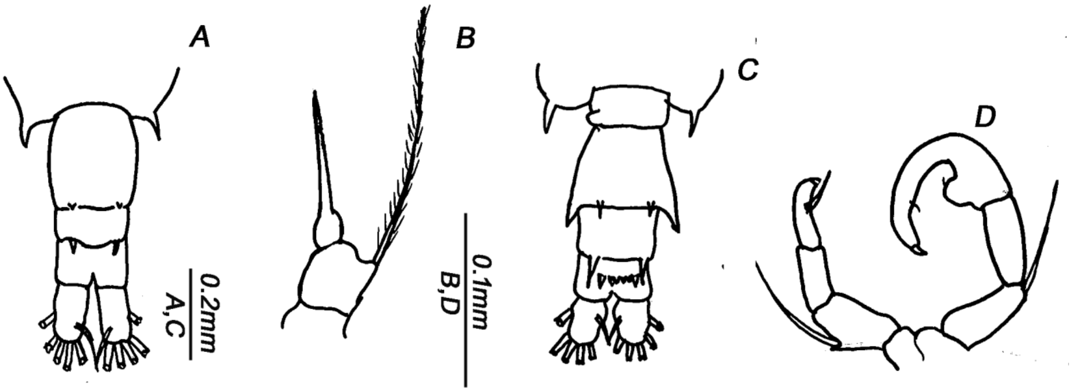

Figure: 58 *Acartia (Odontacartia) spinicauda* Female. A- Ur, B-P5. Male C- Ur, D-P5.

Male. TL: 0.75mm. Second urosome segments with two pairs of spines; inner pairs smaller than outer. Spines on third urosome segment are long. Terminal segment of P5 left with two little terminal spines. P5 terminal claw longer (Fig.58 D).

Remarks: In females, the spines of Pd5 corners are smaller than *A.erythraea* and *A. centrura.*

Distribution: The species was recorded in the Indian Ocean, Gulf of Thailand, Central tropical Pacific, China Seas, North West Pacific, North East Pacific (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kavaratti.

3. *Acartia (Odontacartia) erythraea* Giesbrecht, 1889.

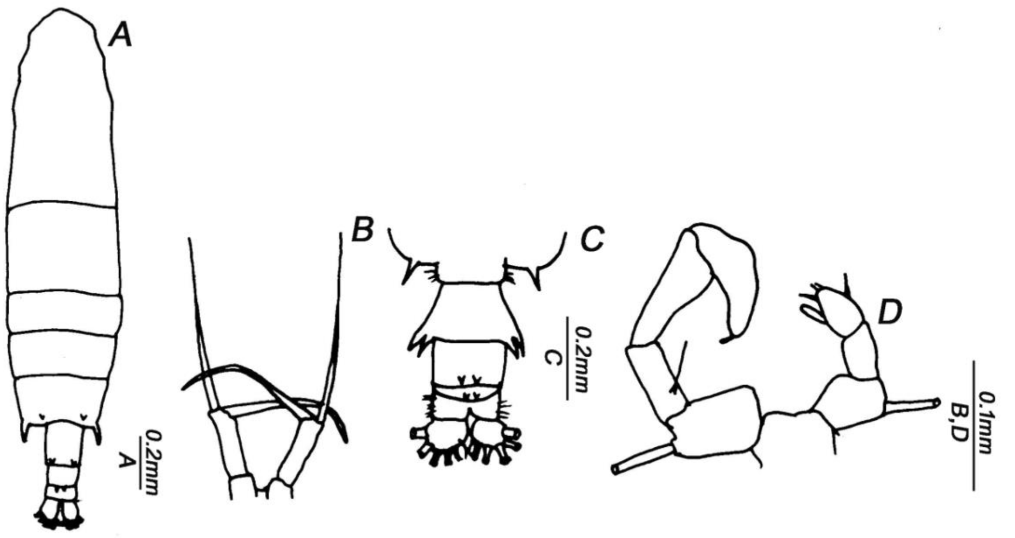

Figure 59. *Acartia (Odontacartia) erythraea* Female. A-Ur, B-P5. Male C- Ur, D-P5.

Female. TL: 0.9-1.4mm (n=3) Rostral filament present. Two strong spine on segment 1 of the A1, a smaller spine on the second segment, three small spines on the third and two larger spines on the fourth segment (Fig. 59 A). A solid spine on each corner of the posterior metasome segment and a pair dorsally, towards the posterior edge of the same segment. A pair of spines on the dorsal rear edge of the genital segment and a tiny pair on the following segment. The P5 is simple, with a curved terminal spiny segment. The outer plumose seta is one and a half times the length of the spine segment (Fig.59 B).

Male.TL: 69-1.2mm (n=4) No strong spines at the base of the A1. The same spine arrangement on the last metasome segment as the female. The second urosome segment is wider than the long, with a pair of prominent spines either side on the posterior margin, of the same size. Two tiny dorsal medial spines on the rear edges of urosome segments 3 and 4 (Fig.59 C). P5 terminal claw thickened slightly curved without any notch (Fig.59 D).

Distribution: The species was recorded in the Indian Ocean, the Red Sea, Gulf of Thailand, Central tropical Pacific, China Seas, Gulf of California and Eastern tropical Pacific (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kalpeni, Kavaratti, Minicoy and coastal waters of the south-west coast of India.

4. *Acartia (Odontacartia) bispinosa* Carl, 1907.

Female. TL: 0.75-1.35mm (n=5). Rostral filaments present. Corners of posterior metasome segment with strong spines; 2 smaller spines dorsal and medially each with tiny spinules just behind them(Fig.60 A). Posterior edge of the genital segment with a pair of sharp spines dorsolaterally. The first segment of the A1 with two strong spines and a smaller spine near the base of these spines (Fig.60 B). The second segment with a unique, distinct, strong curved spine. The slender terminal spines of the P5 curved strongly from around the middle (Fig. 60 C).

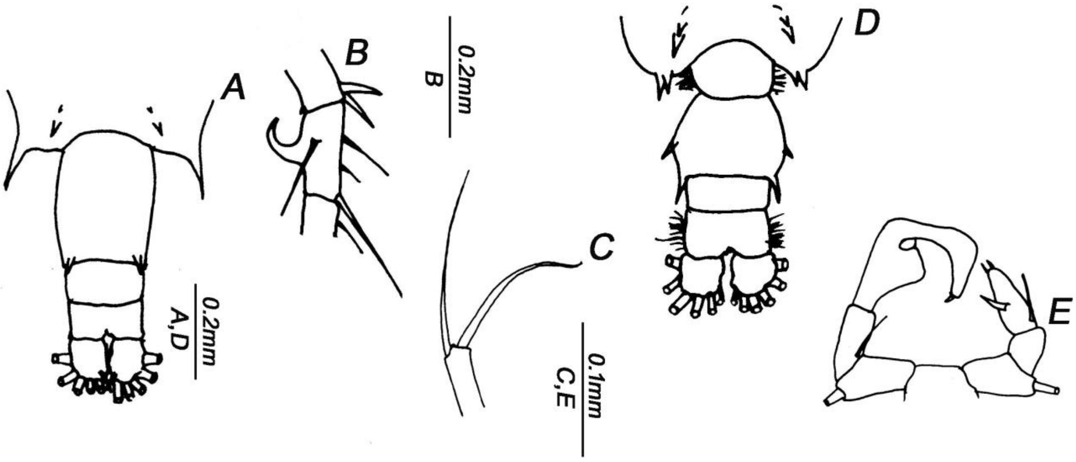

Figure 60. *Acartia (Odontacartia) bispinosa* Female. A-Ur, B-Spine on A1, C-P5. Male D- Ur, E-P5.

Male. TL: 0.5-1.1mm(n=4) Each corner of the posterior metasome segment with a pair of spines, one slightly shorter than the other. A pair of spine one each side of the same segment dorsolaterally, one much smaller than the other and with a fine setule just behind them (Fig.60 D). The second urosome segment has a robust dorsolateral spine on each side of the posterior margin and smaller ones on each side ventrolaterally. Terminal segment of P5 left with two little terminal spines, a stout spine on the spinules along inner margin, and several spinules along the outer margin (Fig.60 E).

Distribution: The species was recorded in the Indian Ocean, the Gulf of Thailand, the Great Barrier Reef, Central tropical Pacific, and Japan Sea, (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Minicoy.

5. *Acartia amboinensis* Carl, 1907

Female. TL: 1.2-1.4mm (n=5) Corners of posterior metasome segment produced into a strong spine on either side laterally and with two small spines dorsolaterally (Fig.61 A). The first segment of the A1 has two strong spines and a minute spine on the posterior margin (Fig.61 B). The second segment has a moderately sized spine on the distal posterior margin and 4-minute spines on the posterior margin. The third and fourth segments each have a small spine on the posterior dorsal margin, and the fifth segment has four small spines. In the P5, the terminal spiny segment has two slight swellings near the base and bends abruptly inwards in the distal half. The external seta is over 1.5 times as long as the terminal spine (Fig.61 C).

Male. TL: 1.2mm. Posterior metasome segment with two strong lateral spines (Fig.61 D). A pair of small spines on each side of the dorsal posterior metasome margin. Sharp spines on the posterior margin of urosome segment 2 with a smaller lateral spine each side; third segment with 2-4 small marginal spines and the fourth segments with 4-6 small marginal spines. P5 basis segments with long, robust external setae (Fig.61 E).

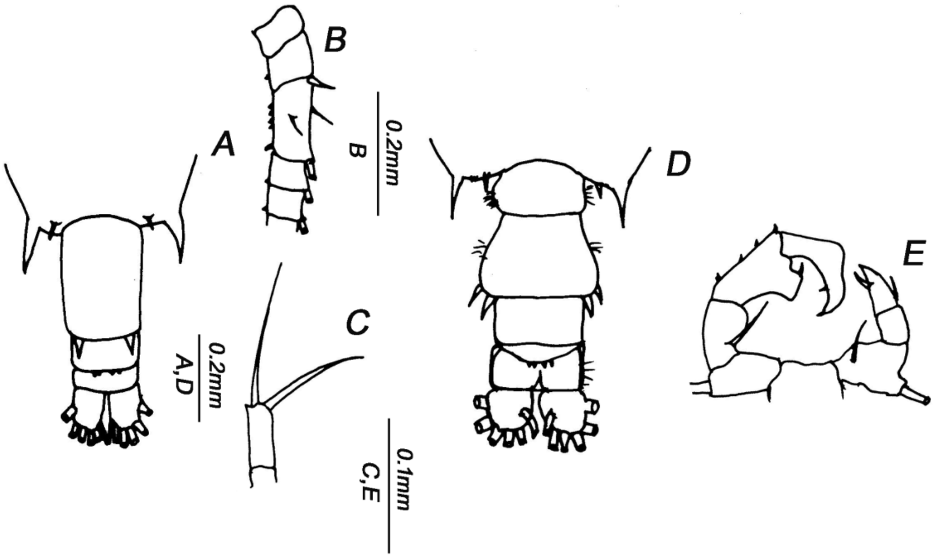

Figure 61. *Acartia amboinensis* Female. A-Ur, B-Spine on A1, C-P5. Male D- Ur, E-P5.

Distribution: The species was recorded in the Indian Ocean, the Gulf of Thailand, Central tropical Pacific, and Japan Sea (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Kalpeni and Kavaratti.

6. ***Acartia (Acanthacartia) fossae*** **Gurney, 1927**

Female. TL: 1.03-1.4mm (n=5) Posterior metasome segment with a row of 4-5 tiny spinules on the dorsoposterior margin (Fig.62 A, B) A1 extends to the posterior border of urosome segment 2. The genital segment with two pairs of lateral tufts of hair on the anterior part. No spines on this or succeeding segments. Terminal segment of P5 almost square, terminal spine swollen near its base, length about half that of the outer seta (Fig.62 C).

Male. TL: 0.8-1.3mm (n=5) Posterior metasome segment with a row of tiny spinules on dorsoposterior margin as in the female (Fig.62 D,E). First urosome segment with lateral tufts of hair. Second urosome segment with dorsolateral rows of tiny spinules arranged across and on the posterior edge of the segment. Third and fourth segments also have tiny spinules on the posterior dorsal edge. The left P5 has a terminal segment with a thick naked terminal spine, one modified spine and one seta on the mid-anterior surface. The inner margin has a row of fine hairs (Fig.62 F).

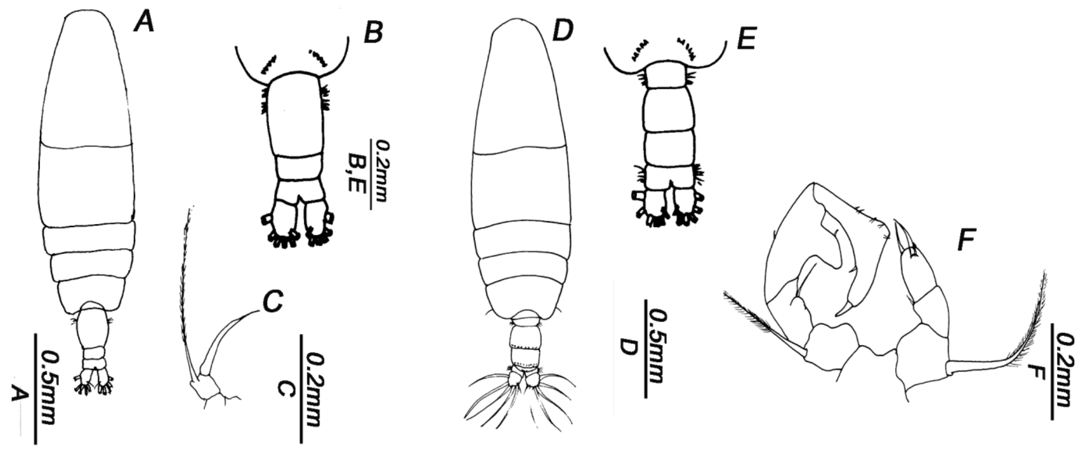

Figure 62. *Acartia fossae* Female. A-habitus dorsal, B- Ur, C-P5. Male D- habitus dorsal, E-Ur, F-P5.

Distribution: The species was recorded in the Indian Ocean, Red Sea, Mediterranean Sea, Great Barrier Reef, Central tropical Pacific, China Seas, and Japan Sea (Razouls et al., 2005-2018). In the present study, this species was observed from lagoon waters of Agatti.

6.2.16. Family: Tortanidae Sars, 1902

1. *Tortanus sp.*

Male. TL. 1.9mm. Posterior corners of pedigerous somite 5 symmetrical, rounded. Ur of 5-somites. Second urosomite with posterolateral and posteroventral processes on the right side (Fig.63.A). P5 right leg (Fig.63 B) coxa broad and acute at its base without ornament; distal half of basis broad and semicircular, bearing digitiform process with proximal and terminal setules on medial margin; Re stout and claw-like, furnished with 2 setules on medial margin. Left leg medial margin of coxa with the large triangular process. Basis elongate, with proximomedial papilla with terminal setule and irregular, rounded processes along inner margin. Exopod 2 curved inwards with the sub-terminal lateral spine.

Remarks: The present specimen very much similar to *Tortanus (Atortus) processus* Mulyadi, Nishida and Ohtsuka 2017.

Distribution: In the present study, this species was observed from lagoon waters of Minicoy.

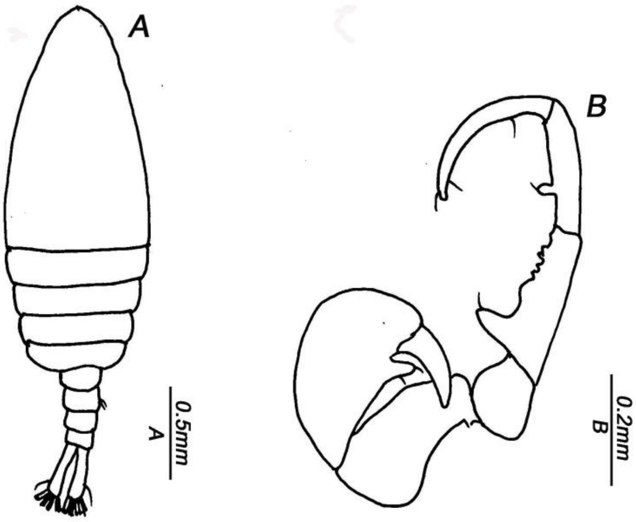

Figure 63. *Tortanus sp.* Male A-habitus dorsal, B-P5.

2. *Tortanus (Atortus) minicoyensis* sp. nov.

A new species of the planktonic calanoid copepod genus *Tortanus*, subgenus *Atortus* is described from the lagoon area of Minicoy Island, South Eastern Arabian Sea. The new species is included in the *tropicus* group, which is mainly distributed in the tropical and subtropical waters of South East Asia. The species can be distinguished from all the other species of the tropicus group by the dorsolateral process of fifth pedigerous somite, hyaline coupling device with the larger left process, and asymmetrical caudal rami with two medial rounded processes in the female and the serrated ridge of the right antennule, strongly curved subdistal seta in the left fifth leg and processes on the coxa and basis of the right fifth leg in male. A detailed description of the species is given in chapter 8.

6.3. DISCUSSION

Order calanoida is one of the most numerous and diverse copepod orders. The adults tend to be much larger than those of other orders. The antennule is long, and the antenna is biramous. Males have a geniculate antennule. The posome is much broader than the urosome and the body. The posterior of the last metasome segment is often asymmetric. In females, posterior of the last metasome segment tends to be bilaterally symmetrical. Females usually have five pairs of swimming legs, occasionally four pairs as in Families Aetideae and

Euchaetidae. The female P5 are usually proportional, in some cases much reduced in size and complexity compared o other swimming legs. Males always have five pairs of swimming legs, the P5 usually highly modified and asymmetrical. Females have between two and four segments in the urosome and males, generally five and in some *Labidocera* spp. it is four. There are usually five setae on each furca, but in some cases, only four or three.

Sixty-two calanoid species under sixteen families from the following genera are described, their distinguishing characteristics are illustrated in this chapter, and they are *Cosmocalanus* Bradford & Jillet, 1974; *Canthocalanus* A.Scott, 1909; *Undinula* A.Scott, 1909; *Acrocalanus* Giesbrecht, 1888*; Calocalanus* Giesbrecht,1888*; Paracalanus* Boeck, 1864*; Bestiolina* Andronov, 1972; *Eucalanus* Dana,1852; *Pareucalanus* Geletin,1976; *Subeucalanus* Geletin,1976; *Clausocalanus* Giesbrecht, 1888; *Rhincalanus* Dana, 1852*; Euchaeta* Philippi,1843; *Euchirella* Lubbock, 1856; *Scolecithrix* Giesbrecht, 1893*, Lucicutia* Giesbrecht & Schmeil, 1898*; Cantropages* Kröyer, 1849*; Pseudodiaptomus* Herrick,1884*; Temora* Baird,1850; *Candacia* Dana, 1846*; Calanopia* Dana, 1853; *Labidocera* Lubbock,1853*; Pontella* Dana, 1846*; Pontellina* Dana, 1852*; Pontellopsis* Brady, 1883*; Acartia* Dana 1846*,* and *Tortanus* Giesbrecht,1898*.*

The family **Calanidae Dana, 1849** represented in the present study with three genera and three species. The species *Cosmocalanus darwini* Lubbock, 1860 under the genus ***Cosmocalanus* Bradford and Jillet,1974**, *Canthocalanus pauper* Giesbrecht, 1888 under the genus ***Canthocalanus* A.Scott,1909** and *Undinula vulgaris* Dana,1849 under the genus ***Undinula* A.Scott,1909**. In family Calanidae, head and first Pd1 usually fused and Pd4 and Pd5 always separate. Rostrum composed of 2 filaments. A1 with robust backwardly directed setae on the third and second last segments. Characteristics of the male P5 differentiate to various genera. Female urosome has four divisions and five swimming legs of similar size with both rami three-segmented. Exopodal joints 3 of P2-P4 each with two spines on the outer edge and five setae on the inner margin. Male A1 are alike and only slightly transformed, never exhibiting any geniculate structure, twenty-five segmented with segments one and two always fused. Males generally with a hump on the mid-dorsal region. P1 to P4 as in the female, the right P5 is usually similar in appearance and size to the other swimming legs (less so in Undinula). While the left various from being similar (Calanus) to drastically modified (Cosmocalanus). Ur five-segmented (Conway 2003).

The family, **Paracalanidae Giesbrecht, 1893**, represented with four genera and five species. They are *Acrocalanus longicornis* Giesbrecht, 1888 under the genus ***Acrocalanus* Giesbrecht,1888**; *Calocalanus pavo* Dana,1849 and *C.plumulosus* Claus, 1863 under the genus ***Calocalanus* Giesbrecht,1888**; *Paracalanus indicus* Wolfenden,1905 under the genus ***Paracalanus* Boeck,1864**; *Bestiolina* sp. under the genus ***Bestiolina* Andronov, 1972.** In the family Paracalandae, Cephalosome and first pedigerous somites usually at least partially fused, pedigerous somites four and five fused or separate. In the female, urosome is two to four segmented; the anal segments usually much longer than any segment between it and the genital segment. Exopodites of P1-P4 three segmented, external margin of P1 to P4 usually fringed with small sines; endopodite of P1 usually two-segmented and in P2-P4, it is three-segmented. Distal spine of exopods with smooth blade-like border. P5 uniramous and asymmetrical. Male Ur five segmented; dorsal hump usually present on Ce. P1-P4 is similar in female, P5 uniramous.

The family **Eucalanidae Giesbrecht, 1893** represented with three genera and six species. The species *Eucalanus elongatus* Dana, 1849 under the genus ***Euclanus* Dana,1852**; *Pareucalanus attenuatus* Dana, 1849 and *P. sewelli* Fleminger,1973 under the genus ***Pareucalanus* Geletin,1976**; *Subeucalanus subcrassus* Giesbrecht, 1888; *S.mucronatus* Giesbrecht,1888 and *S. subtenuis* Giesbrecht, 1888 uder the genus ***Subeucalanus* Geletin,1976**. Copepods under the family Euclanidae were Large and with an elongated transparent body. The female urosome is very short, three or four segmented. Ur five segmented in male, the furca fused to the anal segment in both female and male. Females have a broad genital segment. Anterior Ce is triangular in dorsal view. Ce and Pd1 fused. Pd4 and Pd5 are partially fused. Rostrum with two long filaments. In some species, A1 reaches well beyond the Ur. Female P5 is missing or only on one side or uniramous on the left and biramous on the right (Conway 2003).

Species under the family **Clausocalanidae Giesbrecht, 1893** were small to medium sized copepods which may be confused with *Paracalanus*, but differ in that the females have longer urosome in relation to the length of the body, and the P5 is more robust and simple, bifurcated distally with only tiny spikes on end rather than a long spine. P5 uniramous on both sides, symmetrical, three-segmented. The anterior Ce and posterior metasome segments are rounded. Ce fused to pd1. Rostrum bifurcated. Ur four segmented. Male rostrum reduced to a knob. P5 uniramous, legs of unequal length, longer leg nearly always on the left, five-segmented with segments five short and attached sub-apically to the previous segment; shorter leg, three-segmented, less than half the length of segment1 of the other leg. Under this family, *Clausocalanus arcuicornis* Dana, 1849 under the genus ***Clausocalanus* Giesbrecht,1888** was identified in the present study.

The species *Rhincalanus rostrifrons* Dana, 1849 was identified during the study under the family **Rhincalanidae Geletin, 1976.** The differences between the genera *Eucalanidae* and Rhincalanidae are the absence of P5 from female, the lack of spines on thorax and abdomen, and pair of legs P5 uniramous in male for the first, and P5 present in female, thorax and abdomen spinose in female, and one of the legs P5 of male biramous for the latter Brodsky (1950,1967). Female P5 comprises bilobed transverse plate representing intercoxal sclerite fused to coxae, basis, plus 1-segmented exopod. Basis unarmed or bearing inner seta representing endopod. Male P5 asymmetrical; right leg uniramous, 3-segmented; 1st and 2nd segments unarmed, 3rd segment bearing curved apical spine and, in some species, subapical spinous process. Left leg biramous, comprising unarmed, separate coxa and basis, 2-segment endopod and 1-segmented exopod armoured with distal claw plus up to 4 inner margin setae and outer spinous process (Razouls et al., 2005-2018).

The family **Euchaetidae Giesbrecht,1893** represented in the present study with the species under the genus ***Euchaeta* Philippi,1843.** Four species were recorded, and they are: *Euchaeta marina* Prestandrea, 1833; *E. concinna* Dana, 1849; *E. longicornis* Giesbrecht, 1888; *E. indica* Wolfenden,1905. In the family Eucalanidae, the P5 absent in the female. Male P5 large, well developed, asymmetrical; right leg with 2-segmented exopod and styliform; 1-segmented endopod. Distal exopodal segment elongate, often styliform. Left leg with 2-segmented exopod and small distal process on elongate basis representing endopod. The distal exopodal segment with complex armature typically consisting of serrated lamella, ridged digitiform process, hirsute lobe and movable finger ornamented with a row of setules near tip; the movable finger is drawn out to form long spiniform process in some species.

Euchirella sp. was identified during the present study under **Aetideidae Giesbrecht,1892** family. In this family, Ce and Pd1 fused. Last metasome segment often prolonged in points. Rostum usually strong, bifurcated or straightforward in some species it is absent. Female urosome four-segmented, male five segmented. P5 generally absent in the female, of a simple structure in the male.

Scolecithrix danae Lubbock, 1856 was identified under the family **Scolecitrichidae Giesbrecht, 1893** in the present study. In this family, Ce and Pd1 separate, Pd4 and Pd5 usually fused, occasionally partly or entirely separate. Rostrum typically a bifurcate plate with or without filaments, or represented by paired rostral filaments. Ur 4-segmented in the female. Genital apparatus female is comprising common genital aperture located medially on the ventral surface of genital double-somite; copulatory pore contained within median genital opening. Urosome 5-segmented in the male. Single genital aperture male located ventrolaterally at posterior rim of genital somite on the left side. Caudal rami with up to 7 setae, seta I minute, usually absent. Swimming legs P1 to P4 biramous, typically with 3-segmented rami, except 1-segmented endopod of P1 and 2-segmented endopod of P2. Exopod of P1 sometimes 2-segmented. Endopods of P2 to P4 somewhat flattened, typically ornamented with strong spinules on posterior surfaces; exopods of P2 to P4 sometimes ornamented with spinules. Female P5 usually small, uniramous, typically 3-segmented Exopod is typically bearing 2 or 3 (rarely 4) elements, often highly ornamented with surface spinules. P5 sometimes reduced or absent, as in *Scolecithrix danae.* Male P5 asymmetrical; left leg longer than right, usually biramous with rudimentary endopods; or endopod lost. Left leg primitively 5-segmented, with slender coxa, basis and 3-segmented exopod; Right leg 3, 4 or 5-segmented consisting of coxa, basis and 1 to 3-segmented exopod.

Lucicutia flavicornis Claus, 1863 was identified under the family **Lucicutidae Sars, 1902** in the present study. In this family, males and female have very lone Ur typically over half the length of their bodies. They also have long furca. In perfect specimen, there is a seta on each furca, much longer than the other setae. Female P5 comprising 2-segmented protopod, 2 or 3-segmented endopod and 3-segmented exopod. Inner seta of 2nd exopodal segment styliform. Male P5 asymmetrical; right leg biramous, with both rami, typically 2-segmented, endopod 3-segmented in some species; a distal segment of exopod recurved. Left leg biramous, with both rami 3-segmented; basis often modified, with the process on inner margin.

The family **Centropagidae Giesbrecht,** 1893 represented with four species under the genus ***Centropages* Kroyer, 1849.** The species Centropages *calaninus* Dana, 1849*; C. furcatus* Dana, 1849; *C. gracilis* Dana, 1849; *C. orsinii* Giesbrecht, 1889 were identified in the present study. Species under this family were small to medium-sized copepods and tend to have quite square Ce. Some have the lateral corners of the posterior metasome segment ending in a spine, with a characteristic undulating edge on the section between the spine and the Ur. The male has a complex P5 with one side forming a large claw. One side of the male A1 typically very thickened along part of its length.

Pseudodiaptomus serricaudatus T.Scott, 1894 was the only species identified in the present study under the family **Pseudodiaptomidae Sars, 1902.** Species under this family showing the following general characters. Ce and Pd1 fused or separate, P 4 and five combined or separate. Posterior metasomal corners may be rounded or variously decorated with large posterior spines or rows of spinules. Ur 2 to 4-segmented may be asymmetrical. CR tend to be elongate and asymmetrical. A1 symmetrical, usually 22-segmented. P1 to P4 biramous. In males, Ur 5-segmented. A1 asymmetrical; right geniculate between segments 18 and 19 (Razouls et al. 2005-2018).

Under the family **Temoridae Giesbrecht, 1893**, *Temora discaudata* Giesbrecht, 1889 and *T. turbinata* Dana, 1849 were identified in the present study. The general characters of the species under the family Temoridae as following. In females, Ce and Pd1 separate, Pd4 and Pd5 fused or partly fused. Ur 3 to 4 segmented. CR sometimes elongate, with six setae. Pd1-4 with the endopods 1-, 2- or 3-segmented; exopod segments one and two may be fused. In males, Ur 5-segmented. A1 is distinctly geniculate on the right (Razouls et al. 2005-2018).

The species *Candacia ethiopica* Dana, 1849; *C.bradyi* A.Scott,1902; *C.pachydactyla* Dana,1849; *C.simplex* Giesbrecht,1889*; C.truncata* Dana,1849 were identified under the genus ***Candacia*** **Dana, 1846** and the family **Candacidae Giesbrecht, 1893** in the present study. The general identification characters are as follows. Pr 5-segmented. Pd4 and Pd5 fused. Posterior margin of prosome usually produced into prominent posterolateral processes, sometimes asymmetrical in females, always asymmetrical in males. Ur 3-segmented in the female, with two free abdominal somites. Ur 5-segmented in the male. CR with up to 6 setae. Rostrum poorly developed, bifid but lacking rostral filaments.

The family **Pontellidae Dana,1853** represented in the study under five genus. Genus ***Calanopia*** **Dana,1853** represented with *Calanopia minor* A.Scott, 1902 and *C.thompsoni* A.Scott,1909. ***Labidocera*** **Lubbock,1853** represented with *Labidocera acuta* Dana,1849; *L.detruncata* dana,1849; *L.Kroyeri* Brady,1883; *L.minuta* Giesbrecht,1889; *L.pavo* Giesbrect,1889; *L.bataviae* A.Scott,1909 and *L.madurae* A.Scott,1909. ***Pontella*** **Dana,1846** represented with *Pontella denticauda* A.Scott,1909; *P.fera* Dana,1849*; P.sinica* Chen and Zhang,1965 and *P.spinipes* Giesbrecht, 1889. ***Pontellina*** **Dana,1852** represented with *Pontellina plumata* Dana,1849. ***Pontellopsis*** **Brady,1883** represented with *Pontellopsis armata* Giesbrecht,1889; *P.perspicax* Dana,1849; *P.regalis* Dana,1849 and *P.herdmani* Thompson & Scott, 1903.The characteristics as follows. Ce and Pd1 separate, Pd4 and Pd5 fused or separate. Many have prominent hooks on the sides of the Ce and paired lenses on the dorsal Ce. Eyes usually large, with 1 or 2 pairs of dorsal chitinous lenses and one ventral lens P5 of the female is small and simple but robust. CR with up to 6 setae. A1 with 16-24 segments. In males, Ur 4 to 5 segmented, sometimes segments with asymmetrical processes. Right A1 prehensile, middle section swollen, terminating in 2-4 segments. P5 asymmetrical, coxa and coupler fused to form a transverse plate. Right leg subchelate, comprising an unarmed coxa, basis with one seta, and 2-segmented exopod: segment 1+2 swollen with an external process and spine, segment 3 forming subchela. Left leg comprising basis with an outer seta; exopod segment 1 elongate with an outer seta; exopod segments two and three partly fused with up to 4 outer and distal spines on the apical segment. (Bradford-Grieve, 1999)

The family **Acartidae Sars 1846** represented with the genus ***Acartia* Dana,1846** and the following species were identified in the present study. *Acartia negligens* Dana,1849; *A.spinicauda* Giesbrecht, 1889; *A.erythraea* Giesbrecht,1889; *A.bispinosa* Carl,1907, *A.amboinensis* Carl,1907 and *A.fossae* Gunrey,1927. In the family Acartidae, the female Ce and Pd1 separate, Pd4and Pd5 fused. Postero-lateral angles of prosome rounded or pointed. Ur 3-segmented in female with two free abdominal somites. Ur 5-segmented in male; a single genital aperture located ventrolaterally at posterior rim of genital somite on the right side.CR often slightly asymmetrical, with up to 6 setae. P1 to P4 biramous. Outer distal angles of exopodal segments of P2 to P4 with large spinous processes (Razouls et al., 2005-2018).

The family **Tortanidae Sars, 1902** represented in the present study with a new species under the genus ***Tortanus* Giesbrecht, 1898** and subgenus ***Atortus*.** In family Tortanidae, the species have Ce without a lateral hook. Rostrum absent, horseshoe-shaped plate fringe with hairs anterior to the upper lip. Ce and Pd1 separated, Pd4 and Pd5 fused or separated. Corners of last thoracic somite pointed and sometimes asymmetrical in the female, rounded in the male. Urosome 2 or 3 somites and usually asymmetrical in female; 5 somites in male. CR usually very asymmetrical in female, less so in male. P1-P4 with three exopodal segment, 2 or 3 endopodal segments in P1, two endopodal segments in P2-P4. P5 uniramous in both sexes, 2-3-segmented and sometimes asymmetrical in the female; right P5 male forming a chela (Mulyadi, 2004).

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Chapter - 7

MOLECULAR SYSTEMATICS OF CALANOID COPEPODS

Contents

7.1. INTRODUCTION

Copepod crustaceans living in the oceanic realm have received much attention from molecular biologists, as they are difficult to identify because of their similar morphological characteristics, especially in closely related species. Its great diversity needs accuracy on species identification, because, in some cases, share morphometric and meristic characteristics that tend to confuse the identity of the species. It is also mentioned that co-occurrence of multiple closely related species makes it difficult to determine their female-male correspondence by morphology (Nishida et al., 2015; Mulyadi et al., 2017; Francis and Nishida 2018 and Francis et al., 2018). Hence, molecular techniques are now an essential tool for studies on population structure, phylogeography, and phylogeny of copepods (Sanu et al., 2016). Molecular analysis can provide unambiguous taxonomic discrimination (Bucklin and Wiebe 1998; Lee and Frost 2002; Eyun et al., 2007; Soh et al., 2012), and sequence analysis of mitochondrial genes can reveal intraspecific and interspecific variations (Bucklin et al., 1995; Bucklin and Wiebe 1998; Goetze, 2003). To document the molecular barcode of pelagic copepods from the selected marine habitats of South West coast of Arabian Sea, mitochondrial cytochrome C oxidase 1 (mtCOI) sequences developed for several of the species (for both female and male individuals) that inhabit the study area, and contribute to mainstreaming a barcode library.

7.2. RESULTS

7.2.1. Molecular records and systematics of the calanoid copepods

Mitochondrial COI sequences of 25 copepod species (both female and male individuals) were obtained and submitted in the National Centre for Biotechnology Information (NCBI) database. Among the identified species, mtCOI sequences of *Euchirella sp., Candacia catula, C.truncata, Labidocera kroyeri, L.acuta, L.detruncata, L.madurae, L.minuta, Pontella fera, P.sinica, P.spinipes, pontellina plumata, Pontellopsis armata, Tortanus minicoyensis,* and *Acartia bispinosa* represented the first molecular barcode for the species in the NCBI database (Table 1). A total of 111 sequences were developed during the study period from which more than 99% had more than 500 base pairs. Most of the calanoid copepod sequences were developed from the lagoon waters of Lakshadweep islands, that belonged to 10 families and 15 genera. Calanidae, Eucalanidae, Euchaetidae, Aetidae, Centropagidae, Temoridae, Candacidae, Pontellidae, Tortanidae and Acartidae were the major families with barcodes developed in which the family Pontellidae comprises 14 species and five genera (*Calanopia*, *Pontella*, *Labidocera*, *Pontellina* and *Pontellopsis*). (Table 1).

The Neighbor-joining tree of similarity using K2P distance shows the clustering of calanoid copepods (Fig. 1). The average distance (K2P) among the species was 0.5 %, and the divergence between genus 25.63 % (Table 2); the highest frequency of interspecific divergence within species was between 0 and 2 %, and the variation between genera, all had more than 17%. All the species were clustered according to bootstrap values. Individuals in the same species got arrayed in a single clade with 100% bootstrap values and the average intraspecific divergence 0.5% within the species adequate to confirm the female - male correspondence and the genetic identity of the species from congeners and other copepods species from different families.

Table 1. COI sequences of calanoid species published in the NCBI database with accession numbers (www.ncbi.nlm.nih.gov) accession number for female and male individuals represented by symbols.

Species	Accession Number	No
Order Calanoida		
Family: Calanidae		
Undinula vulgaris Dana, 1849	KJ940173♀,KJ940174♂	2
Canthocalanus pauper Giesbrecht, 1888	KX831912♀, KX831913♂	2
Family: Eucalanidae		
Subeucalanus subcrassus Giesbrecht, 1888	KP842700♀, KP842701♀, KP842702♂, KP842703♂	4
Family: Euchaetidae		

Euchaeta concinna Dana, 1849	KP749945♀, KP749946♀ , KP749947♀, KP749948♂, KP749949♂	5
Euchaeta indica Wolfenden, 1905	KY421045♀, KY421046♂	2
Family Aetideidae		
*Euchirella sp**.	KT800383♀	1
Family: Centropagidae		
Centropages furcatus Dana, 1849	KJ561888♀	1
Family: Temoridae		
Temora discaudata Giesbrecht, 1889	KJ940171♀,KJ940172♂	2
Family: Candacidae		
Candacia catula Giesbrecht, 1889 *	KP068662♀ KP068663♀, KP068664♀, KP068665♂, KP068666♂	5
Candacia truncata Dana, 1849 *	KX831914♀,KX831915♂	2
Family : Pontellidae		
Calanopia thompsoni A. Scott, 1909	KP068656♀, KP068657♀, KP068658♂, KP068659♂	4
Pontella denticauda A. Scott, 1909 *	KT800377♀ ,KT800378♀, KT800379♀ KT800380♀, KT800381♀	5
Labidocera acuta Dana, 1849 *	KJ940166♀, KJ940167♀, KJ940168♂, KJ940169♂, KJ940170♂	5
Labidocera bataviae A. Scott, 1909	KU881728♀, KU881729♀, KU881730♂, KU881731♂	4
Labidocera detruncata Dana, 1849 *	KU881732♀,KU881733♂	2
Labidocera kroyeri Brady, 1883 *	KP068677♀,KP068678♀	2
Labidocera madurae A. Scott, 1909 *	KJ701546♀, KJ852655♀, KJ852656♀, KJ911917♀, KJ933427♂, KJ933428♂, KJ933429♂.	7
Labidocera minuta Giesbrecht, 1889 *	KP068667 ♀, KP068668♀, KP06869♀ KP068670♂, KP068671♂	5
Pontella diagonalis sensu Silas & Pillai, 1973 *	KT282363♂ , KT282364♂, KT282365♂, KT282366♂, KT282367♂, KT282368♂, KT282369♂, KT282370♂, KT282371♂,KT282372♂	10
Pontella spinipes Giesbrecht,1889*	KT267166♀, KT267167♀, KT267168♀, KT267169♀, KT267170♀, KT186887♀, KT186888♀, KT186889♀, KT186890♀, KT186891♀	10
Pontella ferra Dana, 1849 *	KT186882♀, KT186883♀, KT186884♀, KT186885♀, KT186886♂	5
Pontella sinica Chen & Zhang, 1965 *	KT 336554♂, KT 336555♂, KT 336556♂, KT 336557♂, KT 336558♂,KT336559♂, KU881726♀	7
Pontellina plumata Dana, 1849 *	KP068679 ♂, KP068680♂,KP068681♀	3
Pontellopsis armata Giesbrecht, 1889 *	KT186892♀, KT186893♀, KT186894♂, KT186892♂,KT186896♂	5
Family : Tortanidae		
Tortanus minicoyensis sp.nov.*	KP749950♂, KP749951♂, KP749952♂, KP749953♂, KP749954♀, KP749955♀	6
Family: Acartidae		
Acartia bispinosa Carl, 1907 *	KP068672♀ , KP068673♀, KP068674♀, KP068675♂,KP068676♂	5

*Primary submissions in the NCBI database.

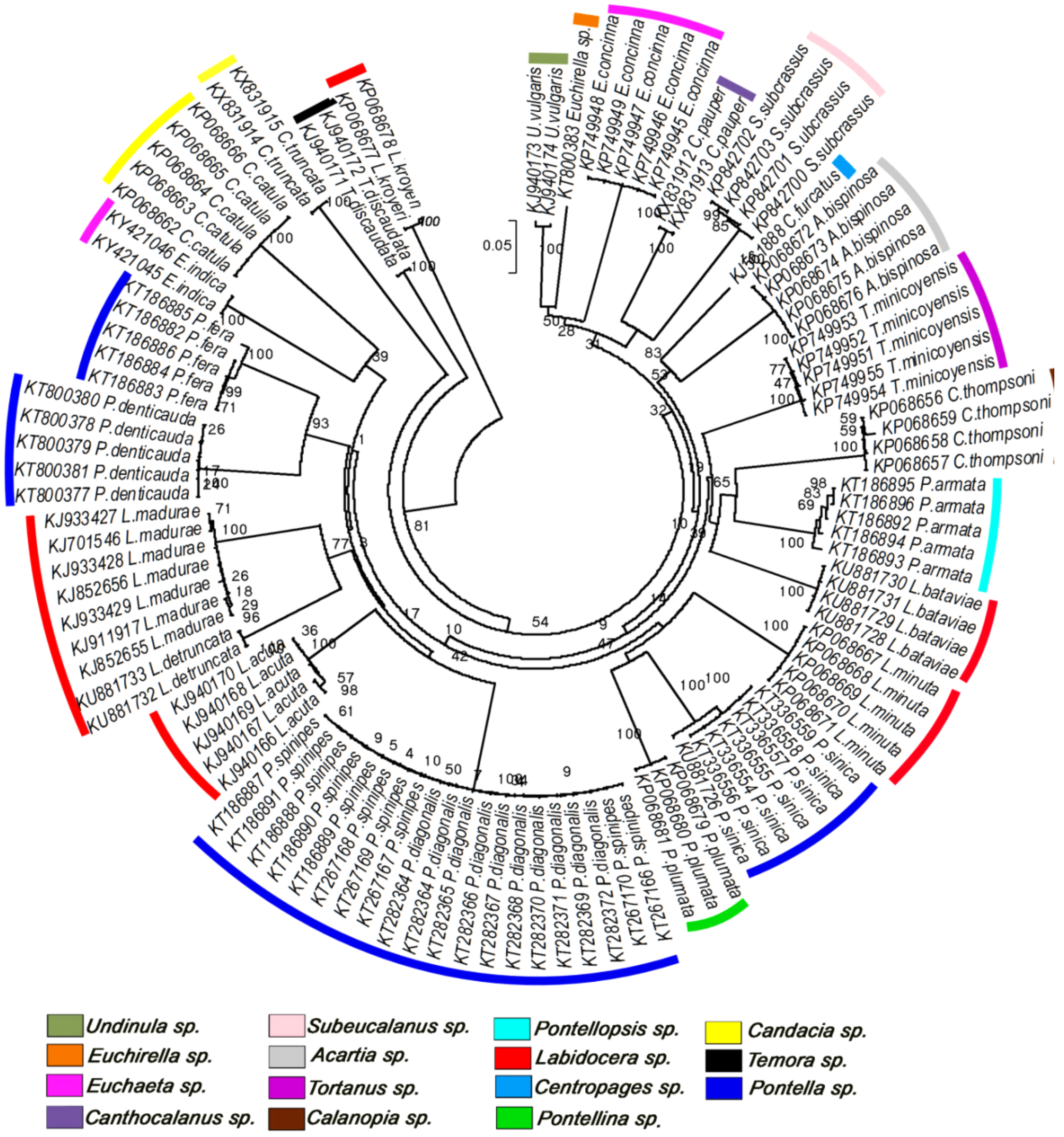

Figure1. Neighbour-joining tree for 25 pelagic calanoid copepod species (Maximum Likelihood, bootstrap= 1000), using K2P distances.

Table 2. Genetic divergences (K2P) at different taxonomic levels.

Comparison within	Taxa	No of comparisons	Minimum (%)	Maximum (%)	Mean Distance (%)
Species	23	105	0.1	2	0.5
Genus	16	50	17.6	49.2	25.63

7.2.2. Barcode library developed for the calanoid copepods.

The present study provides 111 new barcodes from the south-west coast of India for 25 calanoid copepod species. The developed barcodes increase the geographical coverage of existing records and could use as a comprehensive library of DNA barcode sequences for lineages of interest. These new data were analysed with previously published sequences in the NCBI database. From the family **Calanidae Dana,1849,** COI barcode developed for ***Undinula vulgaris*** **Dana, 1849** and ***Canthocalanus pauper*** **Giesbrecht, 1888.** For *U. vulgaris*, the sequence has 636 base pairs length (bp) (KJ940173 and KJ940174) 654 bp for *C.pauper* (KX831912 and KX831913) and 100% similarity with previously submitted data of the species in the NCBI database. The intraspecific divergence was 0% for both the species. From the family **Eucalanidae Giesbrecht, 1893** four sequences with 642bp (KP842700 to KP842703) developed for ***Subeucalanus subcrassus*** **Giesbrecht, 1888.** The sequences blasted in NCBI database with 99% similarity with previously submitted data of the species. The intraspecific divergence of the species ranged from 0 to 0.6% which is adequate to female-male correspondence. From the family **Euchaetidae Giesbrecht, 1893** five sequences (KP749945to KP749949) of 643bp were developed for ***Euchaeta concinna*** **Dana, 1849** and two sequences of 498bp (KY421045 and KY421046) developed for ***Euchaeta indica*** **Wolfenden, 1905.** NCBI- BLAST (Basic Local Alignment Search Tool) result showed that *E.concinna* with 99% and *E.indica* with 97% similarity with the previous data submitted in the NCBI. The intraspecific divergence of both the species was 0%.

The 630bp sequence (KT800383) developed for ***Euchirella sp.*** under the family **Aetideidae Giesbrecht, 1892.** The species was morphologically similar to *Euchirella pulchra* Lubbock, 1856. However, the NCBI BLAST result showed that the present possessed 95% similarity with *E. splendens* Vervoort, 1963 and only 91% with *E.pulchra* which means the present specimen not identical to both the species. Since *E.splendes* is not reported yet from the Indian Ocean, there is a possibility of the species may a new or some other sister species under the genus *Euchirella* recorded from the Indian Ocean. A 480 bp sequence developed (KJ561888) for the species ***Centropages furcatus*** **Dana, 1849** under the family **Centropagidae Giesbrecht, 1893.** BLAST results indicated that the present sequence 99% similar to the previously submitted data of the species from other marine waters.

Two sequences of 617bp (KJ940171, KJ940172) developed for the species ***Temora discaudata* Giesbrecht, 1889,** under the family **Temoridae Giesbrecht, 1893.** The sequence has 0% interspecific divergence, and the BLAST result indicated that the present sequence 100% similar to the previously submitted sequences. Five sequences of 645bp (KP068662 to KP068666) developed for the species ***Candacia catula* Giesbrecht, 1889** and two sequences of 651 bp (KX831914 and KX831915) for ***Candacia truncata* Dana, 1849** under the family **Candacidae Giesbrecht,1893.** The sequences developed for the two species were the first time submission in the NCBI database. The intraspecific distance of the male and female specimen was 0%.

The mt COI sequences developed for the species under the family **Pontellidae Dana,1853 *Pontella denticauda* A. Scott, 1909 , *Labidocera acuta* Dana, 1849; *L. detruncata* Dana, 1849, *L. kroyeri* Brady, 1883; *L. madurae* A. Scott, 1909; *L.minuta* Giesbrecht, 1889 ; *P.diagonalis* sensu Silas & Pillai, 1973; *P. spinipes* Giesbrecht,1889; *P. ferra* Dana, 1849; *P. sinica* Chen & Zhang, 1965; *Pontellina plumata* Dana, 1849; *Pontellopsis armata* Giesbrecht, 1889** were primary submission in NCBI database. Four sequences of 627bp (KP068656 to KP068659) developed for the species *Calanopia thompsoni* has 0.2 to 0.8% interspecific divergence. For the species, *L.acuta* five sequences of 620bp (KJ940166 to KJ940170) were generated. The intraspecific divergence within the species was 0 to 0.3%. Four sequences of 618bp (KU881728 to KU881731) generated for the species *Labidocera bataviae* A. Scott, 1909. The intraspecific divergence within the species was 0%. Two sequences of 618bp (KU881732 and KU881733) developed for the species *L. detruncata*. For the species *L.kroyeri* two sequences of 621bp (KP068677 and KP068678) were developed. For *L.madurae,* seven sequences developed and the sequence lengths ranged from 629 to 642bp. (KJ701546 to KJ933428 and KJ933429). The intraspecific distance of *L. madurae* sequences developed in the present study ranged from 0.2 to 0.9 %. For the species *L.minuta*, five sequences of 627bp developed (KP068667 to KP068671) and the intraspecific distance was 0%.

The developed sequences of female *P. spinipes* and male *P. diagonalis* sensu Silas and Pillai (1973) were submitted to the NCBI database and assigned the following accession numbers: KT186887 to KT186891and KT267166 to KT267170 for female *P. spinipes*, KT282363 to KT282372 for male *P. diagonalis* sensu Silas and Pillai (1973). The base pair length for the developed sequences was 639 bp for the male *P. diagonalis* sensu Silas and Pillai (1973), and 660 bp for the female *P. spinipes*. The female *P. spinipes* and male *P. diagonalis* sensu Silas and Pillai (1973) exhibited 0 - 0.2% intraspecific sequence divergence. For the species *Pontella denticauda,* five sequences of 618bp (KT800377 to KT800381) developed and the intraspecific divergence within the species was 0%. Five sequences of 620bp (KT186882 to KT186886) developed for the species *P.fera*. The intraspecific divergence within this species ranged from 0 to 0.2%. For *P.sinica,* six sequences of 618bp were developed (KT 336554 to KT336559, and KU881726). Intraspecific divergence within the species was 0%. For the species *Pontellina plumata* three sequences of 633bp were developed (KP068679, KP068680, and KP068681) with 0% intraspecific sequence divergence. Five sequences of 618bp (KT186892 to KT186896) developed for the species *Pontellopsis armata* showed and intraspecific sequence divergence ranged from 0 to 0.8% in the present study. The developed sequences of female and male ***Tortanus minicoyensis* sp. nov.** under the genus **Tortanus Giesbrecht, 1898** were submitted to the NCBI database and assigned the following accession numbers: KP749951 to KP749953 for males and KP749954 and KP749955 for females. The level of intraspecific divergence of *T.minicoyensis* sp. nov. ranged from 0 - 0.5%. Five sequences of 630bp (KP068672 to KP068676) for the species ***Acartia bispinosa*** **Carl, 1907** under the family **Acartidae Sars, 1846** were developed with 0% intraspecific sequence divergence.

7.2.3. Revision of taxonomic status of calanoid species through morpho-molecular methods.

This section describes the revisions in the taxonomy of three Pontellid species by morphological and molecular methods. The details are elaborated below. The genus *Labidocera* (Pontellidae) individuals exhibit proximity in morphology; there exists the potential for misidentification. *Labidocera madurae* A. Scott, 1909, may readily be mistaken for *L. pavo* Giesbrecht 1889 or *L. bataviae* A. Scott, 1909. There was significant confusion concerning *Labidocera madurae* A. Scott, 1909 and *Labidocera sp.* from the Hawaiian region (Jungbluth and Lenz, 2013). The neustonic copepods *Pontella spinipes* Giesbrecht, 1889 and *P. diagonalis* Wilson, 1950, both first described by female specimen exhibit very similar morphology and overlapping geographic ranges in the Indian Ocean. While several taxonomists have described males of each species, there has been no definitive evidence for female-male matching (link female and male of the same species) in the two species. Recent reports revealed considerable ambiguities in taxonomic descriptions of the species *Pontella sinica* (Jeong et al., 2008; Mulyadi 2000; Mulyadi 2011). Considering these ambiguities of these species, critical morphological evaluation with the molecular barcodes developed for these species resolved their ambiguities and elucidated their phylogenetic status with congeners.

A. *Labidocera madurae* A. Scott, 1909.

The genus *Labidocera* Lubbock 1853 is chiefly characterised by its aggregation in surface waters (0–30 cm layer) of tropical to warm temperate latitudes. The genus is the largest in the Family Pontellidae, and the majority of its members comprise 52 species (Sherman 1963, 1964; Razouls et al. 2013; Jeong et al. 2014), mostly Indo-Pacific in distribution. They have been widely used for investigations in water masses and major zoogeographic divisions (Fleminger 1957, 1967, 1986; Voronina 1962; Silas and Pillai 1973; Fleminger and Moore 1977; Fleminger et al., 1982; El-Sherbiny and Ueda 2010; Jeong et al., 2014). As the *Labidocera* groups occur allopatrically or sympatrically within a restricted area (Mulyadi, 2002), the phylogenetic relationship of the genus *Labidocera* needs additional investigation by morphological and molecular analysis (Jeong et al., 2014). The genus is divided into five species groups including *detruncata, kröyeri, minuta, pectinata*, and an unnamed group by morphological characteristics (Fleminger et al., 1982; Othman 1986; Mulyadi 1997, 2003). *Labidocera madurae,* which belongs to the *detruncata* group (Fleminger 1967), was originally described by Scott (1909) in material collected from the Malay Archipelago during the Siboga Expedition (stations 16, 66, 71, 81, 98, and 282). However, Scott (1909) reported its close affinity to an Atlantic species, *L. nerii* Kroyer 1849. It was considered neritic in form by several authors who recorded this species from the northern Pacific (Sherman 1963) near Hawaii (Sherman 1967; Hassett and Boehlert 1999) and the Madagascar coastal waters (Gouday 1967). Its taxonomic description from the Mediterranean Sea was first provided by Lakkis (1981) and later by Kovalev and Shmeleva (1982). *L. madurae* was reported in Lebanese waters (Lakkis 1990) and the Iskenderun Bay (north-eastern Mediterranean) by Lakkis et al., (2005). In Indian waters, it has been recorded from the northern Indian Ocean (Madhupratap and Haridas 1986) and the islands of Andaman and Lakshadweep (Silas and Pillai 1973; Madhupratap et al., 1991), and taxonomic description from South Western Indian Ocean by Conway et al. (2003) and Gulf of Mannar and Palk bay by Jagadeesan et al. (2013). Knowledge of the phylogeny of the genus *Labidocera* has been limited; the only published attempt to reconstruct the phylogenetic tree of this genus is by Jungbluth and Lenz (2013), who developed mitochondrial cytochrome oxidase I (mtCOI) sequences of *Labidocera sp.* from Kaneohe Bay and compared them with sequences from three other *Labidocera* species. The *Labidocera* from Hawaii has been identified as most similar to *L. madurae* (Leis 1982; Hassett and Boehlert 1999). However, these could not be compared with the sequences of *L. madurae*, as the mtCOI sequences of the species were not available in the GenBank database (Jungbluth and Lenz 2013). The present study seeks to provide the first DNA barcode developed for *L. madurae* collected from the Kavaratti and Minicoy islands of the Lakshadweep Archipelago (Fig.2), based on mtCOI sequences ranging from 629 to 642 base pairs, and to elucidate phylogenetic relationships among sibling and non-sibling congeneric species under the genus *Labidocera* available from NCBI.

i. *Systematics*

Order	: Calanoida Sars, 1903
Family	: Pontellidae Dana, 1852
Genus	: *Labidocera* Lubbock, 1853
Species	: ***Labidocera madurae*** A. Scott, 1909

ii. *Material examined*

Forty females and twenty-five males were collected from lagoons of the Kavaratti (10°33′N and 72°36′E) and Minicoy (8°15′N and 73°52′E) islands, Lakshadweep Archipelago, in January 2014. Of these, ten females and ten males of *L. madurae* were dissected and examined in detail. In this study, the species was found to occur in a salinity range of 33 to 37 PSU, pH range of 7.72 to 8.76, and temperature range of 26.75 to 30.25 °C.

iii. *Description of the species*

Female: Body length 2.11–2.80 mm. Body elongated, with one pair of circular dorsal eye lenses that are feeble, small, and placed apart. Rostrum deeply bifurcated symmetrically produced posteriorly into pointed processes. The antennules are composed of 23 joints and extend to the end of the urosome. The genital segment is moderately large and asymmetrical, with the middle of the right side considerably inflated. The anal segment is very short. The Furcal rami are symmetrical and are longer than broad. The endopodites of four pairs of swimming feet are two-jointed, in contrast to three-jointed exopodites. The fifth pair of feet is nearly symmetrical. The exopodite is furnished with two outer marginal spines. The apex terminates in three subequal spines. The apex of the endopodite is not bifurcated (Fig. 2).

Male: Body length 1.62–1.96 mm. Males resemble females except in the urosome that has five segments. The fourth and fifth urosomal segments are much shorter than the others. The right antennule is geniculate, segments 18 and 19–21 with dorsal denticulated plates. Short, curved thumb-like process on the proximal outer margin of the first joint of the right exopodite of the fifth pair of feet. Inner margin of hand with a small median spine; palm simple. The claw-like joint long and narrow. The apical joint of the left exopodite is elongate and ovate and is twice as long as broad. The outer margin is furnished with one spine, and the apex bears three spines. The inner margin has a pad of fine hairs (Fig. 2).

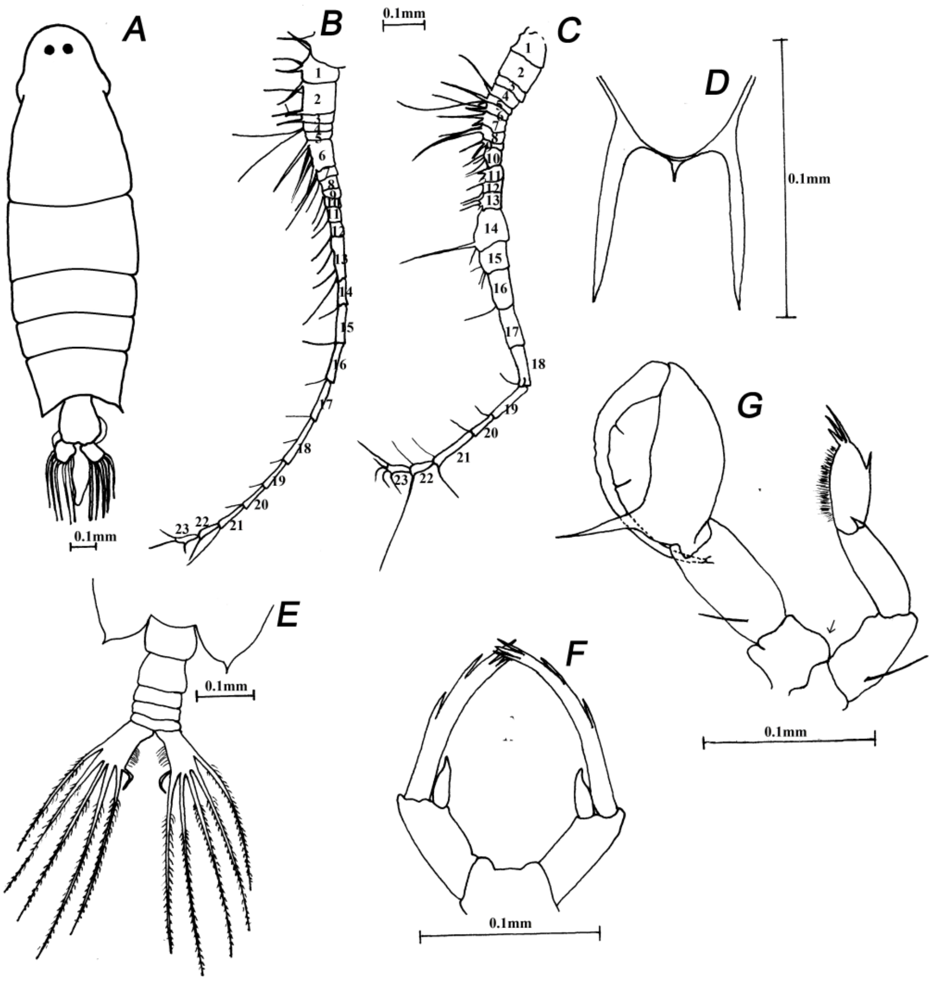

Figure 2 *Labidocera madurae* (A. Scott, 1909): A- Female, dorsal view. B- Female, first antennae. C- Male, geniculate first antennae. D- Rostrum; E- Male urosome dorsal. F- Female, fifth leg. G- Male, fifth leg (arrow indicates the thumb-like process on the exopodite) (Sanu et al., 2016)

iv. *Molecular analysis*

MtCOI sequences were successfully generated using the primer pair, reaction mix, and thermal regime described above. Sequence lengths ranged from 629 to 642 base pairs, with small indels (insertions and deletions). The developed mtCOI sequences of *L. madurae* were submitted to the NCBI database, and the following accession numbers were obtained: KJ701546 to KJ933428 and KJ933429. Additional sequences of genus *Labidocera* present in the NCBI database (Table 2) were incorporated for constructing a phylogenetic tree (maximum likelihood) (Fig. 3). *Pseudocalanus elongatus* (Boeck, 1865) was selected as an out-group. The maximum likelihood (ML) tree exhibited the differential assemblage of Labidocera individuals concerning their speciation. *L. madurae* individuals were arranged within a single clade with high bootstrap value (99%), following the collection of sequences entitled *Labidocera sp.* (accession numbers KC594129–KC594138) bearing bootstrap support of 98 % at the apex of the ML tree.

Table 2. Details of sequences incorporated for analysis

species	Accession numbers	Remarks
Labidocera madurae	KJ852655, ,KJ852656, KJ701546, KJ911917, KJ933428, KJ933429, KJ933427	developed
Labidocera euchaeta	KF977282, KF977283, KF977284, KF977285	obtained
Labidocera rotunda	JQ714066, JQ714065	obtained
Labidocera japonica	JQ714069	obtained
Labidocera acuta	KJ940167 to KJ940170	obtained
***Labidocera* sp.**	KC594129 toKC594139	obtained
Pseudocalanus elongatus	HM770078	obtained

(Sanu et al. 2016)

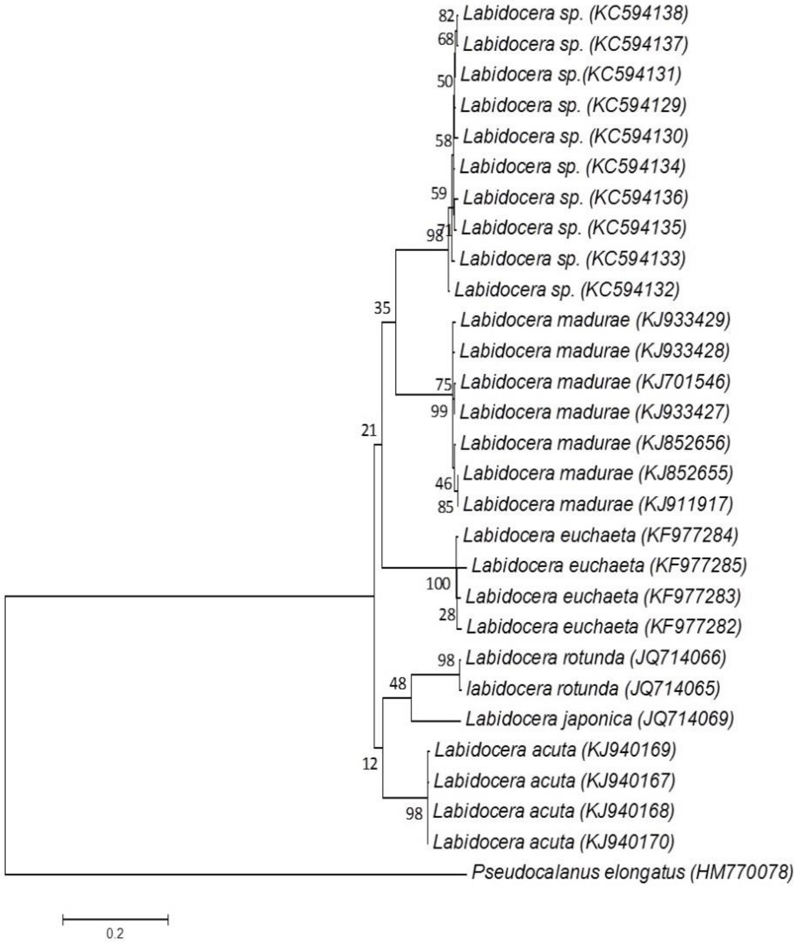

Figure 3. Phylogenetic ML tree based on 1000 pseudo replicas of bootstrap. (Sanu et al. 2016)

From the tree topology, it was clear that *L. madurae* and *Labidocera sp.* individuals were the descendants of a common ancestor and were close relatives in relation to other individuals within the genus. In addition, *L. euchaeta* sequences were also assembled next to the latter with 100 % bootstrap support. Another relative assemblage was exhibited between *L. rotunda* and *L. japonica*. Dual sequences of *L. rotunda* and a single sequence of *L. japonica* formed sister clades of a vertex next to *L. euchaeta* sequences, where *L. rotunda* sequences possessed 98 % bootstrap support. *L. acuta* formed the neighbour of the latter, with 98 % bootstrap support (Fig.3). As expected, the selected out-group *Pseudocalanus elongatus* (accession number HM770078) exhibited a diverged array. In order to justify the results of the phylogenetic tree, genetic distance persisting within the selected individuals was analysed. The level of intra- and interspecific divergence persisting within genus *Labidocera* was evident from distance matrix data. Specifically, *L. madurae* individuals possessed an intraspecific sequence divergence ranging from 0.2 to 0.9 % (Table 3), which reflected and justified the results inferred from the likelihood tree. This value was adequate to establish the genetic identity of *L. madurae* sequences. Also, the level of interspecific divergence among other species supported its cladistic differentiation in the ML tree.

B. *Pontella sinica* Chen & Zhang, 1965

Pontella sinica Chen & Zhang, 1965, a neustonic calanoid copepod belonging to the family Pontellidae, was originally described by Chen & Zhang (1965) by two females collected in the East China Sea off Zhejiang. This mode of action was subsequently followed by Zheng et al. (1982), who described both sexes of the species from the coastal waters of Fujian and synonymised the description of *P. princeps* Sewell, 1932 from the Andaman Sea by Sewell (1932) as *P. sinica*. Meanwhile, Heinrich (1987), possibly unaware of the description of *P. sinica* (cf. Chen & Zhang, 1965), described *P. sewelli* Heinrich, 1987 as a new species from the Andaman Sea, synonymising the specimens described as *P. princeps* by Sewell (1932). Later, Mulyadi (2000), also possibly unaware of descriptions of *P. sinica* (cf. Chen & Zhang, 1965; Zheng et al., 1982) and *P. sewelli* (cf. Heinrich, 1987), described two males from Jakarta Bay as *P. princeps*.

However, Jeong et al. (2008) re-described a male specimen of *P. sinica* from Korean waters and stated that the specimens described as *P. princeps* by Sewell (1932) & Mulyadi (2000), and as *P. sewelli* by Heinrich (1987) were identical to *P. sinica*. However, later on, Mulyadi (2011) changed his identification of *P. princeps* as *P. sewelli* along with *P. sinica*, ignoring the amendment by Jeong et al. (2008) and the priority of *P. sinica* over *P. sewelli*. During a taxonomic study on the copepods in the Indian Ocean, we collected specimens of *P. sinica* from offshore waters of Minicoy Island along with the southwest coast of India. Under the above state of confusion, this study redescribed *P. sinica* by the present specimens with a revision of its synonymy.

i. *Systematics*

Order : Calanoida Sars, 1903
Family : Pontellidae Dana, 1852
Genus : *Pontella* Dana, 1846
Pontella sinica Chen & Zhang, 1965

ii. *Materials examined*

One female (a portion of second and third pediger removed for genetic analysis) and two males, deposited at the Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology (Catalogue entry number: MBM/DBT/11/15 for the female and MBM/DBT/12/15 for the male specimens).

Table 3. Distance matrix showing inter and intra specific percentage divergence of genus *Labidocera* . (Sanu et al 2016)

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1 *L.madurae* (KJ701546)																													
2 *L.madurae* (KJ852656)	0.4																												
3 *L.madurae* (KJ852655)	0.5	0.2																											
4 *L.madurae* (KJ911917)	0.5	0.2	0																										
5 *L.madurae* (KJ933427)	0	0.4	0.5	0.5																									
6 *L.madurae* (KJ933428)	0.7	0.4	0.5	0.5	0.7																								
7 *L.madurae* (KJ933429)	0.9	0.5	0.4	0.4	0.9	0.9																							
8 *L. rotunda* (JQ714066)	34	36	35	35	34	35	36																						
9 *L.rotunda* (JQ714065)	34	36	35	35	34	35	36	0																					
10 *L.japonica* (JQ714069)	35	36	36	36	35	36	36	26	26																				
11 *L.acuta* (KJ940168)	28	28	29	29	28	28	29	28	28	28																			
12 *L.acuta* (KJ940170)	28	28	29	29	28	28	29	28	28	28	0																		
13 *L.acuta* (KJ940167)	28	29	29	29	28	29	29	28	28	28	0.2	0.2																	
14 *L.acuta* (KJ940169)	28	29	29	29	28	29	29	29	29	29	0.4	0.4	0.5																
15 *L.euchaeta (* KF977283)	40	39	40	40	40	39	39	38	38	39	34	34	35	35															
16 *L.euchaeta (* KF977282)	39	38	39	39	39	37	38	39	39	42	35	35	35	36	2														
17 *L.euchaeta (* KF977284)	38	37	37	37	38	36	37	40	40	41	36	36	36	36	1	2													
18 *L.euchaeta* (KF97728)	39	38	39	39	39	38	39	40	40	41	34	34	35	35	2	2	2												
19 *L.sp* (KC594131)	31	31	31	31	31	31	30	31	31	34	30	30	30	31	43	44	40	43											
20 *L.sp* (KC594129)	30	30	30	30	30	30	30	32	32	33	31	31	31	31	42	44	40	43	0										
21 *L.sp (* KC594134)	30	30	30	30	30	30	30	31	31	33	30	30	30	31	42	43	39	42	1	0.5									
22 *L.sp* (KC594133)	29	29	29	29	29	29	29	32	32	33	32	32	32	33	40	42	38	40	1	1	1								
23 *L.sp* (KC594132)	28	28	28	28	28	28	29	30	30	32	30	30	30	31	42	44	40	42	2	2	1	2							
24 *L.sp.* (KC594136)	33	33	33	33	33	32	33	32	32	34	31	31	31	31	44	46	42	45	1	1	1	2	2						
25 *L.sp* . (KC594135)	31	31	31	31	31	31	30	31	31	33	32	32	32	33	44	45	41	44	1	1	1	1	2	0.9					
26 *L.sp.* (KC594138)	31	31	31	31	31	31	31	31	31	34	30	30	30	30	42	43	39	42	0	1	1	2	2	2	1				
27 *L.* sp. (KC594137)	31	31	31	31	31	31	31	31	31	33	29	29	29	30	42	44	40	43	0	1	1	2	2	2	1	0.4			
28 *L* .sp. (KC594130)	30	30	30	30	30	30	29	31	31	33	30	30	30	31	41	43	39	42	1	1	1	2	2	2	1	1	1		
29 *P.elongatus* (HM770078)	950	950	950	950	950	950	950	979	979	968	990	990	990	990	971	971	971	980	970	971	971	971	961	970	970	970	971	970	

iii. *Description of the species*

Female: Body length 5.2 mm (Fig. 4A). Cephalosome triangular with well-defined hooks. Dorsal eye lens moderately developed, frontal, rostral and ventral lens absent. Posterolateral angles of rostrum asymmetrical; right conical process shorter than left (Fig. 4C). Cephalon, first pediger, and fourth and fifth pedigers separate. Fifth pediger asymmetrical with acuminate lobes left lobe longer and wider than the right (Fig. 4D, E). Urosome is asymmetrical with three somites (Fig. 4A, D-F). First somite with large dorsal process, the complex scale-like structure on the dorsomedial surface, and three ventrolateral processes on the right side, of which middle one well developed, extending beyond middle of the second somite, while other processes much smaller; dorsal-most process with bifurcated tip (Fig. 4E). Second urosomal somite oval with semi-circular dorsal process near the posterior margin and three small processes located at even intervals on left lateral margin. Numerous dark coloured spots distributed over second urosomal somite. The distal end of second urosomal somite extending to anal somite in dorsal and ventral position. Anal somite short and asymmetrical. Caudal rami broad and asymmetrical, right ramus larger than left (Fig. 4D, F). Antennule of 25 segments extending beyond the fourth pediger; first nine segments rather smaller than others (Fig. 4B). Antenna to maxilliped and first to fourth swimming legs similar to those of other species of the genus (Mulyadi, 2002; El-Sherbiny & Ueda, 2008; Jeong et al., 2008; El-Sherbiny, 2009). Fifth leg symmetrical; basis with plumose seta and small seta on the proximal posterior surface. Exopod and endopod are one-segmented with bifurcated tips. Exopod with three-minute outer marginal spines, endopod reaching half length of exopod (Fig. 4G).

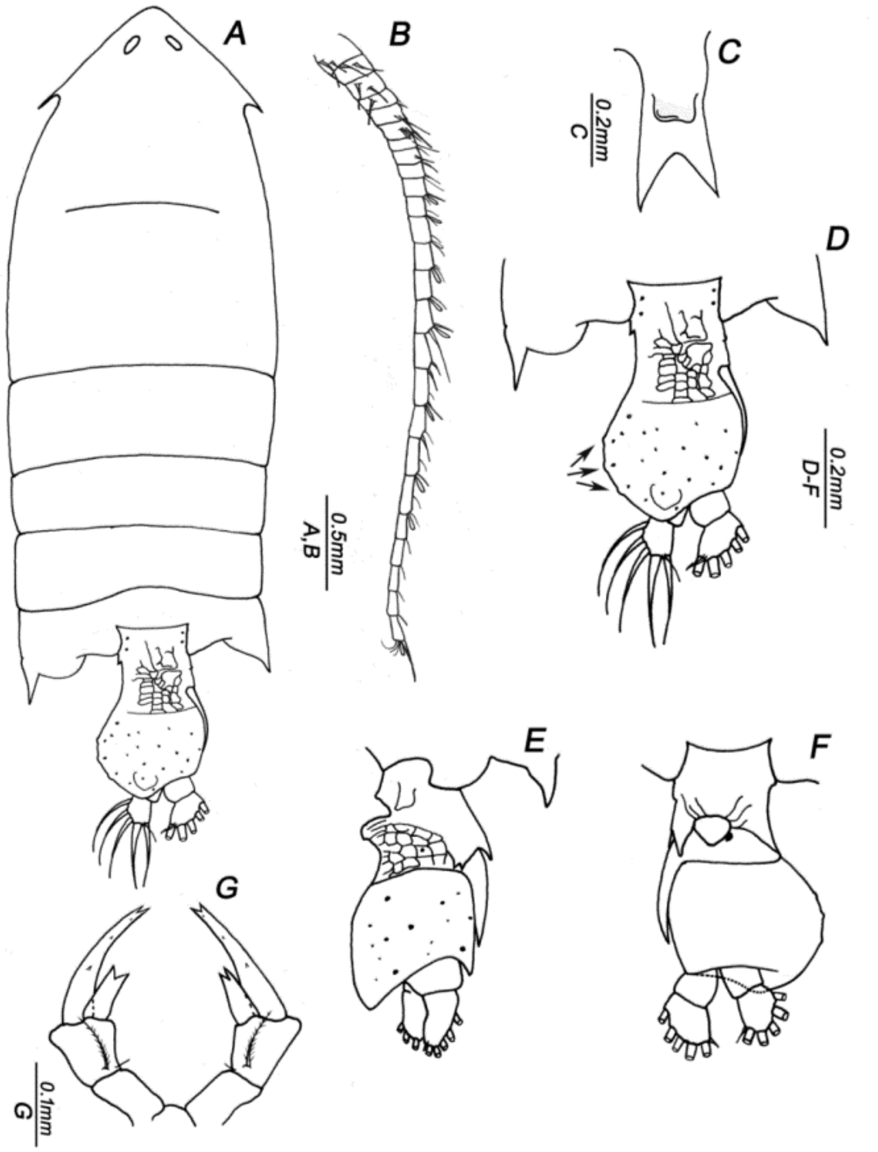

Figure 4. *Pontella sinica* Chen & Zhang, 1965 female. A Habitus, dorsal view; B, right antennule; C, rostrum, posterior view; D, urosome, dorsal view; E, urosome, right lateral view; F, urosome, ventral view; G, fifth legs, posterior view. Arrows indicate three small processes located at even intervals on the left lateral margin of second urosomal somite.

Male: Body lengths 4.35 and 4.47 mm, respectively. Body is robust with prominent cephalic hooks (Fig. 5A). Posterior corners of prosome symmetrical and sharply pointed. Dorsal eye lenses are larger than those of female. Frontal lens absent; a pair of anterior and posterior rostral lenses present. Rostral lenses oval in shape and asymmetrical (Fig. 5B, C). Urosome is comprising five somites; genital somite slightly asymmetrical with a lobe-like projection; caudal rami symmetrical. Right antennule geniculate; ancestral segments I-II, IV-V, VIII-X, X-XII, XIII-XV totally or partially fused. Elongated spine present on segment XVI and a triangular process on segment XVII. Segments XIX and XX each forming large, toothed plate, the latter with digitate process medially. Two smaller coarse and toothed plates present on fused segments XXI-XXIII; distal margin with the pointed triangular process. Segments XXIV-XXVIII completely fused (Fig. 5D). Fifth leg, right coxa and basis longer than left; coxa bearing medial process on outer margin. Each basis with long plumose seta and small seta. Right leg chelate, the first exopodal segment with thumb-like process slightly curved in a sigmoid manner, with a small basal knob on inner-proximal margin, and semi- circular process with basal seta about the midpoint of inner margin. The second exopodal segment with the semi-circular inner-medial process, three setae, each on proximal, medial, and sub-distal points of inner margin, and seta on the anterior surface near distal 1/3. Left leg, the first exopodal segment with medial seta; a second exopodal segment with large sub-basal spine extending beyond the tip of exopod, with small seta near the base. Segment ending in two unequal processes; longer process spatulate with crenulated margin and hirsute mediolaterally. Shorter process truncate distally and armed with short setae on the apex, and two spines at base. (Fig.5E).

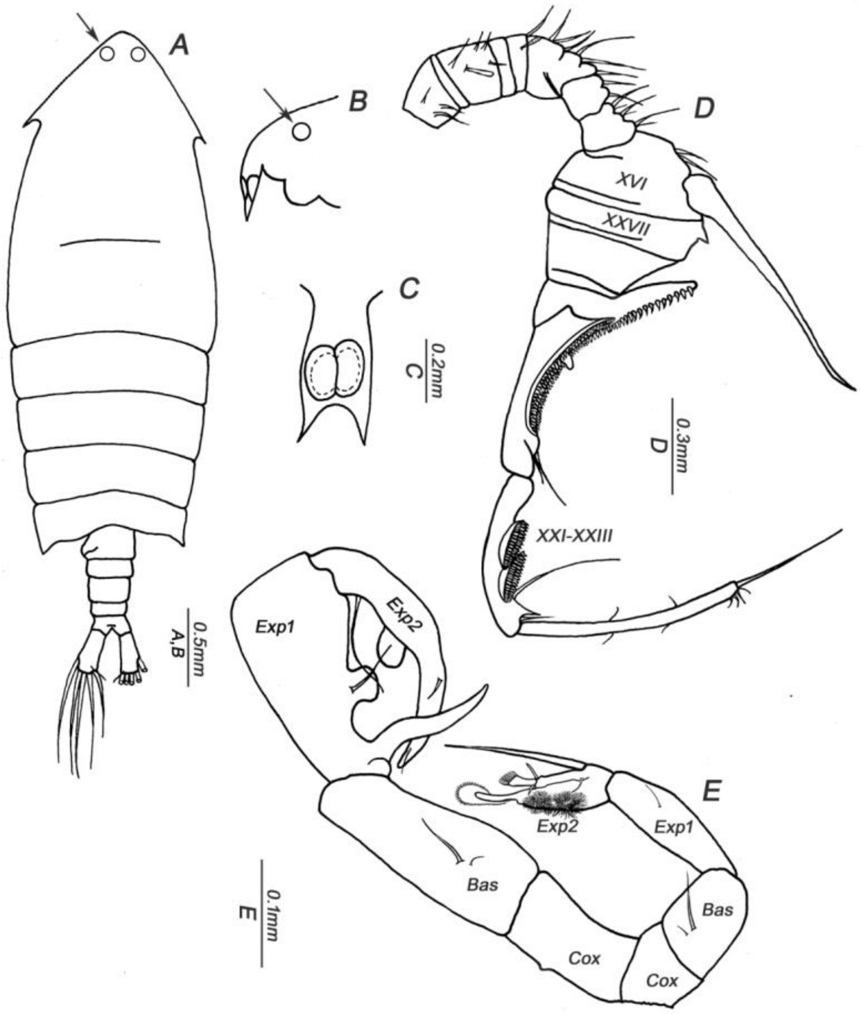

Figure 5. *Pontella sinica* Chen & Zhang, 1965 male. A Habitus, dorsal view; B, head, left lateral view; C, rostrum, posterior view, showing anterior and posterior lower frontal lenses in dotted and solid lines, respectively; D, right antennule, number of segments indicated with Roman numerals; E, fifth leg, posterior view. Arrow indicates dorsal eye lenses. Abbreviations: Cox, coxa; Bas, basis; Exp 1, first exopod; Exp 2, second exopod.

iv. *Molecular analysis*

The mtCOI sequences were successfully generated using the primer pair, reaction mix, and the thermal regime as described above. The developed sequences of *P. sinica* were submitted to the NCBI database, and the following accession numbers were obtained: KT 336554 to KT336559 for the male, and KU881726 for the female specimen(s). The base pair length for all developed sequences was 618. The Maximum Likelihood (ML) analysis and pairwise sequence distance were generated and analysed using the developed sequences as well as mtCOI sequences of their congeneric species acquired from the NCBI database (Table I). *Acartia negligens* Dana, 1849 was selected as an outgroup. The ML tree exhibited the differential assemblage of congeneric species of the genus *Pontella* concerning their speciation (Fig. 6). The sequences of six male and one female *P. sinica* specimens got arrayed within a single clade with high bootstrap value (100%), which was followed by the assemblage of sequences of *P. fera* Dana, 1849 with 54% of bootstrap support which was followed by the assemblage of *P. rostraticauda* Ohtsuka, Fleminger & Onbé, 1987*, P. spinipes* Giesbrecht, 1889 and *P.chierchiae* Giesbrecht, 1889. The selected outgroup *A. negligens* exhibited a diverging array. The level of intra- and interspecific divergence persisting within the genus *Pontella* was evident from the distance matrix data. Specifically, the sequences of male and female *P. sinica* possessed 1.2% intraspecific divergence, which is adequate to confirm the female-male correspondence (Table 4).

Table 4 Distance matrix is showing inter and intraspecific percentage divergence of *Pontella sinica* Chen & Zhang, 1965 and other species under the genus *Pontella*.

	Species with GenBank No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	KT186887 *Pontella spinipes*														
2	KT186888 *P.spinipes*	0													
3	AB206446 *P.rostraticauda*	19.4	19.4												
4	JQ714071 *P.chierchiae*	23.2	23.2	19											
5	KT336555 *P.sinica* ♂	23.2	23.2	21.8	20										
6	KT336554 *P.sinica* ♂	23.2	23.2	21.8	20	0									
7	KT336558 *P.sinica* ♂	23.2	23.2	21.8	20	0	0								
8	KT336557 *P.sinica* ♂	23.2	23.2	21.8	20	0	0	0							
9	KT336556 *P.sinica* ♂	23.2	23.2	21.8	20	0	0	0	0						
10	KT336559 *P.sinica* ♂	23.2	23.2	21.8	20	0	0	0	0	0					
11	KU881726 *P.sinica* ♀	22.3	22.3	21.1	20.5	1.2	1.2	1.2	1.2	1.2	1.2				
12	KT186882 *P.fera*	23.5	23.5	23.8	23.4	21.9	21.9	21.9	21.9	21.9	21.9	21.9			
13	KT186883 *P.fera*	23.5	23.5	23.8	23.4	22.1	22.1	22.1	22.1	22.1	22.1	22.1	0.2		
14	EU856813 *Acartia negligens*	29.8	29.8	28	26.7	29.2	29.2	29.2	29.2	29.2	29.2	29.4	30.3	30.5	

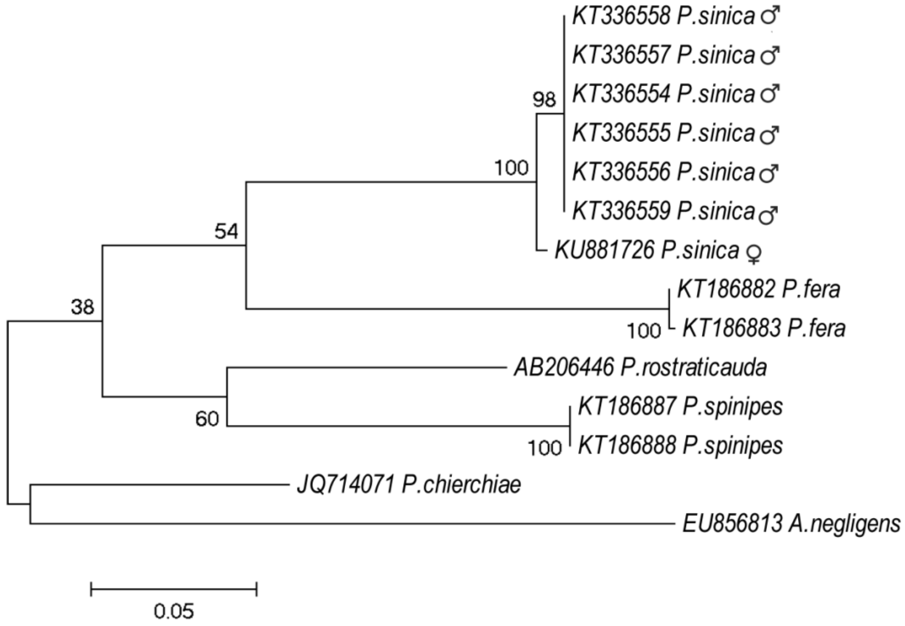

Figure 6. Maximum likelihood tree for *Pontella sinica* Chen & Zhang, 1965 and other *Pontella* species (taken from GenBank with their accession numbers) based on 1000 bootstrap pseudoreplicates.

C. *Pontella spinipes* Giesbrecht, 1889

The calanoid copepod *Pontella spinipes* Giesbrecht, 1889, was described from the Arabian Sea by female specimens. Wolfenden (1905) described a male which he referred to as *P. spinipes* from Maldive and Laccadive Islands, but it was assumed to be *P. diagonalis* by Silas and Pillai (1973). Later, the specimens referred to like the males of *P. spinipes* were described by Sewell (1912), Silas and Pillai (1973), Pillai (1975), and Mulyadi (2000). Meanwhile, *P. diagonalis* Wilson, 1950 was also described by a female specimen from off Jolo Island, the Philippines, and the males referred to as *P. diagonalis* were described by Silas and Pillai (1973), Pillai (1975), and Mulyadi (2000). Although the males presumed to correspond to the females of both species have been described as such, there has been no definitive morphological evidence to assure the proposed female-male matching. Moreover, their geographic ranges, which overlap in the Indian Ocean, and their morphological similarity (Wolfenden 1905; Silas and Pillai 1973), would arouse our suspicion on the proposed female-male matching. During a taxonomic study on the copepods in the coastal waters of the Indian Ocean (Fig.8), we have collected females of *P. spinipes* and males so far assumed to be *P. diagonalis* by the above authors [hereafter referred to as "male *P. diagonalis* sensu Silas and Pillai

(1973)"], often co-occurring in the same net samples, but neither females of *P. diagonalis* nor males so far assumed to be *P. spinipes*. Under this circumstance, this study aimed at obtaining clear evidence on the female-male matching of *P. spinipes* by integrative morphological- and molecular genetic analyses.

i. *Systematics*

Order : Calanoida Sars, 1903
Family : Pontellidae Dana, 1852
Genus : *Pontella* Dana, 1846
Pontella spinipes Giesbrecht, 1889

ii. *Materials examined*

A total of 150 females and 97 males of *P. spinipes* were collected of which ten females and ten males were used for genetic analysis. The other specimens were incorporated into the copepod collection of Department of Marine Biology Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology (Catalog entry numbers MBM/DBT/13/16 for female MBM/DBT/14/16 for male specimens). Of these, 15 specimens, each of females and males, were examined for the following description.

iii. *Description of the species*

Female: Total length 3.75–4.17 mm (mean: 3.97 mm, *n*=15). Body robust (Fig. 7A). Antennule of 23 segments, reaching posterior margin of last pedigerous somite (Fig. 7B). Rostrum bifurcate; upper frontal lens absent; anterior and posterior lower frontal lenses present; diameter of posterior lens 1.3 times that of the anterior lens (Fig. 7C, D). Three blue and rounded processes present mid-dorsally on first three pedigerous somites. Fourth and fifth pedigerous somites separate. Posterolateral corners of fifth pedigerous somite produced posteriorly into largely pointed lobes, of which left one larger than right and reaching near posterior margin of genital somite. Crescent-shaped lobular process present on either side between the pointed lobes of fifth pedigerous somite and insertion of urosome. Urosome two segmented;–second segment invisible in dorsal view. Genital somite bulged on its right lateral margin, extending dorso-posteriorly and completely covering second urosomal somite, with the small process on the right dorsal surface appearing as a conical projection in right lateral view. Irregular ridges and raised areas present on the dorsal surface of genital somite (Fig. 7G). Caudal rami asymmetrical, right ramus larger (Fig. 7E and F). Fifth leg asymmetrical, right leg slightly larger than left; exopod of each leg acuminate and curved with four lateral spinules; endopod about half length of exopod and bifid apically (Fig. 7H).

Male: Total length 3.31–3.73 mm (mean: 3.57 mm, *n*=15). Fourth and fifth pedigerous somites separate. Posterolateral ends of fifth pedigerous somite produced into symmetrical, acuminate lobes (Fig. 8A). Rostrum well developed with upper frontal lens and anterior and posterior lower frontal lenses (Fig. 8B, C); diameter of anterior lower frontal lens-1.4 times those of upper- and posterior lower frontal lenses. Urosome composed of five somites; genital somite asymmetrical with a lobe-like projection on the left side. Caudal rami nearly symmetrical, each with five long plumose and one small seta. Right antennule (Fig. 8D) geniculate; ancestral segment XIV with stout, elongated spine terminating in a bent tapering apex. Fused segments XIX-XX with proximally-oriented scalene-triangular ridge with an anterior row of denticles. Fused segments XXI-XXIII with the anterior process on proximal 1/3, with three stout and 2-minute teeth, of which middle one longest (Fig. 8E); distal 2/3 of anterior margin with denticulate plate; segment ends distally in the falcate spur. Segments XXIV-XXVIII completely fused. Fifth leg with one seta on each basis. Chela on right leg well developed; outer margin of the first exopodal segment with three unequal thumb-like processes basally, of which medial one longest and slightly curved and distal one with basal seta, and semicircular process at mid- to slightly distal part. Second exopodal segment slender, curved and pointed with two setae near base and seta at distal third. Left leg first exopodal segment with inner medial seta and outer distal spine; second exopodal segment with inner seta near distal third, outer seta near distal third, outer distal seta, two unequal distal spines, of which inner one 1.5 time longer than medial, and two rows of setules along inner margin (Fig. 8F).

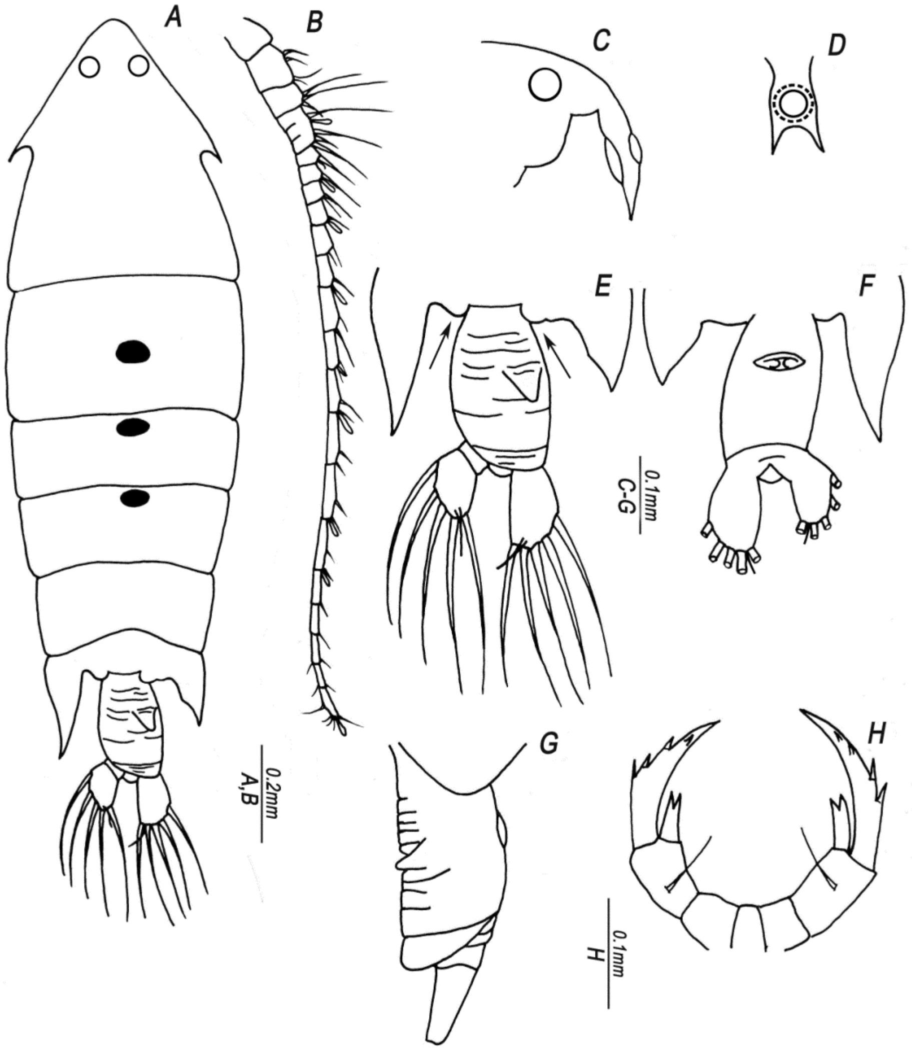

Figure 7. *Pontella spinipes*, female. (A) Habitus, dorsal view; (B) right antennule; (C) head, right lateral view; (D) rostrum, anterior view, showing anterior and posterior frontal lenses in solid and dotted lines, respectively; (E) urosome, dorsal view; (F) urosome, ventral view; (G) urosome, right lateral view; (H). 5th leg, posterior view. Arrow indicates crescent-shaped lobular process present on either side between the pointed lobes of fifth pedigerous somite and insertion of urosome.

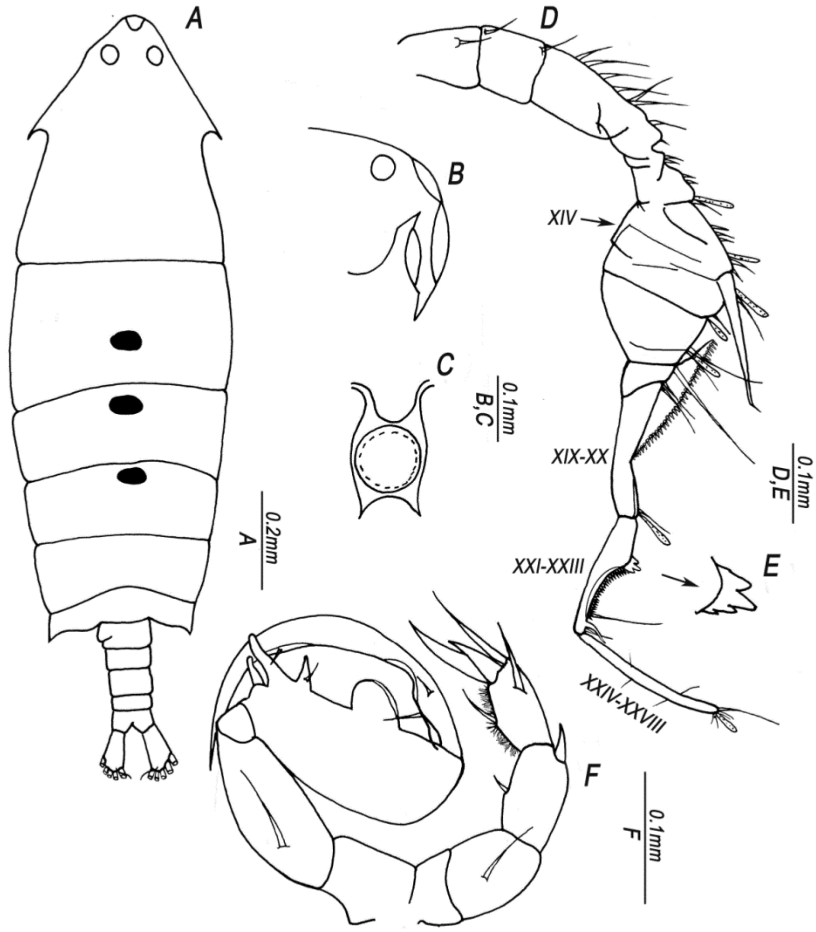

Figure 8. *Pontella spinipes*, male. (A) habitus, dorsal view; (B) head, right lateral view; (C) rostrum, anterior view, showing anterior and posterior lower frontal lenses in solid and dotted lines, respectively; (D) right antennule, number of ancestral segments indicated with Roman numerals; (E) teeth on fused segments XXI-XXIII of right antennule; (F) 5th leg, posterior view.

Remarks: The present female specimens agree with *Pontella spinipes* Giesbrecht, 1889, redescribed by Giesbrecht (1982), Wolfenden (1905), and Silas and Pillai (1973), and distinguished from the two closely similar species, *P. securifer* Brady, 1883, and *P. diagonalis* Wilson, 1950, in the following characters: (1) the left pointed lobe of the fifth pedigerous somite is much larger than the right one (the lobes are subequal in *P. diagonalis*; left one slightly larger than the right one in *P. securifer*); (2) genital somite bulged on its right lateral margin, extending dorso-posteriorly and completely covering second urosomal somite with a small process on right dorsal surface (on the lateral side of genital somite a conspicuous digitiform process is present in *P. securifer*, while a sharply pointed, curved process is present in *P. diagonalis*; see also Tanaka, 1964; Silas and Pillai, 1973; Jeong et al., 2008 for re-descriptions). There have been slight differences in the number of lateral spinules on the exopod of leg five according to these authors: 4 in Giesbrecht (1982) and the present specimens, 3–4 in Silas and Pillai (1973), and 2 in Wolfenden (1905) which may be assumed as an intraspecific variation. The female described as *P. spinipes* by Mulyadi (2011) differs from the present specimens and those described by Giesbrecht (1982) and Silas and Pillai (1973) in (1) the shape of genital somite (much more swollen laterally on the right side than the latters) and (2) the length of the endopod relative to the exopod of the fifth leg (less than 1/4 compared to about 1/2 in the latters. Note that the former length ratio is based on Fig. 6d of Mulyadi (2011) while his text (p. 1523) describes this ratio as about 1/2).

As shown in the list of synonymies, the male of *P. spinipes* had been described under the name *P. diagonalis* (Silas and Pillai 1973; Pillai 1975; Mulyadi 2000), except Wolfenden (1905) who's description of the male *P. spinipes* accords with the present specimens, although morphological details of the specimen are unknown since the author did not present any illustrations [note that the figures of male *P. diagonalis* as described by Mulyadi (2011: Fig. 3) appear to have been copied from Mulyadi (2000: Fig. 4)]. Accordingly, the males described as *P. spinipes* by Sewell (1912), Silas and Pillai (1973), Pillai (1975), and Mulyadi (2000) are considered to belong to another species and distinguished from true male *P. spinipes* (= male *P. diagonalis* sensu Silas and Pillai, 1973) by (1) differences in the shape and size of the processes on the claw of right fifth leg and (2) the size and number of teeth on the elevated process of the fused segments XXI-XXIII of the right antennule (3) conspicuous teeth in *P. spinipes*) ; note that Silas and Pillai (1973) mislabeled the right antennule of their "male *P. diagonalis*" as *P. securifer* (Silas and Pillai 1973: Fig. 22e), as evidenced from their text sentence stating presence of 3 stout subequal teeth on the 19th segment (Silas and Pillai-1973: 825) which accords with their Fig. 22e.

iv. *Molecular analysis*

The developed sequences of female *P. spinipes* and male *P. diagonalis* sensu Silas and Pillai, 1973, were submitted to the NCBI database, and assigned the following accession numbers: KT186887- KT186891 and KT267166 to KT267170 for female *P. spinipes*, KT282363 to KT282372 for male *P. diagonalis* sensu Silas and Pillai, 1973. The base pair length for the developed sequences was 639 bp for the male *P. diagonalis* sensu Silas and Pillai, 1973, and 660 bp for the female *P. spinipes*. In order to confirm the phylogenetic relationship of these specimens, an ML analysis was performed, and pairwise sequence distances were generated and analyzed using the developed sequences as well as the mtCOI sequences of their congeneric species acquired from NCBI database (Table 5). *Acartia bispinosa* Carl, 1907 was selected as an out-group. The ML tree exhibited the differential assemblage of congeneric species of the genus *Pontella* (Fig. 9).

Table 5. Details of sequences incorporated and species abbreviation used in the molecular analysis, as applied for Table 7.

Species	Abbreviation	Accession numbers	Remarks
***Pontella sinica* Chen and Zhang,1965**	PSI	KT336559	Obtained
***P. chierchiae* Giesbrecht,1889**	PC	JQ714071	Obtained
***P. fera* Dana,1849**	PF	KT186882, KT186883	Obtained
***P.diagonalis* sensu Silas & Pillai, 1973**	PD♂	KT282363 to KT282372	Developed
***P.spinipes* Giesbrecht,1889**	PS♀	KT186887 to KT186891 and KT267166 to KT267170	Developed
***P. rostraticauda* Ohtsuka, Fleminger and Onbe, 1987**	PR	AB206446	Obtained
***Acartia bispinosa* Carl,1907**	AB	KP068672	Obtained

The female *P. spinipes* and male *P. diagonalis* sensu Silas and Pillai, 1973, got arrayed within a single clade with the 100% bootstrap value which is distinct from the sequence of *P. rostraticauda* Ohtsuka, Fleminger and One,1987(AB206446). Also, *P. fera* Dana, 1849 (KT186882, KT186883) sequences got assembled next to the latter. *P. sinica* Chen and Zhang, 1965

(KT336558, KT336559) formed sister clade with *P. chierchiae* Giesbrecht, 1889 (JQ714071) next to *P. fera*. As expected, the out-group *A. bispinosa* (KP068672) exhibited a diverged array. In order to justify the results of the phylogenetic tree, genetic distance persisting within the selected individuals was analyzed. The level of intra and interspecific divergence persisting within the genus *Pontella* was evident from distance matrix data (Table 6). Specifically, the females of *P. spinipes* and the males of *P. diagonalis* sensu Silas and Pillai, 1973, exhibited 0 - 0.2% intraspecific sequence divergence while all the other selected species showed considerable genetic divergence justifying the findings of ML tree.

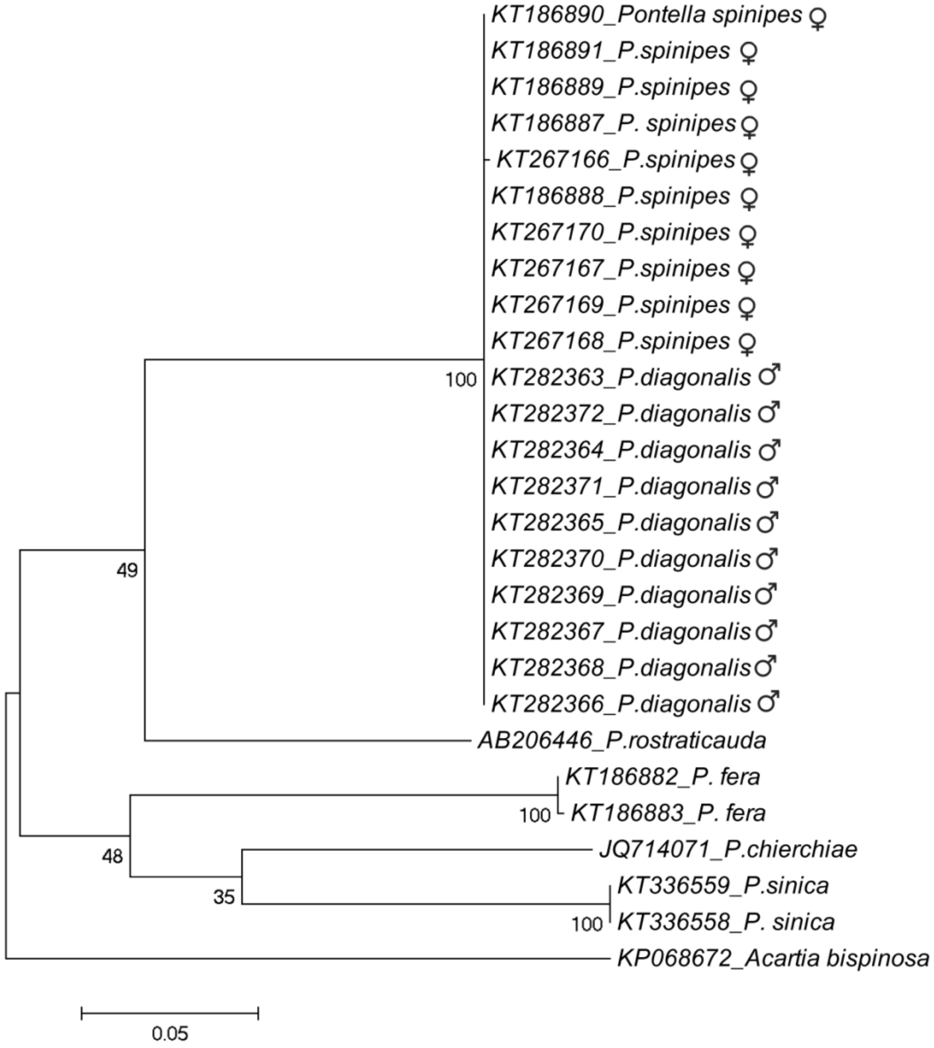

Figure 9. Maximum likelihood tree for *Pontella spinipes* and other *Pontella* species (taken from GenBank with their accession numbers) based on 1000 bootstrap pseudoreplicas.

Table 6. Distance matrix is showing inter and intraspecific percentage divergence of Pontella spinipes and other species under the genus Pontella. See Table 2 for codes for specimens and species

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	|KT336559|PSI																											
2	|KT336558|PS	0.0																										
3	|JQ714071|PC	20.0	20.0																									
4	|KT186882|PF	21.9	21.9	23.4																								
5	|KT186883|PF	22.1	22.1	23.4	0.2																							
6	|KT282367|PD♂	23.2	23.2	23.2	23.5	23.5																						
7	|KT282368|PD♂	23.2	23.2	23.2	23.5	23.5	0.0																					
8	|KT282366|PD♂	23.2	23.2	23.2	23.5	23.5	0.0	0.0																				
9	|KT282369|PD♂	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0																			
10	|KT282370|PD♂	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0																		
11	|KT282365|PD♂	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0																	
12	|KT282371|PD♂	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0																
13	|KT282364|PD♂	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0															
14	|KT282372|PD♂	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0														
15	|KT282363|PD♂	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
16	|KT267168|PS♀	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0												
17	|KT267169|PS♀	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0											
18	|KT267167|PS♀	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0										
19	|KT267170|PS♀	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0									
20	|KT267166|PS♀	23.2	23.2	23.2	23.5	23.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2								
21	|KT186888|PS♀	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2							
22	|KT186887|PS♀	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0						
23	|KT186889|PS♀	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0					
24	|KT186890|PS♀	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0				
25	|KT186891|PS♀	23.2	23.2	23.2	23.5	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0			
26	|AB206446|PR	21.8	21.8	19.0	23.8	23.8	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4		
27	|KP068672|AB	29.5	29.5	27.8	30.3	30.5	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.5	

7.4. DISCUSSION

The growing use of DNA barcodes to discriminate and identify marine animal species has included many studies on zooplankton and some studies of planktonic copepods (Bercial et al.2014). This study presents the results of a comparative analysis of 111 barcode sequences of 25 calanoid species including 85 barcode sequences of 17 calanoid copepod species not included in any previous study. The evaluation comprises Maximum Likelihood and Neighbour Joining automated tree-based and BLAST methods. In the present study, the identification of species based on morphological characteristics was clear for most of the species. The genetic sequence of the species alone does not identify species; a thorough morphological revision is an essential prerequisite to get the correct identification. Morphological identification of calanoid species coupled with the obtained COI gene and its corresponding sequences without any overlap between species. These sequences were the first time attempt and are the start of a library of barcodes of copepods in the south-west coast of India. The speciation of sequences exhibited in the likelihood analysis showed an intraspecific divergence of 0 to 0.5%. The Neighbor-joining tree of similarity using K2P distance shows the clustering of calanoid copepods. The average distance (K2P) among the species was 0.5%. Individuals in the same species got arrayed in a single clade with 100% bootstrap values and the average intraspecific divergence 0.5% within the species adequate to confirm the female-male correspondence and the genetic identity of the species from congeners and other copepods species from different families. With regard mtCOI gene sequence data, which is well accepted and under the threshold value of 4% for calanoid copepods (Bucklin et al., 2010; Sanu et al., 2016; Francis et al., 2018) and is also adequate to confirm the female-male correspondence of the species.

A criticism of metazoan barcoding is the reliance on a single gene, rather than multiple molecular markers. Results obtained from additional genes do not always yield the same results, and caution advised when using only one or few genetic markers. It is possible that there may be better regions for species assignment, and more extended sequences do provide better accuracy and reliability (Roe and Sperling 2007), but the studies by Bercial et al., 2014 proved that even very short COI fragments (<150bp) show acceptable levels of accuracy for species identification. Another criticism is that if pseudogenes were amplified; this is suspected when two or more sequences are amplified from a single specimen. However, since only a single sequence was amplified from all the samples examined, there is virtually no possibility of pseudogene amplification. Because of the relatively rapid evolution of the CO1 gene, its variation may help solve taxonomic problems associated with identification, occurrence and female-male correspondence. The molecular barcodes generated in the present study elucidate many taxonomic ambiguities related to the identification and female corresponding of the calanoid species.

7.4.1. Systematic assessment of *Labidocera madurae* A. Scott, 1909.

The genus *Labidocera* (Pontellidae) individuals exhibit proximity in morphology; there exists the potential for misidentification. A point of major confusion concerning *Labidocera madurae* A. Scott, 1909 and *Labidocera sp.* from the Hawaiian region was resolved in this study, as is evident from the molecular inference that *L. madurae* and *Labidocera sp.* individuals, were the descendants of a common ancestor and close relatives to other individuals within the genus. Attention has been focused in recent years on the importance of different species of the family Pontellidae as possible biological indicators of water masses (Fleminger 1957; Heinrich 1960; Voronina 1962; Sherman 1963). Among the species of the family, *L. madurae* was found to be abundant in the Kavaratti and Minicoy islands. The presence of this species in Minicoy Island, albeit in small numbers, was reported by Madhupratap et al. (1991). Madhupratap and Haridas (1986) proposed that the species is generally aggregated in neritic waters, and therefore dwells inside the lagoon to escape from the oceanic wilderness. Emery (1968) noted that *L. madurae*, although widely distributed, behaved like members of a reef community. A large number of species from this family have been reported in surface waters of the Indian Ocean (Pillai 1975; Silas and Pillai 1973). It has been noted that pontellid species exhibit significant intraspecific variation in complex sexually modified structures, thereby displaying different phenotypes

(Jeong et al. 2014). A thorough review of previous records of *L. madurae* revealed little information regarding its morphological and molecular taxonomy. This species may be easily mistaken for *Labidocera pavo* Giesbrecht 1889 or *L. bataviae* A. Scott 1909. The antennae, mandibles, maxillae, and maxillipeds of *L. madurae* are similar to those of *L. pavo* and *L. bataviae*. In both sexes of the species, the rostrum is similar to that of *L. bataviae*. Male urosomal segments and the left fifth leg also resemble that of *L. bataviae*. However, male *L. madurae* are easily distinguishable from *L. pavo* and *L. bataviae* by the features of the right fifth leg chela. A lateral tooth at the base of the thumb in the right fifth leg of males that is characteristic of *L. pavo* and *L. bataviae* is absent in *L. madurae*. The shape of the palm region is straight in *L. pavo*, whereas it is concave in *L. madurae* and is a raised broad central tooth in *L. bataviae* (Giesbrecht 1892; Scott 1909; Sewell 1932; Silas and Pillai 1973). Thorough scrutiny of the literature revealed a lack of molecular data for Labidocera madurae. Jungbluth and Lenz (2013) reported Labidocera individuals from Kaneohe Bay, Hawaii, exhibiting close morphological proximity to *L. madurae* according to previous references (Leis 1982; Hassett and Boehlert 1999). The authors were successful in developing mtCOI sequences for their specimens, as the absence of *L. madurae* mtCOI sequences in the public database prevented them from confirming the speciation of their specimens as *L. madurae*. They entitled the obtained mtCOI sequences *Labidocera sp*. and deposited them in the public database (accession numbers KC594129–KC594138). We selected these sequences for analysis, and our findings confirm that they are not from *L. madurae* individuals, irrespective of the fact that there will be no cryptic speciation or heteromorphy persisting within the species. The latter findings are also supported in the morphological similarity between *Labidocera sp*. and *L. madurae*, since this was evident in ML tree topology, as these sequence groups obtained neighbouring arrays. Hence it could be delineated that our developed mtCOI sequences for *L. madurae* represented the first molecular marker for the species. The genetic congruence of these sequences was evident by their assemblage within the ML tree, as they formed a major clade with 98 % bootstrap support. Further confirmation regarding the authority of these sequences in establishing the speciation of *L. madurae* is revealed in the distance matrix, which exhibited intraspecific divergence of 0.2 to 0.9 % with regard to mtCOI gene sequence data, which is well accepted and under the threshold value of 4 % for calanoid copepods (Bucklin et al. 2010). Therefore, these data provide morphological and genetic confirmation of the speciation of *L. madurae*.

7.4.2. *Pontella sewelli* Heinrich, 1987 as a junior synonym of *P. Sinica* Chen & Zhang, 1965.

The present specimens of *Pontella sinica* agree with the descriptions of *P. sinica* by Chen & Zhang (1965: female), Zheng et al. (1982: female and male) and Jeong et al. (2008: male), those of *P. princeps* by Sewell (1932: female and male) and Mulyadi (2000: male), and those of *P. sewelli* by Heinrich (1987: female and male) and Mulyadi (2011: female). This agreement concerns the morphology of the cephalosome, the fifth pediger, the abdominal somites, and the fifth legs of both sexes, and the right antennule of the male, as described above. As for the eye lenses in the female, however, there are inconsistencies among the above descriptions. Chen & Zhang (1965) and Zheng et al. (1982) mentioned "ventral lens relatively large", but no ventral lens is indicated in their figures (Chen & Zhang, 1965, pl. 45 fig. 9; Zheng et al., 1982, fig. 48b). According to Mulyadi (2011), the ventral lens is absent in the female, which agrees with the present specimen. Meanwhile, Sewell (1932) described a "well-developed rostral lens" without showing a figure, while the figures of Heinrich (1987, figs. 1-3) indicate absence of frontal and rostral lenses and the presence of a structure that seems to be a ventral lens, contrary to his text that says: "Rostral lenses of moderate size". We carefully examined the present specimen and confirmed that the frontal, rostral and ventral lenses are lacking in the female. *Pontella sinica* is easily distinguished from its congeners by the characteristic shape of the first and second abdominal somites in the female and the characteristic ornaments of the right fifth leg in the male, as described above. The present examination of related literature reconfirms the synonymy proposed by Jeong et al. (2008) who confirmed the priority of *Pontella sinica* Cheng & Zhang, 1965, over *P. sewelli* Heinrich, 1987, which was referred to as valid by Mulyadi (2011). The present description also marks the western-most record of *P. sinica*, extending its range to the eastern Indian Ocean, and provides definitive genetic evidence for the conspecific status of the previously described female and male.

7.4.3. Validation of Male *Pontella spinipes* Giesbrecht, 1889.

The analysis of mitochondrial cytochrome oxidase subunit I (mtCOI) sequences of the specimens revealed that the females of *P. spinipes* Giesbrecht, 1889, and the males of *P. diagonalis* sensu Silas and Pillai (1973) are genetically identical, providing a definitive evidence for assignment of the latter to *P. spinipes* (Sanu, Nishida & Bijoy Nandan 2018). These findings necessitate a re-examination of the female-male matching of other related species, based only on morphology, by molecular-genetic analysis as applied in the present study. The present genetic analysis demonstrates that the male *Pontella* specimens described by Silas and Pillai (1973), Pillai (1975), and Mulyadi (2000) under the name *Pontella diagonalis* belong to *Pontella spinipes* Giesbrecht 1889; the latter was described in detail by Giesbrecht (1982) based on females. A possibility of sequence mismatch between conspecific female and male due to introgression may be ruled out since the sequences' specimens were collected from multiple distinct areas of the Arabian Sea. Another possibility, that male *P. spinipes* and female *P. diagonalis* have precisely the same sequence, is also highly unlikely considering the generally accepted differences between congeneric copepod species, including those in *Pontella*, is much greater than ca.10% in COI. Accordingly, the males described as *P. spinipes* by Sewell (1912), Silas and Pillai (1973), Pillai (1975), and Mulyadi (2000) are considered to belong to another, unknown species. Proving this necessitates the molecular-genetic analysis that the present study applied, which should include *P. diagonalis* females and the females and males that have been identified as closely related to *P. securifer*.

Wolfenden (1905) noted the co-occurrence of a male (= male *P. diagonalis* sensu Silas and Pillai (1973)) and 3 *P. spinipes* females in a plankton sample. Silas and Pillai (1973) mentioned the co-occurrence of males (= male *P.diagonalis* sensu Silas and Pillai (1973)) and females of *P. spinipes* along with "*P. diagonalis*", the gender of which was not specified but may have included males that were *P.*

spinipes. In the present study we collected *Pontella fera* Dana, 1849, *P. sinica* Chen & Zhang, 1965, and *P. denticauda* A. Scott, 1909 at Stn 9 and *P. fera* at Stns 2, 12, 45, and 48, along with *P. spinipes*, many females and males of which were collected together at all stations but *P. diagonalis* did not occur at all. All these observations are consistent with the present results of female-male correspondence based on genetic information, in that female and male *P. spinipes* have been collected together on many occasions. It should also be noted that several species of *Pontella* have often been collected together in same stations and plankton-net tows (*e.g.* Brady 1883; Sewell 1912; Sherman 1964; Silas and Pillai 1973; Mulyadi 2000; this study). This would suggest the presence of mechanisms for co-existence of multiple congeneric species in relatively small areas and the two dimensional habitat in their neustonic life, either by differentiating their habitat water, as defined by various physicochemical and/or biotic factors (Sherman 1964), and/or food resources (Ohtsuka 1985), inviting further research on their microhabitats and feeding ecology.

The ability to understand the dynamics of the plankton community depends on the ability to accurately measure the diversity of species and to accurately identify individuals’ species morphologically similar. This work confirms that the molecular and morphological methods can be considered complementary and when applied in combination, constitute a powerful tool for identification with minimal errors not only of copepods in the Arabian Sea but in the adjoining marine areas; the results are the first step in building databases of sequences and update morphological identification keys.

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Chapter - 8

A NEW SPECIES OF *TORTANUS* (*ATORTUS*) (COPEPODA, CALANOIDA, TORTANIDAE) FROM MINICOY ISLAND, SOUTH EASTERN ARABIAN SEA

Contents

8.1 INTRODUCTION

The calanoid copepod genus *Tortanus* Giesbrecht 1898 (Calanoida, Tortanidae) currently comprises 47 species (Walter and Boxshall, 2018); these are mainly distributed in coastal waters of the Indo West Pacific and north-western Atlantic (Mulyadi et al., 2017). They are known to be typical carnivores feeding on copepods and other zooplankters (Uye et al*.,* 1994; Ambler and Frost, 1974; Hoof and Bollens, 2004; Nishida et al., 2015, Mulyadi et al., 2017). Five subgenera have so far been recognized in this genus: *Tortanus* (*Tortanus*) Giesbrecht 1898, *T.* (*Eutortanus*) Smirnov, 1933, *T.* (*Boreotortanus)* Ohtsuka, 1992, *T.* (*Acutanus*) Ohtsuka, 1992 and *T.* (*Atortus*) Ohtsuka, 1992. The subgenus *Atortus,* accommodating 32 nominal species (Mulyadi et al., 2017), is regarded as the most advanced and is distributed exclusively in the Indo-West Pacific region; it tends to occur in more or less oligotrophic clear high-salinity (34-40 psu) waters sometimes strongly influenced by warm currents or in coral reefs and sea grass beds (Ohtsuka and Kimoto, 1989; Ohtsuka and Reid , 1998; Ohtsuka et al., 2000; Nishida and Cho, 2005; Nishida et al., 2015, Mulyadi et al., 2017). It is also mentioned that co-occurrence of multiple closely related species of *T.* (*Atortus*) make it difficult to determine their female-male correspondence solely on the basis of morphology (Nishida et al., 2015; Mulyadi et al., 2017) and the morphological studies with the analysis of genetic markers are essential to establish the female correspondence (Francis and Nishida, 2018; Sanu et al., 2018). The present chapter describes a new species of *Tortanus* (*Atortus*) from the coral lagoon area of Minicoy Island, southeastern Arabian Sea; molecular data of the new species are also provided to determine the female-male correspondence among the specimens examined.

8.2. RESULT

8.2.1. *Systematics*

Order : Calanoida Sars, 1903
Super family : Diaptomoidea Baird, 1850
Family : Tortanidae Sars, 1902
Genus : *Tortanus* Giesbrecht & Schmeil, 1898
Tortanus* (*Atortus*) *minicoyensis sp. nov.

8.2.2. *Material examined*

Holotype: adult female, dissected parts were preserved in a small vial in 4% formaldehyde/ seawater with a drop of glycerol (ZSI- C6655/2). Allotype: adult male (ZSI-C6656/2). Paratypes: 5 females ZSI-C6657; 1 dissected, 4 intact males ZSI-C6658/2. Fifteen intact females (MBM/DBT/10/15) and 15 intact males (MBM/DBT/09/15) preserved in a vial were deposited as non-type materials.

8.2.3. Key to the species of subgenus *Atortus* from the Indian Ocean:

Adult females

1. Genital compound somite asymmetrical..2
2. Genital compound somite right anterolateral margin slightly swollen................ *T. andamanensis*
3. Caudal rami slightly asymmetrical with left ramus stouter and shorter than the right one.. *T. insularis*
4. Genital compound somite with a bulge on the left or right side...5
- Genital compound somite strongly asymmetrical, with the pointed process on the right ventrolateral side..*T. magnonyx*
5. Genital compound somite expanded anterolaterally on both sides ending in small papilla with apical spinule, right expansion strongly convex to straight laterally.................... ....*T. recticauda*
6. Genital compound somite with a small bulge on the left side, caudal rami asymmetrical with left ramus stouter and right ramus slightly curved, fifth leg with spine at distal end.. ... *T. tropicus*
- Genital compound somite with a prominent bulge on the right side with two dorsoventral spines, caudal rami asymmetrical with left ramus slightly larger and

right ramus not curved, fifth legs without spines at distal end………………………………………………………………………….... *T. minicoyensis* sp. nov.

Adult males.

1. Left leg 5 subdistal seta strongly curved along hemispherical tip with the granular surface, and right coxa of leg5 truncate with a uncinated corner, basis bearing medial bilobed process near mid-length………………………………………………………………………………………… *T. recticauda*

2. Left leg 5 with subdistal spiniform terminal seta, and right leg coxa produced into the rectangular process, basis bearing rounded, flattened process located at inner distal corner……………………………………………………………………….. ..*T. nishidai*

3. Right leg 5 coxa without any process……………………………………………………….. 4

\- Basis bearing small rounded process….. *T. tropicus*

4. Left leg 5 subdistal seta serrated along inner margin, and right leg 5 basis tapering proximally with triangular process…………………………………… *T. magnonyx*

5. Left leg 5 terminal portion of second exopodal segment acutely pointed at tip, with serrated subdistal seta, and right leg 5 coxa bearing three acutely pointed prominences of unequal size, basis bearing large bilobed process at mid-length…………………… ……………………………………………………………………...*T. insularis*

6. Left leg 5 with subdistal blunt seta, and right leg 5 coxa semi-spherical with semi-spherical medial process, basis semi-circular with the medial process being ocarina-shaped with depression on distomedial margin and with small rounded process at distal side of its base……………………………………….... *T. andamanensis*

7. Left leg 5 with subdistal short seta, and right leg 5 coxa semi-circular with small bilobed medial process, basis semi-circular with finger-like medial process… ……………………………………………………………………………………………….*T. sigmoides*

8. Left leg 5 subdistal seta strongly curved along hemispherical tip with the granular surface, and right leg 5 coxa semi trapezoid with a beak-shaped medial process, basis semi-circular and bearing triangular medial process …………………… …………………………………………………………………………….....*T. minicoyensis* sp.nov.

8.2.4. *Description of the species*

Female: Prosome (Fig. 1A) about 3.5 times as long as urosome. Cephalosome and first pedigerous somite separate; fourth and fifth somite fused.

Fifth somite asymmetrical: left margin with a notch, right margin with the single downward directed triangular lobe. Urosome of 2 somites. Genital compound somite slightly asymmetrical; right margin with a prominent bulge at about midpoint (Fig. 1C) with 2 ventrolateral spines (Fig.1D). Second urosomite (anal somite) completely fused with caudal rami. Caudal rami asymmetrical, with two rounded processes. Left ramus slightly larger than right ramus (Fig. 1A, C). All specimens have hyaline coupling device with left process larger than the right one, covering the dorsolateral process of fifth pedigerous somite and left lateral surface of genital compound somite (Fig. 1 A, C, D). Antennule symmetrical (Fig. 1B), reaching posterior margin of caudal ramus; ancestral segments I-IX, XI-XIV, XXVI-XXVIII totally or partially fused. Armatures 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. 2A) coxa unarmed; basis and first endopodal segment completely fused with short medial seta at proximal third, distomedial short seta and distolateral row of spinules, second and distal segments incompletely fused, distal segment with proximolateral setules and 6 apical setae; exopod 3-segmented, proximal segment short, unarmed, middle and distal segment incompletely fused with 3 and 2 setae, respectively. Mandible blade (Fig. 2C) with 5 cuspidate teeth, main tooth and second ventral-most tooth separated by wide diastema; both teeth with articulated tip; dorsal-most tooth monocuspidate while remaining 2 teeth bicuspidate, 4 dorsal-most teeth with 4 longitudinal spinule rows proximally; mandibular palp basis elongate and unarmed;(Fig. 2B) palp biramous, basis elongate, cylindrical; endopod 2-segmented, proximal segment unarmed, distal segment with 6 setae. Exopod 1-segmented, with 5 setae (Fig. 2B). Maxillule (Fig. 2D) precoxal arthrite with 12 spinulose setae and 1-minute seta; coxal endite with 3 stout, spinulose terminal setae. Maxilla (Fig. 2E) 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. 2F) syncoxa with two endites, each with spinulose seta; basis unarmed; endopod with 3 medial spinulose setae and lateral seta. Legs 1-4 with 2-segmented endopods and 3-segmented exopods

(Fig. 3 A-D). Distal endopod segment of legs 1-4 with hair tuft on subdistal, anterior. Seta and spine formula as in Table 1. Outer setae on leg1 basis minute. Leg 5 uniramous (Fig. 2G), 2-segmented, symmetrical with coxa and intercoxal sclerite fused as a basal plate; exopodal lobe trapezoid with distolateral seta bearing fine hairs along its margin.

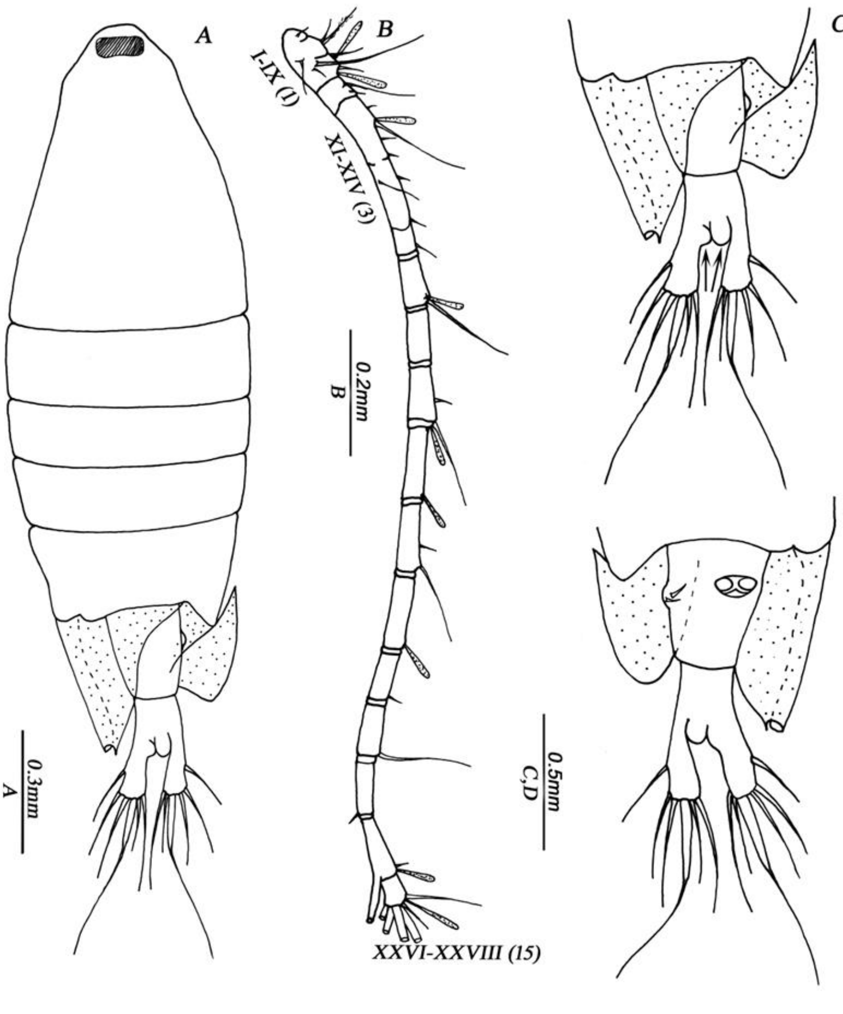

Figure 1. *Tortanus (Atortus) minicoyensis* sp. nov., female (holotype) A, habitus , dorsal view; B, antennule; C, urosome dorsal view; D, urosome ventral view, coupling device is dotted in A, C, D. Arrows indicate two rounded process on the caudal rami.

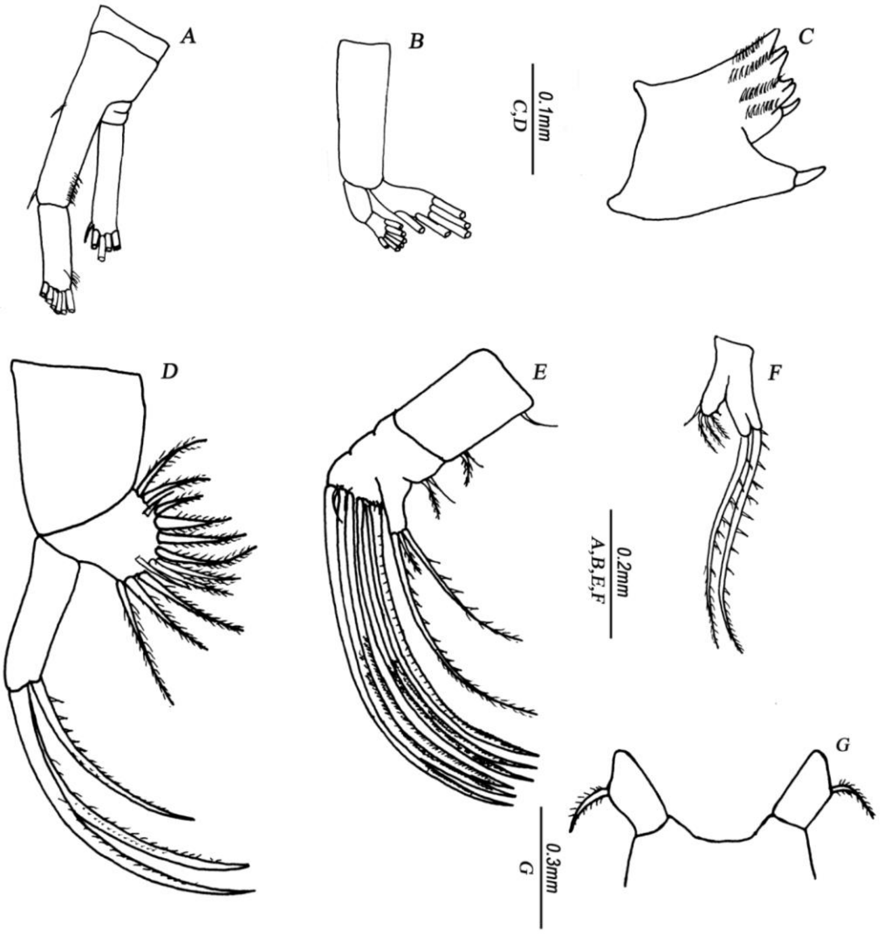

Figure 2. *Tortanus (Atortus) minicoyensis* sp. nov., female (holotype) **A,** antenna; **B,** mandible palp; **C,** mandible gnathobase; **D,** Maxillule; **E,** maxilla; **F,** maxillipede; **G,** leg 5.

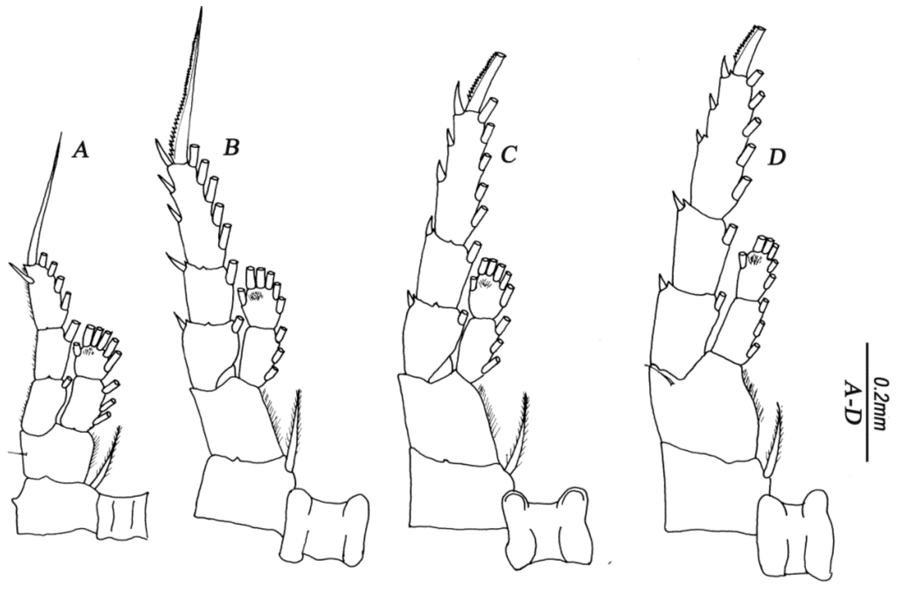

Figure 3. Tortanus (Atortus) minicoyensis sp.nov. female (holotype), leg 1-4, anterior view. A, leg1; B, leg2; C, leg3; D, leg4.

Table 1. Seta (in Arabic numerals) and spine formula (in Roman numerals) of legs 1-4 of female *Tortanus minicoyensis* sp. nov.

	Coxa	Basis	Exopod segment 1;2;3	Endopod segment 1;2
Leg1	0-1	1-0	0-1;0-1;I,I,4	0-3;1,2,3
Leg2	0-1	0-0	I-1;I-1;III,I,5	0-3;1,2,3
Leg3	0-1	0-0	I-1;I-1;III,I,5	0-3;1,2,3
Leg4	0-1	1-0	I-1;I-1;III,I,5	0-3;1,2,3

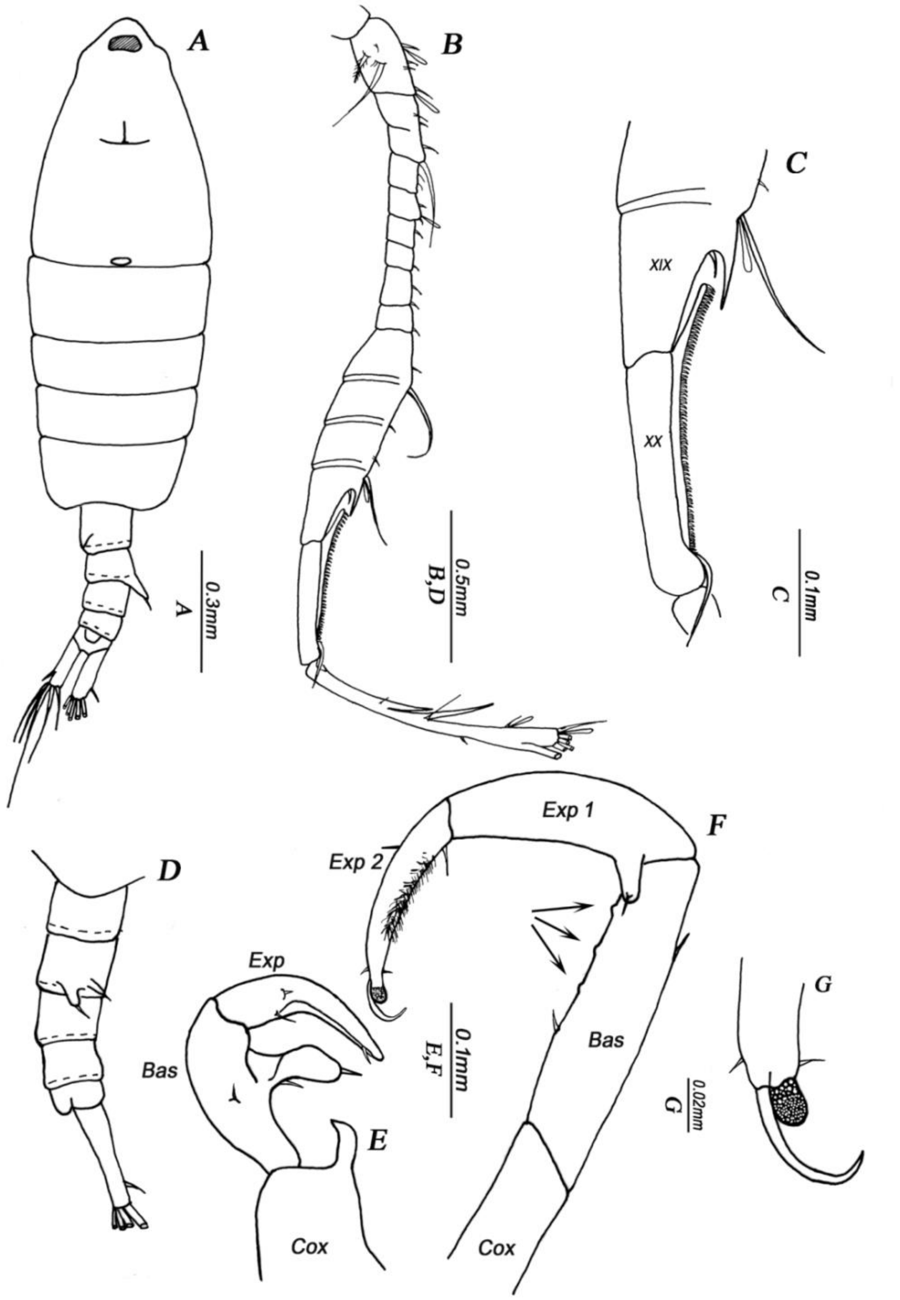

Figure 4. *Tortanus (Atortus) minicoyensis* sp. nov., male (allotype). **A,** habitus, dorsal view; **B**, **C,** antennule; **D,** urosome right lateral view; **E,** right leg 5 posterior view; **F,** left leg 5 posterior view; **G,** second exopodal segment of left leg 5.

Male: Prosome about 3 times as long as urosome (Fig. 4A). Posterior corners of pedigerous somite 5 symmetrical, rounded. Urosome of 5-somites. Second urosomite with posterolateral and posteroventral processes on the right side (Fig. 4D), of which latter smaller, each with minute seta on the tip. Caudal rami nearly symmetrical.

Cephalic appendages are similar to those of female except right antennule. Right antennule geniculate (Fig. 4B); ancestral segment 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. The anterior surface of segment XX furnished with a serrated ridge which retroflexed near base of segment XX and extending to the triangular process of segment XIX (Fig. 4B, C). Hinge joint formed between segment XX and fused segments XXI-XXIII. The distal end of the segment with a long spinous process extending the half-length of the fused segments XXIV-XXVIII. Legs 1-4 as in female. Right leg 5 coxa semi trapezoid (Fig. 4E) with the beak-like medial process; basis semi-circular with seta on posterior surface and digitiform medial process bearing 2 setae, one distal and the other basal (Fig. 4E). Exopod 1-segmented, slightly curved inwards, tapering distally into the narrow tip, bearing 1minute seta on mid-anterior and Left leg 5 longer than the right (Fig. 4F). Coxa without seta. Basis elongate, straight, with 3 low, rounded processes at regular intervals and lateral seta at distal third and medial seta halfway along the inner margin of the segment. Exopod 2-segmented, the proximal segment with proximomedial, digitiform process bearing subdistal seta, the distal segment with patches of setules on the anterior surface, 2 lateral minute setae, two medial setae, and blunt subdistal seta strongly curved along the hemispherical tip of the segment with the granular surface (Fig. 4G).

Etymology

The specific name minicoyensis refers to the name of the type locality of this species. It, therefore, is a toponymic term, agreeing in gender with the (masculine) generic name.

Table 2. Differential diagnosis of the female *T. minicoyensis* sp. nov. from all the other species of the *tropicus* group.

Species	5th pedigerous somite	Coupling device	Caudal rami
***T. minicoyensis* sp. nov.**	Left margin with a notch and right margin with a single downward directed triangular lobe (Fig. 2 A, C, D).	Left process larger than right covering the dorsolateral process of fifth pedigerous somite and lateral surface of genital compound somite (Fig. 2 C, D).	With two medial rounded processes, left ramus slightly larger than right (Fig. 2 C, D).
T. bowmani	Slightly asymmetrical with posterior extensions of both sides subequel (Othman 1987 Fig.4 A).	Left process larger and right process extending posteriorly reaching beyond furcal rami (Othman 1987 Fig.4 A, C).	Symmetrical with inner margin of right ramus having a slight indent (Othman 1987 Fig.4 A).
T. digitalis	Asymmetrical, right side with irregular ventrolateral process, left with irregularly produced ventrolateral lobe. (Ohtsuka and Kimoto 1989 Fig.5 A, C, D, E and F).	Not described (Ohtsuka and Kimoto 1989 Fig.5 A, B).	Asymmetrical (Ohtsuka and Kimoto 1989 Fig.5 A, B).
T. giesbrechti	Asymmetrical, in dorsal view, has four posterior lobes: the left one is longest, the median one is rounded and same length to right lobe, a short acute lobe between the right and median lobes (Jones and Park 1968 Figs.1,2,4,5)	Right process extends more towards the back and left process more extends towards the dorsal (Jones and Park 1968 Figs 4,5)	Nearly symmetrical and bent to the left in dorsal view (Jones and Park,1968 Fig.4)

T. longipes	Asymmetrical with left posterior process more produced than the right (Tanaka 1965 Fig.250 a, c).	Slightly asymmetrical (Tanaka 1965 Fig.250 a).	Asymmetrical, left ramus slightly broader (Tanaka 1965 Fig.250 a).
T.rubidus	Asymmetrical with left posterior process more produced than the right (Ohtsuka and Kimoto 1989 Fig.7 A, C).	Not described (Ohtsuka and Kimoto 1989 Fig.7 A, B).	Asymmetrical with left ramus one rounded process (Ohtsuka and Kimoto 1989 Fig.7 A, C).
T.ryukyuensis	Nearly symmetrical (Ohtsuka and Kimoto 1989 Fig.2 A, C).	The left process is larger extending beyond caudal rami (Ohtsuka and Kimoto 1989 Fig.2 A, C).	Nearly symmetrical (Ohtsuka and Kimoto 1989 Fig.2C).
T.taiwanicus	Slightly asymmetrical with posterior extensions of both sides subequal (Chen and Hwang 1999 Fig. 1 A).	Not described (Chen and Hwang 1999 Fig.1 A, B).	Nearly symmetrical (Chen and Hwang 1999 Fig. 1 A).
T.tropicus	Nearly symmetrical, the right side being produced backwards in a wing-like process (Sewell 1932 Fig.131 a).	Not described (Sewell 1932 Fig.131 a).	Asymmetrical with distinctly stouter left ramus at its base than that of right (Sewell 1932 Fig.131 a).
T.vietnamicus	The right process produced more posteriorly than the left (Nishida and Cho 2005 Fig.1 A, C).	Left process larger and its posterior margin extending beyond posterior end of caudal rami (Nishida and Cho 2005 Fig.1 C).	Asymmetrical with a slightly concave process on an anteromedial region of right ramus (Nishida and Cho 2005 Fig. 1A)
T.andamanensis	The right process produced more posteriorly than the left	Right process larger, covering the dorsolateral process of the fifth pediger and right lateral surface of genital compound somite	Symmetrical with left ramus slightly produced medially while the right ramus concave (Nishida,

	(Nishida, Anandavelu and Padmavati 2015 Fig.1 A).	(Nishida, Anandavelu and Padmavati 2015 Fig.1 A, B.)	Anandavelu and Padmavati 2015 Fig1 A, D).

Table 3. Differential diagnosis of the male *T.minicoyensis* sp.nov. from all the other species of the *tropicus* group.

Species	Serrated ridge of the right antennule	Right leg 5 coxa	Right leg 5 basis	Left leg 5 subdistal seta
***T. minicoyensis* sp.nov.**	Produced proximally over one-third of segment XIX and the ridge slightly raised from the surface plane of the segment (Fig 5 B, C).	Semi trapezoid with a beak-shaped medial process (Fig.5E).	Bearing triangular shaped medial process with depression on distomedial margin and fused at the distal side of its base (Fig 5E).	Strongly curved along hemispherical tip with the granular surface (Fig 5 F, G).
T. bowmani	Close to the base or attached (Othman 1987Fig.5 E).	Bearing rounded and upward directed projection (Othman 1987 Fig.5 F).	Large rectangular projection (Othman, 1987 Fig.5 F).	Rounded process ending in an inward curving terminal seta (Othman, 1987 Fig.5 F).
T. digitalis	Produced over one third of segment XIX but in different shape (Ohtsuka and Kimoto 1989, Fig.6 E).	Blunt inner sub terminal papilla (Ohtsuka and Kimoto 1989 Fig.6 F, G).	Large inner middle projection (Ohtsuka and Kimoto 1989 Fig.6 F, G).	Long, not strongly curved (Ohtsuka and Kimoto 1989 Fig.6 F, G).
T. giesbrechti	Slightly curved upwards (Johns and Park 1968 Fig.21).	Swollen and without a process (Johns and Park 1968 Fig.22).	Finger-like projection (Johns and Park, 1968 Fig.22).	Short subdistal seta (Johns and Park 1968 Fig.22).

T. longipes	Produced about two third the length of the segment XIX and curved at tip (Tanaka 1965 Fig. 250j).	Without any process (Tanaka 1965 Fig. 250 k).	Short process (Tanaka 1965 Fig.250 k).	Short subdistal seta (Tanaka 1965 Fig. 250 k).
T. rubidus	Raised from the surface plane of the segment XIX and slightly curved upwards (Ohtsuka and Kimoto 1989 Fig 9 F).	Large sub terminal process on inner distal margin (Tanaka 1965 Fig.251 e, Ohtsuka and Kimoto 1989 Fig.8 B, Fig 9 G)	Bearing bilobed lamellate projection (Ohtsuka and Kimoto, 1989 Fig.8B, Fig.9G).	Long subdistal seta (Tanaka 1965 Fig.251 e, Ohtsuka and Kimoto 1989 Fig 8 B, Fig9 G).
T. ryukyuensis	Produced proximally to mid-length of segment XIX and close to the base (Ohtsuka and Kimoto 1989 Fig.4F).	Without any process (Ohtsuka and Kimoto 1989 Fig.4 G, I).	Large rectangular projection (Ohtsuka and Kimoto 1989 Fig.4 G, I).	Short subdistal seta (Ohtsuka and Kimoto 1989 Fig.4 G, H).
T. taiwanicus	Produced proximally to the mid-length of the segment XIX (Chen and Hwang 1999 Fig. 2 G, H).	Bearing blunt inner sub terminal papilla (Chen and Hwang 1999 Fig.2 K).	Large leaf-like projection on inner middle margin (Chen and Hwang 1999 Fig.2 K).	Subdistal seta curved inwards (Chen and Hwang 1999 Fig. 2 K)
T. tropicus	Produced completely over the segment XIX (Sewell 1932 Fig. 131 f).	Without any process (Sewell 1932 Fig.131 g).	Small rounded process (Swell 1932 Fig 131 g).	Not clear in the description (Sewell 1932, Fig. 131g)
T. vietnamicus	Retroflexed near base of segment XX and extending to triangular	Semi trapezoid with rectangular process	Triangular and expanded laterally with rectangular process	Blunt subdistal seta curved along hemispherical tip of the segment bearing granular

	process of segment XIX (Nishida and Cho 2005 Fig.3 D, E).	bearing 4 minute process (Nishida and Cho 2005 Fig.3 F).	(Nishida and Cho 2005 Fig.3F).	process(Nishida and Cho 2005 Fig.3G).
T.andamanensis	Produced proximally over one-third of segment XIX (Nishida, Anandavelu and Padmavati 2015 Fig.4 D)	Semi trapezoid with semi-spherical medial process (Nishida, Anandavelu and Padmavati 2015 Fig.4 F,G)	semi-circular and ocarina-shaped medial process with depression on distomedial margin and with small rounded process at distal side of its base (Nishida, Anandavelu and Padmavati 2015 Fig.4F,G)	blunt distal seta (Nishida, Anandavelu and Padmavati 2015 Fig.4 F, H)
T. sigmoides	Sigmoid shape and produced proximally to middle of segment XIX (Nishida Anandavelu and Padmavati 2015 Fig.5 D).	Semi-circular with small bilobed medial process (Nishida, Anandavelu and Padmavati 2015 Fig.5 F,G).	Semi-circular with finger like medial process (Nishida, Anandavelu and Padmavati 2015 Fig 5F, G).	Short subdistal seta (Nishida, Anandavelu and Padmavati 2015, Fig.5 F, H).

8.2.5. Molecular *analysis*

The mtCOI sequences were successfully generated using the primer pair, reaction mix, and the thermal regime described above. The developed sequences of female and male *T. minicoyensis* sp. nov. were submitted to the NCBI database and assigned the following accession numbers: KP749951 to KP749953 for males and KP749954 and KP749955 for females. ML analysis was performed, and pairwise sequence distances were generated and analysed using the developed sequences as well as the mtCOI sequences of their nine congeneric species acquired from NCBI database (Table 4).

Pseudodiaptomus serricaudatus T. Scott, 1894 (KP739843) was selected as the out-group. The ML tree exhibited the differential assemblage of congeneric species of the genus *Tortanus* (Fig. 5). Female and male *T.minicoyensis* sp.nov. sequences got arrayed within a single clade with high bootstrap value (100%); which is distinct from the sequence all other sequences of subgenus *Atortus* based on 1000 bootstrap pseudoreplicas (Fig. 5).

Table 4. Details of sequences incorporated and species abbreviation used in the molecular analysis, as applied for Table 5.

Species	Abbreviation	Accession No.	Remarks
Tortanus (Atortus) minicoyensis sp.nov. ♂	TM♂	KP749951 - KP749953	Developed
Tortanus (Atortus) minicoyensis sp.nov. ♀	TM♀	KP749954 , KP749955	Developed
T.(Boreotortanus) discaudatus	TD	AF513648	Obtained
T. (Atortus) erabuensis	TE	AF474113	Obtained
T.(Tortanus) forcipatus	TF	AF513649, AY145431	Obtained
T.(Atortus) ryukyuensis	TR	AF474114	Obtained
T.(Atortus) insularis	TI	KC287905, KC287906	Obtained
T.Eutortanus) derjugini	TDE	AF513647, AF474112	Obtained
T.(Eutortanus) dextrilobatus	TDX	AY145430	Obtained
T.(Eutortanus) komachi	TK	JN605792	Obtained
T. (Eutortanus) vermiculus	TV	JN605791	Obtained
Pseudodiaptomus serricaudatus	PS	KX100481	Obtained

The outgroup *P. serricaudatus* exhibited maximum diverge array. The level of inter and intraspecific divergence persisting within the genus *Tortanus* was evident from the distance matrix data. Specifically, *T.minicoyensis* sp. nov. possessed an intraspecific sequence divergence ranging from 0 - 0.5% (Table 5).

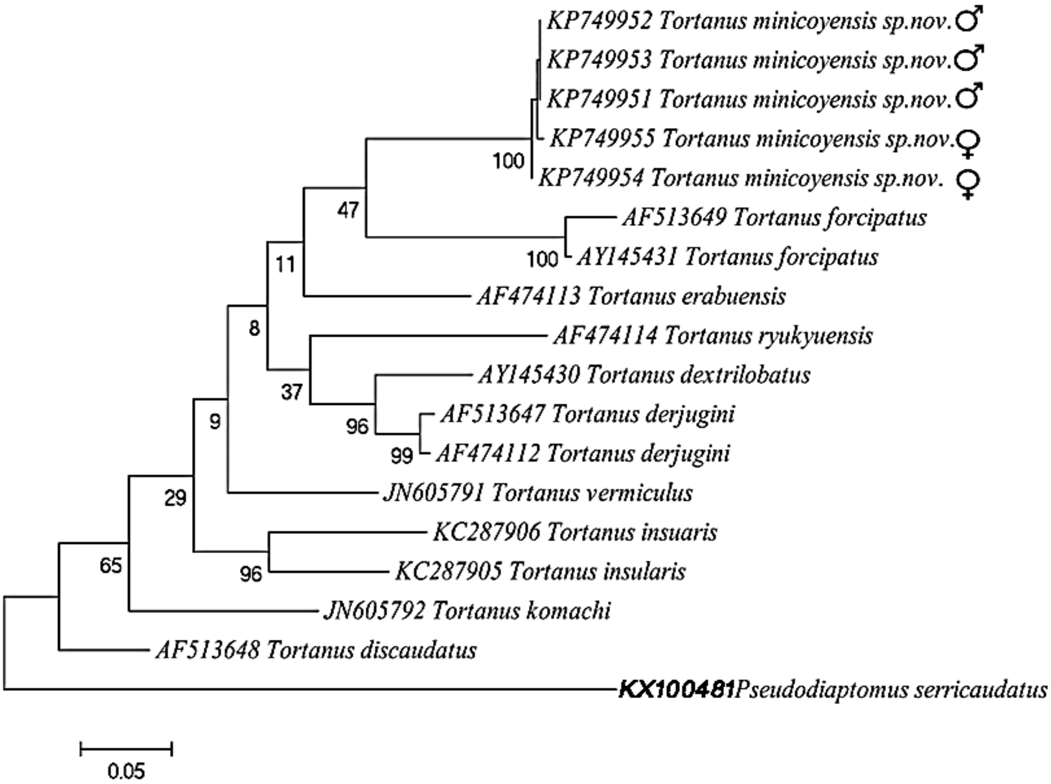

Figure 5. Maximum likelihood tree for the species *Tortanus (Atortus) minicoyensis* sp.nov. and other species under the genus *Tortanus* (taken from GenBank with their accession numbers) based on 1000 bootstrap pseudoreplicas.

Table 5. Distance matrix showing inter and intraspecific percentage divergence of *Tortanus minicoyensis* sp. nov. and other species under the subgenus *Atortus.* See Table 4 for codes for specimens and species.

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	KP749952 TM♂																		
2	KP749953 TM♂	0																	
3	KP749951 TM♂	0	0																
4	KP749954 TM♀	0.5	0.5	0.5															
5	KP749955 TM♀	0.5	0.5	0.5	0.5														
6	AF513648 TD	24.6	24.6	24.6	24..2	242													
7	AF474113 TE	20.5	20.5	20.5	20.5	20.2	17.4												
8	AF513649 TF	23.9	23.9	23.9	23.9	23.6	22	21.5											
9	AY145431 TF	20.9	20.9	20.9	20.9	20.6	20.1	19.2	3.8										
10	AF474114 TR	24	24	24	24	24	26.4	22	25.7	24.7									
11	KC287906 TI	24.9	24.9	24.9	25.2	24.9	20	21.7	27.3	24.9	24.7								
12	KC287905 TI	23.6	23.6	23.6	23.6	23.6	19.4	22.6	24.3	22.7	24.6	17.6							
13	AF513647 TDE	19.6	19.6	19.6	18.9	18.9	20.4	17.1	24.4	22	19	21.1	23.3						
14	AF474112 TDE	20.5	20.5	20.5	20.5	20.5	20.1	17.1	25.1	23.1	19.3	20.4	22.6	1.5					
15	AY145430 TDX	22.5	22.5	22.5	22.5	22.5	19.4	21.3	24.7	23.1	21	21.4	21.2	9.3	9.3				
16	JN605792 TK	21.9	21.9	21.9	21.9	21.5	18.7	21.3	25.8	25.2	26.3	23.4	22.2	19.8	20.1	19.7			
17	JN605791 TV	19.9	19.9	19.9	20.6	20.6	18.4	18.6	24	22	22.6	19.4	20.3	15.8	15.2	18.7	20.6		
18	KX100481 PS	49.8	49.8	49.8	49.3	49.3	42	51.2	52.4	50.4	51.8	54.2	52.7	47	46.1	49	51.6	47.4	

8.3. DISCUSSION

The subgenus *Atortus* has been classified into two morphological groups; the first one is the *tropicus* group sensu Othman, 1987 and the second is the *murrayi* group sensu Othman, 1987 (Ohtsuka and Kimoto, 1989; Mulyadi *et al.* 2017). From the structure of female leg 5, male antennule and leg5, *Tortanus (A.) minicoyensis* sp. nov. is assigned to the *tropicus* species complex within the subgenus *Atortus* Ohtsuka, 1992. The species complex is defined by the combination of the following characters (1) second male urosomite with a process on the right side, (2) anterior end of the serrated margin of the ancestral segment XX of the male right antennule produced proximally over segment XIX, and (3) distal segment of leg 5 of the female either slender and asymmetrical or subquadrate (Bowman 1971). The female of *T. minicoyensis* sp. nov. can be distinguished from all the other species of the *tropicus* group (*T. bowmani* Othman, 1987, *T. digitalis* Ohtsuka & Kimoto 1989 , *T. giesbrechti* Johns & Park 1968, *T. longipes* Brodsky, 1948*, T. rubidus* Tanaka, 1965*, T. ryukyuensis* Ohtsuka & Kimoto 1989*, T. taiwanicus* Chen & Hwang 1999*, T. tropicus* Sewell, 1932*, T. vietnamicus* Nishida & Cho, 2005*, T. andamanensis* and *T.sigmoides* Nishida, Anandavelu & Padmavati, 2015) by the shape and proportions of (1) posterior dorsolateral processes of fifth pedigerous somite,(2) coupling device, and (3) caudal rami (Table 2). The male is distinguished from all the other species of *tropicus* group by the characteristic shape and proportions of (1) serrated ridge of segment XX of the right antennule and (2) strongly curved subdistal seta in the left fifth leg and processes on the coxa and basis of the right fifth leg (Table 3).

The genus *Tortanus* Giesbrecht 1898 comprises five distinct subgenera. Each subgenus has its restricted distribution (Ohtsuka and Reid 1998). The Indo-pacific genus *Tortanus* inhabits tropical-temperate eutrophic waters, whereas the subgenus *Atortus* is mainly distributed in tropical/ subtropical oligotrophic waters. *Tortanus (Atortus) andamanensis* and *T. sigmoides* Nishida, Anandavelu & Padmavati, 2015; *T. insularis* Ohtsuka & Conway, 2005; *T. magnonyx* Ohtsuka & Conway, 2005; *T. nishidai* Ohtsuka, El Sherbiny & Ueda, 2000; *T. recticauda* Giesbrecht,1889; *T. tropicus* Sewell, 1932 were the species of the subgenus

Atortus hitherto known from the Indian Ocean (Razouls et al. 2005-2018). Among them, *T. tropicus* was largest (female 2.71mm; male 2.29mm) (Sewell 1932). However, the new species herein described has the highest length range known in the genus (female 2.66-2.94 and male 2.25-2.74mm). *T. minicoyensis* was found to swarm along with *Acartia bispinosa* Carl, 1907, *Labidocera madurae* A. Scott, 1909*, Undinula vulgaris* Dana, 1849*,* and *Centropages orsinii* Giesbrecht, 1889 were also found along with the collection. The swarming behaviour of members of the subgenus *Atortus* were observed in oligotrophic clear waters mainly in subtropical and tropical areas (Kimoto et al. 1988; Ohtsuka and Kimoto 1989; Ohtsuka and Reid 1998; Ohtsuka et al. 2000) as a response to the presence of prey copepod and also to avoid visual predators (Ohtsuka et al. 2000). *T. minicoyensis* sp. nov. was found to occur in highly saline oligotrophic coral lagoon of Minicoy Island, South West coast of India. In the present study, COI sequences were developed for *T.minicoyensis* sp.nov. to bring out the molecular variance from the congeners and established the female-male correspondence of the species. The speciation of *T. minicoyensis* sp.nov. is exhibited in the genetic distance matrix, which showed an intraspecific divergence of 0 to 0.5%, which is under the threshold value of 4% for calanoid copepods (Sanu et al. 2016). The mtCOI sequences developed in this study should be useful to identify and resolve the ambiguity with the closest congeners.

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Chapter - 9

SUMMARY AND CONCLUSION

Zooplankton forms an essential component of the pelagic food web in the ocean system. Calanoid copepods are the dominant groups in marine subtropical and tropical waters and exhibit great diversity in morphology and habitats they occupy. Most studies in the Arabian Sea have elaborated on the ecology and diversity of calanoids; however, there is a severe shortage of information on the morpho-taxonomy and molecular status of copepods which is a prerequisite for understanding the community ecology of the species and their role in the food web structure. Pioneering studies for the last three decades, interesting taxonomic information from the Arabian Sea have been documented during International Indian Ocean Expedition IIOE; 1962-65 and only a few notable works. However, Lakshadweep islands are notable hotspots of marine biodiversity occupying a significant part of the Arabian Sea that has been least investigated on the copepod ecology and their community structure. This PhD thesis is the partial outcome of the Dept. of Biotechnology, Govt. of India funded project (2013-2016) on the ecology, taxonomy and systematics of pelagic copepods from the oceanic and lagoon waters of Lakshadweep and coastal waters of the south-west coast of India based on a spatial and temporal scale.

Seasonal changes in the climate in the marine environment play an important role in the ecological cycle in the Arabian Sea. The biological productivity of the seas in this region is dependent on the complex physical, chemical and biological process active in the medium and subsequently transferred to different trophic levels. The water temperature and salinity inside the lagoon were higher throughout the study period. The highest surface water temperature of 30°C was observed in Agatti and Kavaratti, and highest salinity of 36 psu was observed during winter monsoon 2014 in Kalpeni. The salinity values did not vary much in the lagoon stations. In the oceanic stations around the Minicoy Island during spring intermonsoon 2015, the average surface water temperature observed was 30.53 ± 0.19^{o}C and the salinity was 33.9 ± 0.39 psu.

During the same period, temperature ranges from 30.22 to 31.09°C and salinity 34.26 to 35.37psu in the coastal stations of the Arabian Sea. During fall intermonsoon, SST was less compared to spring intermonsoon (29.61 to 29.82 °C). Surface salinity was comparatively slightly higher than spring intermonsoon (34.81 to 36.38psu) and increases towards to the northern latitudes as observed during spring intermonsoon 2015.

The lagoon ecosystems are net autotrophic and release oxygen into the water column; dissolved oxygen is usually high. The dissolved oxygen in the surface waters was highest observed during fall intermonsoon 2013 inside the Kavaratti atoll (6.09±0.17 ml/L). The lowest value was observed in Agatti lagoon during spring intermonsoon 2016 (3.32±0.1 ml/L). In the oceanic stations around the Minicoy Island; the average dissolved oxygen value was 4.19±0.54 ml/L which comparatively lower than the lagoon stations of Minicoy. During spring intermonsoon 2015, the average DO observe along the coastal stations were 4.21±0.64ml/L and which is lower (3.83±0.04 ml/L) during fall intermonsoon. During the study, the chlorophyll-a distribution inside the lagoon ranged from 0.14 (Kavaratti, spring intermonsoon 2016) to 0.68±0.01 mg/m^3 (Kalpeni, fall intermonsoon 2013). The average Chlorophyll-a concentrations during fall intermonsoon were lower when compared to spring intermonsoon (0.21±0.02mg/m^3). In both the seasons, the concentration of Chlorophyll-a progressively increases towards northern latitudes.

The zooplankton density of different islands ranged from 6 to 56 ind./m^3 during various seasons. Zooplankton density in Agatti atoll ranged from 37 to 56 ind./m^3 and biomass ranged from 0.02 to 0.04ml/m^3. The copepod density ranged from 10 to 17 ind. /m^3 during winter monsoon 2015 and 18 to 28 ind./m^3 during spring intermonsoon 2016. A comparison of the present observations with the earlier studies in the Agatti lagoon, *Undinula vulgaris*, *Paraeucalanus attenuates, Centropages furcatus, Temora discaudata, Temora turbinate, Acartia negligens* and *Pontellina plumata* were observed in the present and previous studies. The calanoid species *Acartia fossae* found in the present study is the first report of the species from lagoon waters of Lakshadweep. Zooplankton density in lagoon waters of Bangaram ranged from 37 to 52 ind./m^{3,} and the biomass ranged from

0.06 to 0.09 ml/m^3. Eight species of calanoid copepods were identified from Bangaram and the species *Undinula vulgaris* is the significant share to the total calanoid copepods. In lagoon waters of Kalpeni, zooplankton density ranged from 10 to 37 ind./m^{3,} and biomass ranged from 0.01 to 0.02ml/m^3. During the fall intermonsoon sampling, holoplankton composition was higher than that of meroplankton (63.5% in station 1 and 76.9% in station 2). While duringt the winter monsoon, meroplankton becomes the primary composition (72 and 56.3%). During fall intermonsoon 2013, calanoid copepod formed the dominant component (16.22 and 25.64%). Among the meroplankton, Fish eggs and larvae (14.85 and 10.26%) dominated during fall intermonsoon 2013. Decapod crustacean larvae dominated (41.31 and 42.05%) during winter monsoon 2014. In this period, Euphausiacea dominated among the holoplankton (19.14 and 30.11%) and copepods were only the fourth abundant group (5.29 and 6.25%). Comparison between the present observations and the earlier studies in the Kalpeni lagoon indicated that many calanoid species that were reported in the previous study were not found to occur in the present study except the species *Pontellina plumata*, *Labidocera pavo* and *Acartia amboiensis*.

Zooplankton density in Kavaratti atoll ranged from 6 to 29 ind./m^3. A total of 24 mesozooplankton taxa were observed in the present study. Among the calanoids, the families Candacidae, Calanidae, Pontellidae, Temoridae, Psuedodiaptomidae, Centropagidae and Oithonidae were dominated. Zooplankton density in Minicoy lagoon ranged from 11 to 27 ind./m^{3,} and the biomass ranged from 0.05 to 0.2ml/m^3. Twenty-one zooplankton taxa were identified from the lagoon waters of Minicoy during the study period. Holoplankton composition was higher than meroplankton in the three sampling seasons. The highest meroplankton composition (60.6%) in station two during fall intermonsoon 2013 were due to the abundance of live corals in station 2. A total of 21 calanoid species were observed from the Minicoy lagoon in which a new species *Tortanus minicoyensis* of the genus *Tortanus* subgenus *Atortus* was described during winter monsoon 2014. Among the identified species, *Acrocalanus longicornis* and *Calanopia thompsoni* were found exclusively during summer monsoon 2014.

In the oceanic stations around Minicoy Island, zooplankton density and biomass was higher compared to the lagoon samples. Zooplankton abundance ranged from 16 to 42ind./m^{3,} and biomass from 0.08 to 0.18ml/m^3. There are 19 zooplankton taxa that were observed along with the oceanic stations of Minicoy. Calanoid copepods were the significant group in all stations. The chaetognaths were the second dominant group, and their abundance is higher in the windward side than leeward stations. A total of 39 calanoid species belonging to 13 families were identified from the oceanic stations. Spatial variation of copepod occurrence was in this study, the species *Labidocera pavo*, *Pontella spinipes*, *Pontellopsis perpicax* and *Pontella regalis* observed only in the leeward side, and *Labidocera madurae* and *Pontella denticauda* were observed only in the windward side. The pontellid copepod *Calanopia thompsoni* was observed inside the Minicoy lagoon was not observed in the adjacent oceanic waters of Minicoy.

In coastal waters of the south-west coast of India, during spring intermonsoon 2015, zooplankton density ranged from 81 to 197 ind./m^3 while during fall intermonsoon 2015, it ranged from 70 to 150 ind./m^3. The biomass ranged from 0.03 to 0.22ml/m^3 and 0.01 to 0.05 ml/m^3 respectively. During spring intermonsoon, 20 zooplankton taxa were observed, while during fall intermonsoon, 17 taxa were present. Forty-two calanoid species 12 families were observed during spring intermonsoon, 27 species under 11 families were observed during fall intermonsoon. From the lagoon waters of Lakshadweep, a total of 27 species under 11 families and 15 genera has been identified from lagoon waters during the present study. From oceanic waters around Minicoy Island, 39 calanoid species under 13 families and 18 genera were identified. During the entire study period, 62 calanoid species under 16 families and 26 genera were observed. The species *Paracalanus attenuatus*, *P.sewelli*, *Subeucalanus mucronatus*, *S.elongatus*, *S.subtenuis*, *Euchaeta longicornis Centropages furcatus, C.orsini, Pontella denticauda, P.sinica, Pontellopsis perspicax, P.regalis,* and *Acartia erythraea* were observed only during spring intermonsoon along the coastal waters, and *Pontellopsis herdmani* and *Euchaeta indica* were observed only during fall intermonsoon.

Sixty-two calanoid species under sixteen families from the following genera are described, their distinguishing characteristics are illustrated in this study and they are *Cosmocalanus*; *Canthocalanus*; *Undinula*; *Acrocalanus; Calocalanus; Paracalanus; Bestiolina*; *Eucalanus*; *Pareucalanus*; *Subeucalanus*; *Clausocalanus*; *Rhincalanus; Euchaeta*; *Euchirella*; *Scolecithrix, Lucicutia; Cantropages; Pseudodiaptomus; Temora*; *Candacia; Calanopia*; *Labidocera; Pontella; Pontellina; Pontellopsis; Acartia,* and *Tortanus*.

The family Calanidae represented in the present study with three genera and three species. The species *Cosmocalanus darwini* under the genus *Cosmocalanus* Bradford and, *Canthocalanus pauper* under the genus *Canthocalanus* and *Undinula vulgaris* under the genus *Undinula*. The family, Paracalanidae, represented with four genera and five species. They are *Acrocalanus longicornis* under the genus *Acrocalanus*; *Calocalanus pavo* and *C.plumulosus* under *Calocalanus*; *Paracalanus indicus* under *Paracalanus*, *Bestiolina* sp. under the genus *Bestiolina*.

The family Eucalanidae represented with three genera and six species. The species *Eucalanus elongatus* represented under the genus *Euclanus*; *Pareucalanus attenuatus* and *P. sewelli* under the genus *Pareucalanus*; *Subeucalanus subcrassus*; *S.mucronatus* and *S. subtenuis* under the genus *Subeucalanus* and *Clausocalanus arcuicornis* under the genus *Clausocalanus* was identified in the present study. The species *Rhincalanus rostrifrons* was identified during the study under the family Rhincalanidae. The family Euchaetidae represented in the present study with the species under the genus *Euchaeta*. Four species were recorded, and they are *Euchaeta marina*; *E. concinna*; *E. longicornis*; *E. indica*. *Euchirella* sp. was identified during the present study under Aetideidae family. *Scolecithrix danae* was represented under the family Scolecitrichidae. *Lucicutia flavicornis* was identified under the family Lucicutidae. The family Centropagidae represented with four species under the genus *Centropages*. The species *Centropages calaninus; C.furcatus*; *C.gracilis*; *C.orsinii* were identified in the present study. *Pseudodiaptomus serricaudatus* was the only species identified in the present study under the family Pseudodiaptomidae. Under the family Temoridae, *Temora discaudata* and *T. turbinata* were identified.

The species *Candacia ethiopica*; *C.bradyi*; *C.pachydactyla*; *C.simplex; C.truncata* were identified under the genus *Candacia* and the family Candacidae.

The family Pontellidae represented in the study under five genus. Genus *Calanopia* represented with *Calanopia minor* and *C.thompsoni*. *Labidocera* represented with *Labidocera acuta*; *L.detruncata*; *L.Kroyeri*; *L.minuta*; *L.pavo*; *L.bataviae* and *L.madurae*. *Pontella* represented with *Pontella denticauda*; *P.fera; P.sinica* and *P.spinipes*. *Pontellina* represented with *Pontellina plumata*. *Pontellopsis* represented with *Pontellopsis armata*; *P.perspicax*; *P.regalis* and *P.herdmani*.

The family Acartidae with the genus *Acartia* and the following species were identified in the present study. *Acartia negligens*; *A.spinicauda*; *A.erythraea*; *A.bispinosa*, *A.amboinensis* and *A.fossae*. The family Tortanidae represented in the present study with a new species under the genus *Tortanus* and subgenus *Atortus*. The present study agrees with the descriptions of the species from their original descriptions.

This study presents the results of a comparative analysis of 111 barcode sequences of 25 calanoid species including 85 barcode sequences of 17 calanoid copepod species not included in any previous study. The identification of species based on morphological characteristics was clear for most of the species. These sequences were the first time attempt and are the start of a library of barcodes of copepods in the south-west coast of India. The speciation of sequences exhibited in the likelihood analysis showed an intraspecific divergence of 0 to 0.5%. The Neighbor-joining tree of similarity using K2P distance shows the clustering of calanoid copepods. The average distance (K2P) among the species was 0.5%. Individuals in the same species got arrayed in a single clade with 100% bootstrap values and the average intraspecific divergence 0.5% within the species adequate to confirm the female-male correspondence and the genetic identity of the species from congeners and other copepods species from different families.

The genus *Labidocera* (Pontellidae) individuals exhibit proximity in morphology; there exists the potential for misidentification. *Labidocera madurae*, (Pontellidae), may readily be mistaken for *L. pavo* or *L. bataviae*. A point of significant confusion concerning *Labidocera madurae* and *Labidocera sp.* from the Hawaiian region was resolved in this study, as is evident from the molecular inference that *L. madurae* and *Labidocera sp.* individuals were the descendants of a common ancestor and close relatives to other individuals within the genus.

The neustonic copepods of the family Pontellidae - *Pontella spinipes* and *P. diagonalis*, both first described by female specimen exhibit very similar morphology and overlapping geographic ranges in the Indian Ocean. While several taxonomists have described males of each species, there has been no definitive evidence for female-male matching (link female and male of the same species) in the two species. An analysis of mtCOI sequences of the specimens collected from the Arabian Sea revealed that the females of *P. spinipes* and the males of *P. diagonalis* are genetically identical, providing definitive evidence for assignment of the latter to *P. spinipes*. These findings necessitate a re-examination of the female-male matching of other related species, based only on morphology, by molecular-genetic analysis as applied in the present study.

Pontella sinica a neustonic calanoid copepod belonging to the family Pontellidae, was initially described from the East China Sea off Zhejiang. Recent reports revealed considerable ambiguities in taxonomic descriptions of the species *Pontella sinica*. Considering these inaccuracies in *P.sinica*, critical evaluation of the morphological characteristics of *P.sinica* and female-male correspondence of the species with molecular confirmation using mtCOI sequences gives confirmation to the original description of *P. sinica* with definitive evidence to the female-male correspondence, and confirms that the male *P. princeps* described from Andaman, and Java Sea and *P. sewelli* described from the Indian Ocean and East Java Sea are the synonym of *P. sinica* and gives to first confirmed record of *P. sinica* in Indian waters.

A new species of the planktonic calanoid copepod genus *Tortanus*, subgenus *Atortus* is described from the lagoon area of Minicoy Island, southeastern Arabian Sea. The specific name *minicoyensis* refers to the name of the type locality of this species. It, therefore, is a toponymic term, agreeing in gender with the (masculine) generic name. The new species is included in the *tropicus* group, which is mainly distributed in the tropical and subtropical waters of South East Asia. The genus *Tortanus* (Calanoida, Tortanidae) currently comprises 47 species; these are mainly distributed in coastal waters of the Indo West Pacific and north-western Atlantic. They are known to be typical carnivores feeding on copepods and other zooplankters. Five subgenera have so far been recognized in this genus: *Tortanus (Tortanus)*, *T. (Eutortanus)*, *T. (Boreotortanus)*, *T. (Acutanus)* and *T. (Atortus)*. The subgenus *Atortus,* accommodating 32 nominal species, is regarded as the most advanced and is distributed exclusively in the Indo-West Pacific region; it tends to occur in more or less oligotrophic clear high-salinity (34-40 PSU) waters sometimes strongly influenced by warm currents or in coral reefs and seagrass beds.

The species can be distinguished from all the other species of the *tropicus* group by the dorsolateral process of fifth pedigerous somite, hyaline coupling device with larger left process, and asymmetrical caudal rami with two medial rounded processes in the female and the serrated ridge of the right antennule, strongly curved subdistal seta in the left fifth leg and processes on the coxa and basis of the right fifth leg in male. The mtCOI sequence of the specimens obtained with 642 base pairs confirmed the female-male correspondence and revealed the genetic identity of the species which is herein compared with mtCOI sequences of congeners. *Tortanus (Atortus) andamanensis* and *T. sigmoides*, *T. insularis*, *T. magnonyx, T. nishidai*, *T.reticauda*, *T. tropicus* were the species of the subgenus *Atortus* hitherto known from the Indian. In the present study, COI sequences were developed for *T.minicoyensis sp.nov*. to bring out the molecular variance from the congeners and established the female-male correspondence of the species. The mtCOI sequences developed in this study would be useful to identify and resolve the ambiguity with the closest congeners.

In conclusion, this is an important study made over the lagoon waters of Lakshadweep and coastal waters of the south-west coast of India after the IIOE (1962-65). Prior to the present study not much was known on the diversity, distribution of the species inside the lagoon and coastal waters, and morpho-molecular taxonomy of copepods from the study area. The present study provides an authentic database for future studies on copepods and related fishery oceanographic studies in the lagoon and coastal waters of the south-west coast of India. Sixty-two calanoid species under sixteen families and twenty-seven genera were described, and their distinguishing characteristics are illustrated in this study. DNA barcode data based on mtCOI sequences for the marine copepods (111 sequences for 25 species) were not previously sequenced from the lagoon waters of Lakshadweep and south-west coast of India. This work confirms that the molecular and morphological methods can be considered complementary and when applied in combination, constitute a powerful tool for identification with minimal errors not only of copepods in the Arabian Sea but in the adjoining marine areas; the results are the first step in building databases of sequences and update morphological identification keys. The study fulfils the goals enshrined in UN convention in Biodiversity (CBD) where India is a signatory under the Aichi Biodiversity Targets (2011-2020) that stresses the need for reducing biodiversity loss, strengthen capacity building (taxonomists) and make available scientific data and knowledge on biodiversity and its application. Therefore based on the study, the following recommendations are put forth:

Futuristic outlook and recommendations from the study

- Most of the studies reported from the Lakshadweep lagoon areas and the coastal zone in the southwest Arabian Sea has portrayed the biodiversity strength on the community structure and distribution of zooplankton, but with least information on the taxonomy and species characteristics specific to copepods and many others. This pioneering PhD programme has thus critically explored and documented the zooplankton diversity, specifically the taxonomy of calanoid copepod species by expertly blending the conventional morpho taxonomic and molecular tools. Thus studies on similar lines are to be executed in the Indian Ocean region so that many ambiguities in the species characteristics can be resolved.
- It is evident that the mesozooplankton community in the study area are more susceptible to variations on the temporal scale rather than spatial scale and the number of calanoid species was higher in the oceanic stations than the lagoon area. So effective steps are to be taken to carry out relevant studies for long-term data sets with sufficient field sampling (both

lagoon and open ocean area) on a seasonal/monthly basis for understanding the ecological alterations in the ecosystem.

- The relevance of the present study is in resonance with the three values of Convention on Biological Diversity (CBD), i.e. the conservation of biodiversity by understanding morpho-taxonomy of the relevant species and its sustainable development by profiling it into aquaculture field and equitable sharing of benefits arising from genetic resources by providing DNA barcodes. The government should take proper initiatives through various funding agencies for fulfilling this objective through appropriate studies in different marine ecosystems. The CBD guidelines suggest for transfer and also deposit of voucher specimens in authorized international institutions for research purpose in verifying the taxonomic status of different species, which is part of collaborative efforts. However, the National Biodiversity Authority, India through their acts and guidelines do not permit the transfer of any specimens for such research and related studies for resolving the ambiguities of various species. This is a bottleneck that needs to be seriously addressed by the respective agencies.
- Morphotaxonomy associated with molecular methods along with substantial funding will enable us to explore and document zooplankton as well as copepod communities from the coastal and marine habitats, that will provide the key role as secondary consumers- a significant part of the biological pump in the marine ecosystem. Therefore such taxonomic revelations and documentation will only supplement and enrich our knowledge and understanding of the changing productivity patterns and marine ecosystem health.
- A significant limitation of DNA barcoding is the problem of incorrect species identification in the published database, which remarkably reduces the reliability and usefulness of the approach. This problem was detected in our study by comparison with the sequences of congeners of the species from GenBank. Solutions to reduce these inaccuracies are the documentation of the line drawings and photographs of the species, retention of voucher specimens of the species for later examination, and

increase the databases and taxon sampling densities both systematically and geographically, thus allowing recognition of errors at the time of data submission.

- Copepods are the sensitive indicators of local and global climate change as key ecosystem service providers. Dedicated molecular database sites for copepods need to be developed to clarifying the species status from different coastal marine ecosystems. The whole genome sequencing of important copepod species will also provide insight on a wide range of studies which will also address the critical questions in ecology and evolution of the species.

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REFERENCES

Achuthankutty CT, Madhupratap M, Nair VR and Rao TSS (1980) Zooplankton biomass and composition in the western Bay of Bengal during late southwest monsoon. Indian J Mar Sci 9: 201-20.

Achuthankutty CT, Nair SRS, Haridas P, Madhupratap M (1989) Zooplankton composition of the Kalpeni and Agatti atolls, Lakshadweep archipelago. Indian J Mar Sci 18: 151-154.

Achuthankutty CT, Ramaiah N, and Padmavathi G (1998) Zooplankton variability and copepod assemblage in the coastal and estuarine waters of Goa along the central-west coast of India. IOC workshop report.142:1-11.

Aiyar RG, Menon KS (1936) Plankton rewards for the' years 1929 and 1930. J Madras Univ 8:1-43.

Albaina A, Uriarte I, Aguirre M, Abad D, Iriarte A, Villate F, and Estonba A (2016) Insights on the origin of invasive copepods colonizing Basque estuaries; a DNA barcoding approach. Biodiversity Records 9:51.

Alves FA , Érika PC, Lucas GP F, Aislan GC, Arnaud Bertran and Sigrid Neumann-L (2018) First report of deep-sea copepod *Megacalanus princeps* Wolfenden, 1904 (Calanoidea: Megacalanidae) from southwestern Atlantic. J Brazilian Crus Soc 0.1590/2358-2936e2017007.

Ambler JW, and Frost BW (1974) The feeding behaviour of a predatory planktonic copepod, Tortanus discaudatus. Limnology and Oceanography 19(3):446-451.

Andrews JC and Pickard GL (1990) The physical oceanography of coral reef systems, In: Ecosystem of the world. 25, Coral Reefs (ed. Dubinisky, Z) Elsevier, Amsterdam. pp: 11-48.

Andronov VN (1972) Veslonogie rachki Bestiola gen. n. (Copepoda, Paracalanidae). Bestiola gen. n. (Copepoda, Paracalanidae). Zoologicheskii Zhurnal 51(2):290-292.

Anjusha A, Jyothibabu R, Jagadeesan L, Arya PM, Sudheesh K, Kiran K, Ullas N, Deepak MP (2013) Trophic Efficiency of Plankton Food Webs: Observations from the Gulf of Mannar and the Palk Bay, Southeast Coast of India. J Mar Syst 115-116: 40-61.

Annandale N and Kemp S (1915). Fauna of the Chilka Lake. The Echiuroidea of the lake and of the Gangetic Delta. Memoirs of the Indian Museum 5(1): 57–63.

Anon (1968) Zooplankton sampling. UNESCO Monogr. Oceanogr.,Methodology, 2.

Anon (2008) Report on visit to Lakshadweep – a coral reef wetland included under National Wetland Conservation and Management Programme of the Ministry of Environment and Forests. 30 October to 1st November.

APHA (2005) Standard method for the examination of water and waste water. APHA, Washington. USA. 1368pp.

Ardania D, Yusli W, and Mohammad MK (2017) First record of blue-pigmented Calanoid Copepod, *Acrocalanus sp.* in the whale shark habitat of Cendrawasih Bay, Papua – Indonesia. AACL Bioflux 10(4): 739-745.

Baars MA (1999) On the paradox of high mesozooplankton biomass, throughout the year in the western Arabian Sea: Reanalysis of IIOE data and comparison with newer data. Indian J Mar Sci 28 (2):125-137.

Baek SY, Jang HK, Choi EH , Ryu SH, Kim SK, Lee JH, Lim YJ, Lee J, Jun J, Kwak M, Lee YS, Hwang JS, Venmathi Maran BA, Chang CY, Kim IH, and Hwang UW (2016) DNA Barcoding of Metazoan Zooplankton Copepods from South Korea. PLoS ONE 11(7): e0157307. doi:10.1371/journal. pone.0157307.

Bainbridge V (1972) The zooplankton of the Gulf of Guinea. Bulletin of Marine Ecology, 8, 61-97.

Bal DV, and Pradhan LB (1945) First Progress Report on investigations on fish eggs and fish larvae from Bombay Waters, 1944 - 45, Govt. Central Press, Bombay.

Balachandran VK , Gopinathan CP, Pillai VK, Nandakumar A,Valsal KK (1997) Chlorophyll profile of the euphotic zone in the Lakshadweep Sea during the southwest monsoon season., Indian J Fish 44(1) : 29-4.

Baliarsingh SK, Suchismita S, Aneesh AL, rinivasa Kumar T, Sahu KC (2018) Zooplankton Distribution in Coastal Water off Gopalpur, North-Western Bay of Bengal. J Ocean Univ China 17: 879.

Bamber RN (2010) Coastal saline lagoons and the Water Framework Directive. Natural England Commissioned Reports.

Banse K (1994) On the coupling of hydrography, phytoplankton, zooplankton, and settling organic particles offshore in the Arabian Sea Proc. Indian Acad Sci (Earth Planet Sci) 103:125-161.

Banse K (1995) Zooplankton: Pivotal role in the control of ocean production: I. Biomass and production. ICES J Mar Sci 52: 265–277.

Beaugrand G, and Ibanez F (2004) Monitoring marine plankton ecosystems. II: Long-term changes in North Sea calanoid copepods in relation to hydro-climatic variability. Inter Res Mar Ecol Prog Ser 284:35-47.

Beaugrand G, Keith MB, Alistair LJ, Sami S and Philip CR (2003) Plankton effect on cod recruitment in the North Sea. Nature 426: 661–664.

Beyrend-Dur D, Sami Souissi, and Hwang JS (2013) Population dynamics of calanoid copepods in the subtropical mesohaline Danshuei Estuary (Taiwan) and typhoon effects. Ecol Res DOI 10.1007/s11284-013-1052-y.

Bijoy Nandan S, Sanu VF and Harikrishnan M (2014) Taxonomy and Molecular description of *Labidocera acuta* Dana, 1849 (Calanoid copepod) from Lakshadweep archipelago, South West coast of India". Marine Ecosystems – Challenges and Opportunities 2 – December 2014, Kochi, pp. 205-207.

Blanco-Bercial L, Bradford-Grieve J, Bucklin A (2011) Molecular Phylogeny of the calanoda (Crustacea: Copepoda). Mol Phylogenet Evol 59(1): 103-113.

Boeck A (1864) Beskrivelse og fremlagde Tegninger af 4 norske Decapoder, undersogte af Overlaege Danielssen og ham. Forhandlinger i Videnskabs-Selskabet i Christiana 1863: 189-190.

Bowman TE (1971) *Tortanus scaphus* and *Tortanus lophus*, new Pacific planktonic copepods, with notes on *Tortanus murrayi* (Calanoida, Tortanidae). Pacific Science 25: 521-528.

Bradford JM and Jillett JB (1980) The Marine Fauna of New Zealand: Pelagic Calanoid Copepods: Family Aetideidae. Memoirs N Z Oceanographic Institute 86: 1-102.

Brady GS (1883) Report on the Copepoda collected by H. M. S. Challenger during the years 1873-76. Report on the Scientific Results on the Voyage of H.M.S. Challenger during the years 1873-76 Zool Vol. VIII: 1-142, 55 plates.

Brady GS (1910) Zoologie 3.Die marinen copepoden der Deutschen Sü"olar-Expedition 1901-1903. I. Über die copepdeon der stämme Hapacticoida, Cyclopoida, Notodelphyoida and Caligoida. Deutsche Sü"olar-Expedition 11), heft 5:497–593.

Brady HB (1883) Note on Syringammina, a New Type of Arenaceous Rhizopoda. Proc Royal Soc Lond 35(224-226): 155-16.

Brien TD (2002) Comparison of zooplankton biomass coverage in World Ocean Database 2001 COPEPOD: A Global Plankton Database. A review of the 2005 database contents and creation of new global zooplankton biomass fields U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-F/SPO-73, 136p.

Brien TD (2005) COPEPOD: A Global Plankton zooplankton biomass fields. U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-F/SPO-Database. A review of the 2005 database contents and creation of new global 731, 36p.

Brinton E and Gopalakrishnan K (1973) The Biology of Indian Ocean (Eds) Zeizschel B and Geleach SA, Springer verlag Berlin 357-382.

Brodsky KA (1950) Calanoida of polar and far-eastern seas of the U.S.S.R. Opredeliteli po Fauna SSSR 35: 1-442.

Bruggen AVC (1997) Willem Vervoort, eminent zoologist and museum director, a sketch of his life and work on the occasion of his 80th birthday in 1997. Commemorative volume for the 80th birthday of Willem Vervoort in 1997.

Bucklin A, Wiebe PH, Smolenack SB, Copley NJ, Beaudet JG, Bonner KG, Färber-Lorda James J, and Pierson J (2007) DNA barcodes for species identification of euphausiids (Euphausiacea, Crustacea). J Plankton Res 29(6) 483-493.

Bucklin A, and Wiebe PH (1998) Low mitochondrial diversity and small effective population sizes of the copepods *Calanus finmarchicus* and *Nannocalanus minor*: possible impact of climatic variation during recent glaciation. J Hered 89:383–392.

Bucklin A, Frost BW (2003) Molecular systematic and phylogenetic assessment of 34 calanoid copepod species of the calanidae and clausocalanidae.,Marine Biology. 142(2): 333-343.

Bucklin A, Frost BW, Kocher TD (1995) Molecular systematics of six calanus and three Metridia species (Calanoida: Copepoda). Mar Biol 121:655-664.

Bucklin A, Hopcroft RR, Kosobokova KN et al (2010) DNA BARCODING of Arctic Ocean holozooplankton for species identification and recognition. Deep Sea Res Pt II 57:40–48.

Bucklin A, Lajeunesse TC, Curre E, Wallinga J, Garrison K (1996a) Molecular genetic diversity of the copepod, *Nannocalanus minor*: genetic evidence of species and population structure in the N.Atlantic Ocean. J Mar Res 54:285-310.

Bucklin A, Sundt R, Dahle G (1996b) Population genetics of *Calanus finmarchicus* in the North Atlantic. Opelia 44:29-45.

Bucklin A, Wiebe PH (1998) Low mitochondrial diversity and small effective population sizes of the copepods Calanus finmarchicus and Nannocalanus minor: possible impact of climatic variation during recent glaciation. J Hered 89:383–392.

Burton RS (1998) Intraspecific phylogeography across the Point Conception biogeographic boundary. Evolution .Volume: 52(3):734-745.

Campos CC, Garcia TM, Neumann-Leitão S, Soares MO (2017). Ecological indicators and functional groups of copepod assemblages. Ecol Ind 83: 416–426. http://dx.doi. org/10.1016/j.ecolind.2017.08.018.

Carl J (1907) Copépodes d'Amboine. Revue suisse Zoologie 15: 7–18.

Castro P and Huber MH (2003) Marine Biology (fourth edition). McGraw Hill, ISBN 0072852909, 9780072852905. 468pp

Caudill CC and Bucklin A (2004) Molecular phylogeography and evolutionary history of the estuarine copepod, *Acartia tonosa*, on the Northwest Atlantic coast. Hydrobiologia 511:91-102.

Chako PI (1950) Marine plankton from waters around the Krusadai Island. Proc Indian Acad Sci 31B: 162-174.

Chen G and Hare MP (2008) Cryptic ecological diversification of a planktonic estuarine copepod, *Acartia tonsa*. Mol Ecol 17: 1451-1468.

Chen M, Dongyoung K, Hongbin L, and Chang-K K (2018) Variability in copepod trophic levels and feeding selectivity based on stable isotope analysis in Gwangyang Bay of the southern coast of the Korean Peninsula. Biogeosciences, 15:2055-2073.

Chen QC, Hwang JS (1999) A new species of *Tortanus* (Copepoda, Calanoida) from Taiwan, Crustaceana 72: 265-271.

Chen QC, Zhang SZ (1965) The planktonic copepods of the Yellow Sea and the East China Sea I. Calanoida. Stud Mar Sinica 7:20-131.

Chiba S, Tadokoro K, Sugisaki H, and Saino T (2006) Effects of Decadal Climate Change on Zooplankton Over The Last 50 Years In The Western North Pacific. Global Change Biology 12: 907–920.

Choquet M, Kosobokova K, Kwasniewski S, Hatlebakk M Dhanasiri AKS, Melle W, Daase M, Svensen C, Søreide JE, and Hoarau G (2018) Can morphology reliably distinguish between the copepods *Calanus finmarchicus* and *C. glacialis*, or is DNA the only way?. Limnol and Oceanogr: Methods doi: 10.1002/lom3.10240.

Clarke KR, and Warwick RM (2001). Comparing the severity of disturbance: a meta-analysis of marine macrobenthic community data. Mar Ecol Prog Ser 92: 221-232. DOI: 10.3354/ MEPS09222.

Claus C (1863) Die frei lebenden Copepoden mit besonderer Berucksichtigung der Fauna Deutschlands, der Nordsee und des Mittelmeeres. Verlag von Wilhelm Engelmann, Leipzig 1-230, pls. 1-37.

Cleve PT (1901) Plankton from the Indian Ocean and the Malay Archipelago. Kungliga Svenska Vetenskapsakademiens Handlingar, n. ser. copepod family Eucalanidae. 35: 1-58 Proc R Soc Lond B 270, 2321–2331.

Colwell RR (1996) Global climate and infectious disease: the cholera paradigm, Science, 274(5295): 2025-203.

Conway VP, Rowena GW, Joanna HDC, Christopher PG, and David B (2003) Guide To the coastal and surface zooplankton of the South – Western Indian Ocean. Mar Biol Ass UK Occasional Publication No. 15.

Cornils A, and Held C (2014) Evidence of cryptic and pseudocryptic speciation in the Paracalanus parvus s pecies c omplex (Crustacea, Copepoda, Calanoida). Front Zool 11: 19. doi:10.1186/1742-9994-11-19

Cornils A, Jan S , Petra S , Mahatma L , Claudio R, Sigrid B S-S (2010) Mesozooplankton distribution in the Spermonde Archipelago (Indonesia, Sulawesi) with special reference to the Calanoida (Copepoda). Deep-Sea Res II 57:2076–2088.

Cornils A, Schnack-Schiel SB, Hagen W, Dowidar M, Stambler N, Plahn O, and Richter C (2005) Spatial and temporal distribution of mesozooplankton in the Gulf of Aqaba and The Northern Red Sea in February/March 1999. J Plankton Res 27 (6): 505–518.

Currie RI. (1963) The Indian Ocean Standard Net, Deep Sea Res 10: 27-32.

Dana JD (1846) Notice of some genera of Cyclopacea. Annals and Magazine of Natural History 18:181-185. Also in: Am. J. Sci. (2)1:225-230.

Dana JD (1849) Conspectus Crustaceorum quae in Orbis Terrarum Circumnavigatione, Carolo Wilkes e Classe Reipublicae Foederatae Duce, lexit et descripsit. Am j Sciarts 8:424-428.

Dana JD (1852) Conspectus crustaceorum, quae in orbis terrarum circumnavigatione, Carolo Wilkes, e classe Reipublicae foederatae duce, lexit et descripsit Jacobus D. Dana. Pars II. Proceedings of the American Academy of Arts and Sciences. 2 (2):9-61.

Dana JD (1853) Crustacea. Part II. In: United States Exploring Expedition. During the years 1838, 1839, 1840, 1841, 1842. Under the command of Charles Wilkes. USNC Sherman. Philadelphia. 14: 689-1618.

Davis CC (1955) The marine and freshwater plankton. Michigan State University Press, Michigan.

Deschutter Y, Gabriela V, Jonas M, Klaas D, Karel DS, and Marleen DT (2018) Distribution of the invasive calanoid copepod Pseudodiaptomus marinus (Sato, 1913) in the Belgian part of the North Sea. BioInvas Records 7(1): 33-41.

Devi CBL, Stephen R, Aravindakshan PN, and Meenakshikunjamma PP (1996) Ichthyoplankton from Andaman and Nicobar Seas. In: Pillai V. K, Abidi S. A H, Ravindran V, Balachandran K. K, Agadi V. V. (Eds.), Procceedings of Second Workshop on Scientific Results: FORV Sagar Sampada, India, 239-248.

Doi H, Chang KH, and Obayashi Y (2008) Attached microalgae contribute to planktonic food webs in bays with fish and pearl farms. Marine Ecol Prog Ser 353: 107-13.

Dorairaj K, Soundarasrajan K, and Jagadis I (1997) Studies on marine fauna of the Mahathma Gandhi marine national park, wandoor, South Andaman, Part 1: Corals, Journal of the Andaman Science Association. 13:10-31.

Dwivedi SN and Choubey AK (1998) Indian Ocean large marine ecosystems: Need for national and regional framework for conservation and sustainable development. In: Sherman, K. Okemwa E. and Ntiba M., Eds., Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability, and Management, Blackwell Science, Cambridge, 327-333.

Eberl R, Cohen S, Cipriano F, Carpenter EJ (2007) Genetic diversity of the pelagic harpacticoid copepod *Macrosetella gracilis* on colonies of the cyanobacterium *Trichodesmium* spp. Aquat Biol 1:33–43.

Ekblad C (2008) The effect of predatory chaetognaths on zooplankton assemblages at the start of the spring bloom in Glacier Bay, Alaska, U.S.A. equatorial Indian Ocean. Paper presented at the third conference on Copepoda, London abstract, 63.

Elayaraja P and Ramanibai R (2006) Abundance and diversity of plankton in Pulicat lake. Seshaiyana 14 (1):3- 4.

EL-Sherbiny MM (2009) First record and redescription of *Pontella princeps* Dana, 1849 (Copepoda; Pontellidae) in the Red Sea with notes on its feeding habits. Catrina, 4(2): 1-10.

EL-sherbiny MM and Ueda H (2008). Redescription of the poorly known calanoid copepod *Pontella karachiensis* Fazal-Ur-Rehman, 1973 from the Red Sea with notes on its feeding habits. Plankton & Benthos Research, 3: 10-17.

El-Sherbiny MM, and Al-Aidaroos AM (2017) A new species of *Calanopia* (Copepoda, Calanoida, Pontellidae) from the plankton of the central Red Sea. Mar Biodiv DOI 10.1007/s12526-017-0694-3.

El-Sherbiny MM, Ueda H (2010) *Labidocera boxshalli* sp. nov, a new calanoid copepod (Crustacea; Pontellidae) from the Red Sea. Org Divers Evol 10:23–29

Emery AR (1968) Preliminary observations on coral reef plankton. Limnol Oceanogr 13:293–303.

Everaert G, Lisbeth VC, Maarten DR, Albert AK, Jan M, Michiel V, Colin RJ (2018) Risk assessment of microplastics in the ocean: Modelling approach and first conclusions. Environ Pollut 242:1930-1938.

Eyun S, Lee Y, Suh HL, Kim S, and Soh HY (2007) Genetic identification and molecular phylogeny of *Pseudodiaptomus* species (Calanoida, Pseudodiaptomidae) in Korean waters Zool Sci 24:265-271.

Fenaux R (1972) Premières données spécifiques sur les rap-ports poids/taille chez les appendiculaires en Méditer-ranée. Rapp Comm Int Mer Médit 23:67– 69.

Fernandes V, and Ramaiah N (2009) Mesozooplankton community in the Bay of Bengal (India): spatial variability during the summer monsoon. Aquat Ecol 43:951–963.

Fitzer SC, Caldwell GS, Close AJ, Clare AS, Upstill-Goddard RC, and Bentley MG (2012) Ocean acidification induces multi-generational decline in copepod naupliar production with possible conflict for reproductive resource allocation. J Exp Mar Bio Ecol. 30-36.

Fleminger A (1957) New Calanoid Copepods of Pontella Dana and Labidocera Lubbock with notes on the distribution of this genera in the Gulf of Mexico. Ttilane Stud Zool 5(2):19–34.

Fleminger A (1967) Taxonomy, distribution and polymorphism in the *Labidocera jollae* group with remarks on evolution within the group (Copepoda: Calanoida). Proc US Natl Mus 120:1–61.

Fleminger A (1973) Pattern number, variability and taxonomic significance of integumental organs (sensilla and glandular pores) in the genus *Eucalanus* (Copepoda, Calanoida) Fishery Bulletin 7(4):956-1010.

Fleminger A (1986) The Pleistocene equatorial barrier between the Indian and Pacific Oceans and a likely cause forWallace's Line.UNESCO Tech Pap Mar Sci 49:84–97.

Fleminger A Hulsemann K (1973) Relationship of Indian Ocean epiplanktonic calanoids to the world oceans, in: The biology of the Indian Ocean, edited by B. Zeitzschel, Springer-Verlag, Berlin, 339-347.

Fleminger A, Moore E (1977) Two new species of *Labidocera* (Copepoda, Calanoida) from the western tropical North Atlantic region. Bull Mar Sci 27:520–529.

Fleminger A, Othman BHR, Greenwood JG (1982) The *Labidocera pectinata* group: an Indo-West Pacific lineage of planktonic copepods with descriptions of two new species. J Plankton Res 4:245–270.

Folmer O, Black M, Hoeh W, Lutz R and Vrijenhoek R (1994) DNA primers for amplification of mitochondrial cytochrome c oxidase subunit I from diverse metazoan invertibrates. Mol Mar Biol Biotechnol 3: 294-299.

Francis SV, Nishida S. (2018) Amendment of the status of *Pontella sewelli* Heinrich, 1987 as a junior synonym of *P. sinica* Chen & Zhang, 1965, with confirmation of female-male matching by genetic analysis (Copepoda, Calanoida). Crustaceana 91(4):439-449.

Fukuoka K, Shimoda T, Abe K (2015) Community structure and abundance of copepods in summer on a fringing coral reef off Ishigaki Island, Ryukyu Islands, Japan. Plankt Benthos Res 10:225–232.

Gajbhiye SN (2002) Zooplankton - Study methods, importance and significant observations. Proceedings of the National Seminar on Creeks, Estuaries and Mangroves - Pollution and Conservation, 28th to 30th November, 2002, Thane. Ed. by: Quadros, G. 21-27p.

Gajbhiye SN, Nair VR, and Desai BN (1984). Diurnal variation of zooplankton in Malad creek, Bombay. Indian Journal of Marine Science. 13:75-79.

Garcia RD, Garcia PE and Reissig M (2013) Sexual size dimorphism in calanoid copepods (Centropagidae) from Patagonia (Argentina). New Zeal J Mar Fresh Res doi.org/10.1080/00288330.2013.802699.

Gardiner J S (Ed.) (1903) The fauna and Geography of the Maldive and Laccadive Archipelagoes. Cambridge Univ Press Cambridge pp: 1-11.

Gardiner JS (Ed.) (1906) The fauna and geography of the Maldive and Laccadive Archipelagoes, being the account of the work carried on and of the collections made by an expedition during the years 1899 and 1900. Volume II and supplements I and II. At the University Press: Cambridge. 473-1079.

Gauns M, Madhuprathap M, Ramaiah N, Jyothibabu R, Fernandes V, Paul TJ, and Prasanna Kumar S (2005) Comparitive accounts of biological productivity characteristics and estimates of carbon fluxes in the Arabian Sea and Bay of Bengal., Deep Sea Res II (52) doi:10.1016/j.dsr2.2005.05.009.

Geletin Yu V (1976) The ontogenetic formation of abdomen in copepods of genera *Eucalanus* and *Rhincalanus* (Copepoda, Eucalandae) and new system of these copepods. In:Explorations of the fauna of the seas, 18(26):75-93.

George J (1968) A preliminary report on the distribution and abundance of planktonic ostracods in the Indian Ocean. Bulletin of National Institute of Oceanography India 38: 641–648.

Gerber RP (1981) Species composition and abundance of lagoon zooplankton at Eniwetak atoll, Marshall islands. Atoll research Bulletin No.247.The Smithsonian institution Washington, D. C., U.S.A.

Giesbrecht W (1888) Elenco dei Copepodi pelagici raccolti dal Tenente di vascello Gaetano Chierchia durante il viaggio della R. Corvetta 'Vettor Pisani' negli anni 1882-1885 e dal Tenente di vascello Francesco Orsini nel Mar Rosso, nel 1884. Atti della Accademia Nazionale dei Lincei, Rendiconti dell' Classe di Scienze Fisiche Matematiche e Naturali (4)4: 284-287, 330-338.

Giesbrecht W (1889) Elenco dei Copepodi pelagici raccolti dal Tenente di vascello Gaetano Chierchia durante il viaggio della R. Corvetta 'Vettor Pisani' negli anni 1882-1885 e dal Tenente di vascello Francesco Orsini nel Mar Rosso, nel 1884. Atti della Accademia Nazionale dei Lincei, Classe di Scienze Fisiche Matematiche e Naturali Rendiconti (4)5 sem. 1:811-815; sem. 2:24-29.

Giesbrecht W (1892) Systematik und Faunistik der pelagicschen Copepoden des Golfes von Neapel und der angrenzenden Meeres- Abschnitte. Fauna u Flora Golf Neapel 19: 1–831 pls1-54

Giesbrecht W (1893) Systematik und Faunistik der pelagischen Copepoden des Golfes von Neapel und der angrenzenden Meeres-Abschnitte. Fauna und Flora des Golfes von Neapel und der Angrenzenden Meeres-Abschnitte, Herausgegeben von der Zoologischen Station zu Neapel. 19:1-831.

Girijavallabhan KG, Davidraj I and SAlavandi SV (1989) Hydrobiology of the lagoon. ln: Marine living resources of the Union Territory of Lakshadweep. Bull Cent Mar Fish Res Inst 43: 200-211.

Goetze E (2003) Cryptic speciation on the high seas; global phylogenetics of the copepod family Eucalanidae. Proc R Soc Lond B 270:2321–2331.

Gomes HR, Goes JI, Saino T (2000) Influence of physical process and freshwater discharge on the seasonality of phytoplankton regime in the Bay of Bengal. Cont Shelf Res 20: 313–330.

Gopalakrishnan TC, and BalachandranT (1992) North-south diversity of Scolecithricidae species (Copepoda: Calanoida) in the Indian Ocean. Oceanography of the Indian Ocean. Ed. by: Desai, B.N., 167-175p.

Gopalakrishnan TC, and Devi KS (1998) Distribution of Scolecithricidae (Copepoda: Calanoida) in the Indian Ocean. Pelagic Biogeography ICoPB II. Proceedings of the 2nd International Conference. Final report of SCOR/IOC working group 93, Ed by: Pierrot-Bults, A.C.; Spoel, S. van der 127-136p.

Gopalakrisnan K, and Brinton E (1969) Preliminary observations on the distribution of Euphausiacea from the International Indian Ocean Expedition. Proc. Symp. Indian Ocean, March 1967. Nat Inst. Sci. India (NISI) Bull 38, Part II, p. 594-611.

Goswami SC (1973) Observations on some planktonic groups of Kavaratti atoll (Laccadives)., Indian Nat Sc Acad 39b:676-686.

Goswami SC and Rao TSS (1981) Copepod swarm in the Campbell Bay (Andaman Sea). Indian J Mar Sci 10:274-275.

Goswami SC and Selvakumar RA (1977) Plankton studies in the estuarine system of Goa. Proc Symp Warm Water Zooplankton. Special Publication, pp. 337-353.

Goswami SC and Usha Goswami (1990) Diel variation in zooplankton in Minicoy lagoon and Kavaratti atoll (Lak-shadweep Islands). Indian J Mar Sci 19: 120-124.

Goswami SC, Sarupria JS and Bhargava RMS (1992).zooplankton standing stock assessment and fishery resources in the Indian sea,Tn :Oceanography of the Indian Ocean ,edited by B.N.Desai(Oxford & IBH publ.Co.New Delhi),217-226.

Gouday R (1967) Note preliminairesur la systematique et la repartition annuelle des copepods deaeauxsuperficielles de tulear (Madagascar). Rec travStn mar Endoume 6:71–100.

Gurney R (1927) Report on the Crustacea. Copepoda (littoral and semiparasitic). Zoological Results of the Cambridge Expedition to the Suez Canal, 1924, no. 35. Trans Zool Soc Lond 22:451-577.

Gutierrez MF, Ülkü Nihan, Tavşanoğlu , NicolasVidal, JinleiYu, FrancoTeixeira-de Mello, Ayşe Idil, Çakiroglu, Hu He, Zhengwen Liu, Erik Jeppesen (2018) Salinity shapes zooplankton communities and functional diversity and has complex effects on size structure in lakes. Hydrobiologia 813(1):237-255.

Hall TA (1999) BioEdit: a user-friendly biological sequence alignment editor and analysis program for windows 95/98/NT. Nucleic Acids Symp Ser 41:95-98.

Hammer RM (1981) Day-night differences in the emergence of demersal zooplankton from a sand substrate in a kelp forest. Mar Biol 62:275–280.

Haridas P (1982) Studies on the Zooplankton of Easturies along South West Coast of India. PhD thesis. University of Cochin 256pp.

Haridas P and Madhupratap M (1978). *Acartia dweepi*, a new species of copepod (Acartiidae; Calanoida) from Lakshadweep. Current Science, Bangalore 47(5):176-179.

Haridas P, Madhupratap M, Rao TSS (1973) Salinity, temperature, oxygen & zooplankton biomass of the backwaters from Cochin to Alleppey. Indian J Mar Sci 22: 94-103.

Haridevi CK (2013) Spatial and temporal variation of phytoplankton community and their growth limiting factors in Cochin back waters. Ph.D Thesis, Cochin University of Science and Technology.

Harris RP, Wiebe PH, Lenz J, Skjoldal HR, and Huntley M (eds) (2000) ICES Zooplankton Methodology Manual. Academic Press, New York 684 pp.

Harvell C, Kim K, Burkholder, Colwell R, Epstein PR, Grimes D, Hofmann E, Lipp E, Osterhaus A, and Overstreet RM (1999) Emerging marine diseases--climate links and anthropogenic factors. Science 285(5433): 1505-1510.

Hassett RP, Boehlert GW (1999) Spatial and temporal distributions of copepods to leeward and windward of Oahu, Hawaiian Archipelago. Mar Biol 134:571–584.

Heidelberg KB, Sebens KP, Purcell JE (2004) Composition and sources of near reef zooplankton on a Jamaican forereef along with implications for coral feeding. Coral Reefs 23:263–276.

Heinrich AK (1960) On the subsurface plankton in the Central Pacific ocean. Trudy Inst Okeanol 41:42–47 (in Russian)

Heinrich, AK (1987) New species and subspecies of Pontella (Copepoda: Pontellidae) from the eastern part of the Indian Ocean. Zoologicheskii Zhurnal, 66: 932-938.

Herman AW (1983) Vertical distribution patterns of copepods, Chlorophyll, and production in northeastern Baffin Bay. Limnol and Oceanogr 28:709-719.

Herrick CL (1884) Final report on the Crustacea of Minnesota, included in the orders Cladocera and Copepoda, together with a synopsis of the described species in North America, and keys to the known species of the more important genera. Reports of the Geological and Natural History Survey of Minnesota 12(5):1-192, pls. 1-29.

Hildebrandt N, Niehoff B, Sartoris FJ. Long-term effects of elevated CO2 and temperature on the Arctic calanoid copepods *Calanus glacialis* and *C. hyperboreus*. Mar Pollut Bull 80:59-70.

Hill RS, Allen LD, and Bucklin A (2001) Multiplexed species-specific PCR protocol to discriminate four N. Atlantic Calanus species, with an mtDNA gene tree for ten Calanus species. Mar Biol 139: 279-287.

Hirabayashi T, and Ohtsuka S (2014) A new species of Labidocera (Copepoda, Calanoida, Pontellidae) collected from Okinawa, southwestern Japan, with establishment of five Indo-West Pacific species groups in the *L. detruncata* species complex. ZooKeys 447: 21-34.

Honey UK Pillai, Jayalakshmy KV, Biju A, Jayalakshmi KJ, Paulinose VT, Devi CBL, Nair VR, Revichandran C, Menon NR, Achuthankutty CT and Panampunnayil SU (2014) A comparative study on mesozooplankton abundance and diversity between a protected and an unprotected coastal area of Andaman Islands., Environ Monit Assess 186: 3305-3319.

Hooff RC, Bollens SM (2004) Functional response and potential predatory impact of Tortanus dextrilobatus, a carnivorous copepod recently introduced to the San Francisco Estuary. Mar Ecol Prog Ser 277: 167-179.

Humes AG (1994) How many copepods? Hydrobiologia 292/292 1-7.

Huys R and Boxshall GA (1991) Copepod evolution. The Ray Society, London, England, 159: 1-468.

Hwang JS, Ram Kumar, Chih-WH, Albert YK, Sami S, Ming-HH, Jiunn-TW, Wen-Cheng Liu, Chi-FW, and Qing-CC (2010) Patterns of Zooplankton Distribution along the Marine, Estuarine, and Riverine Portions of the Danshuei Ecosystem in Northern Taiwan. Zool Stud 49(3): 335-352.

Jacob PK and Menon MD (1947) Copepods of the West Hill Sea Proc Indian Acad Sci Sect.B 177-194.

Jacoby CA, and Greenwood JG (1988) Spatial, temporal, and behavioral patterns in emergence of zooplankton in the lagoon of Heron Reef, Great Barrier Reef, Australia. Mar Biol 97:309–328.

Jagadeesan L, Jyothibabu R, Arunpandi N, and Parthasarathi S (2017) Copepod grazing and their impact on phytoplankton standing stock and production in a tropical coastal wate during the different seasons. Environ Monit Assess 189:105.

Jagadeesan L, Jyothibabu R, Anjusha A, Arya PM, Madhu NV, Muraleedharan KR, Sudheesh K (2013) Ocean currents structuring the mesozooplankton in the Gulf of Mannarand the Palk Bay, southeast coast of India. Prog Oceanogr 110:27–48.

Jagadeesan L, Perumal P, Francis KX, and Biju A (2016) Multigene DNA barcodes of Indian strain *Labidocera acuta* (calanoida: copepoda). Indian J Biotechnol 15:57-63.

James PSBR, Pillai CSG, Pillai PP, Livingston P, and Mohan M (1987) Marine fisheries research in Lakshadweep- A historical resume. Mar Fish In/or Serv T & E Ser 68: 7-9.

Jasmine P (2009) Mesozooplankton of the Arabian Sea and the Bay of Bengal with special reference to planktonic ostracods. PhD thesis, Cochin University of Science and Technology.

Jayabarathi R, Padmavati G and Anandavelu I (2012) Abundance and Species Composition of Harpacticoid Copepods from a Sea Grass Patch of South Andaman, India. Current Res J Biol Sci 4(6): 717-724.

Jayabarathi R, Padmavati G and Anandavelu I (2014) Spatial heterogeneity of benthic copepods: a comparative aspect on composition, abundance, and correlation. Zool Stud 54:51.

Jayalakshmy KV, Saraswathy M and Maheswari Nair (2009) Effect of water quality parameters on the distribution of *Pleuromamma* (Copepoda–Calanoida) species in the Indian Ocean: a statistical approach. Environ Monit Assess 155:373–392.

Jean Jose J, Udayakumar P, Ajimon VJ, Shibu R, Narendrababu R, and Baiju R S (2010) Hierarchical analysis of zooplankton assemblages over semidiel pattern in the lagoon of Kavaratti atoll, Lakshadweep archipelago, India. Current Res J Biol Sci 2(4):294-298.

Jeffrey SW (1968) Photosynthetic pigments of the phytoplankton of some coral reef waters. Vol 13(2):350.

Jeong HG, Hae-Lip, and Ho YS (2009) Pontellopsis Species (Copepoda, Pontellidae) in the the Lawson's Bay, Waltair. Andhra Univ Mem Oceanogr 62, 2:137-146.

Jeong HG, Soh HY, Suh HL (2014) Morphological and genetic differentiation of heteromorphy in *Labidocera rotunda* (Copepoda, Calanoida, Pontellidae). Zootaxa 3764(2):181–191.

Jeong HG, Suh H-L, Yoon YH, Choi IH, Soh HY (2008) The first two neustonic calanoid copepods, *Pontella securifer* and *P. sinica* (Calanoida, Pontellidae) in the South Sea, Korea. Ocean Sci J 43:91-100.

Jeyam GM, and Ramanibai R (2017) Molecular characterization and phylogenetic analysis of cyclopoid copepod Mesocyclops leuckarti using mtCOI. International J Bioassays 5365-5368.

Jiesbrecht W and Schmeil O (1898) Copepoda. I. Gymnoplea. Das Tierreich 6: 169 pp.

Jónasdóttir SH, Kiorboe T, Tang KW, St John M, Visser AW, Saiz E, and Dam HG (1998) Role of diatoms in copepod production: good, harmless or toxic? Mar Ecol-Prog Ser 172:305-308.

Jones EC, Park TS (1968) A new species of Tortanus (Calanoida) from Pago Harbor, American Samoa. Crustaceana, (Suppl. 1), Studies on Copepoda: 152-158. Malaysia. Malaysian Nature Journal. 41: 61-73.

Jones S and Kumaran M (1980) Fishes of the Laccadive archipelago. Indian J Fish 6 (1): 30-57.

Jose JJ, Appukuttan Chandran, Lincy Alex, Aaron P, Lipton (2014) Notes on the Egg Bearing Cyclopoid Copepod, *Oithona similis* Claus,1866 of the Arabian Sea., Not Sci Biol 6(1):31-35.

Jungbluth MJ, Lenz PH (2013) Copepod diversity in a subtropical bay based on a fragment of the mitochondrial COI gene. J Plankton Res 35(3):630–643.

Jyothibabu R, Jagadeesan L, Karnan C, Arunpandi N, Pandiyarajan R.S and Balachandran KK (2018) Ecological indications of copepods to oxygen-deficient near-shore waters. Ecol Indic 93: 76–90.

Jyothibabu R, Madhu NV, Habeebrehman H, Jayalakshmy KV, Nair KKC, Achuthankutty CT (2010) Re-evaluation of 'paradox of mesozooplankton' in the eastern Arabian Sea based on ship and satellite observations. J Mar Syst 81: 235–251.

Jyothibabu R, Madhu NV, Jayalakshmi KV, Balachandran KK et al (2006) Impact of fresh water influx on microzooplankton mediated food web in a tropical estuary (Cochin backwaters - India). Estuar Coast Shelf Sci 69:505-518.

Jyothibabu R, Maheswaran PA, Madhu NV, Ashraf TTM, Gerson VJ, Venugopal P, Nair KKC (2004) Differential response of winter cooling on biological production in the northeastern Arabian Sea and northwestern Bay of Bengal. Curr Sci 87:783-793.

Jyothibabu R, Maheswaran PA, Madhu NV, Ashraf TTM, Gerson VJ, Venugopal P, Nair KKC (2004) Differential response of winter cooling on biological production in the northeastern Arabian Sea and northwestern Bay of Bengal. Curr Sci 87:783-793.

Jyothibabu R., Mohan AP, Jagadeesan L, Anjusha A, Muraleedharan KR, Lallu KR, Kiran K, Ullas N, (2013) Ecology and trophic preference of picoplankton and nanoplankton in the Gulf of Mannar and the Palk Bay. J Mar Syst 111-112: 29-44.

Kasapidis P, Siokou I, Khelifi-Touhami M, Grazia Mazzocchi M, Matthaiaki M, Christou E, De Puelles MLF, Gubanova , Capua ID, Batziakas S, And Frangoulis C (2018) Revising the taxonomic status and distribution of the *Paracalanus parvus* species complex (Copepoda, Calanoida) in the Mediterranean and Black Seas through an integrated analysis of morphology and molecular taxonomy. J Plankton Res 40(5): 595–605.

Kasturirangan LR (1963) Key to the identification of the more common pelagic copepods of the Indian coastal waters., INCOR., Vol. 2.New Delhi: C S I R Publications.

Kavitha M, Padmavathy P, Srinivasan A, Jawahar P, Ranjith L and Linga Prabu D (2018) Copepod Abundance and Diversity from Offshore Region of Tuticorin, South East Coast of India. Int J Curr Microbiol App Sci 7(4):2767-2792.

Kesarkar KS, and Anil AC (2010) New species of Paracalanidae along the west coast of India: *Paracalanus arabiensis*. J Mar Biol Ass UK 90(2):399-408.

Khodami S, McArthur JV, Blanco-Bercial L, and Arbizu PM (2017) Molecular Phylogeny and Revision of Copepod Orders (Crustacea: Copepoda). Scientific reports 7: 9164 | DOI:10.1038/s41598-017-06656-4.

Kodama T, Taku W, Naoki I, Yoshitake T, Takashi T, Ken-IF, Haruyuki M, and Tsuneo G (2018) Spatial variations in zooplankton community structure along the Japanese coastline in the Japan Sea: influence of the coastal current. Ocean Sci 14: 355–369.

Kovalev AV, Shmeleva AA (1982) The fauna of copepods (Copepoda) in the Mediterranean sea. Ekologiya Morya 8:82–87 (in Russian).

Koya CNH (2000) Studies on ecology, chemical constituents and culture of marine macro algae of Minicoy Island, Lakshadweep. PhD. Thesis, CIFE, Mumbai, India.

Kurihara H (2008) Effects of CO2 -driven ocean acidification on the early developmental stages of invertebrates. Mar Ecol Prog Ser 373: 275±284.

Kusum KK, Vineetha G, Raveendran TV, Muraleedharan KR, Achuthankutty CT (2017) Plankton and the Invisible Barriers in the Tropical Ocean J Aquac Mar Biol 6(4): 00162. DOI: 10.15406/jamb.2017.06.00162.

Kusum KK, Vineetha G, Raveendran TV, Nair VR, Muraleedharan KR, Achuthankutty CT and Joseph T (2014) Chaetognath community and their responses to varying environmental factors in the northern Indian ocean. J Plankton Res 36(4): 1146- 1152.

Lakkis S (1981) On the presence of some rare copepods in the Levantine Basin. Proceedings of the first international conference on copepoda: 24–28 August 1981: Amsterdam, The Netherlands. Crustaceana supplement No. 7 pp 286–304.

Lakkis S (1990) Composition, diversitdet successions des copdpodesplanctoniques des eauxlibanaises (Mdditerrande orientate).Oceanol Acta 13(4):489–502.

Lakkis S, Toklu B, Zeidane R and Sarihan E (2005) Importance of copepods in the zooplankton community of Iskenderoun Bay (North eastern Mediterranean). 9th Int conf on copepoda. Tunis.

Lalli CM and Parsons TR (1997) Biological Oceanography: An Introduction. DOI https://doi.org/10.1016/B978-0-7506-3384-0.X5056-7.

Lathasumathi C, Patricio de LRE, Mariadoss K and Chelladurai S (2017) Seasonal variation of community composition of zooplankton in the Palk strait, (9-10 °N, Arabian sea, India). Bulletin de la Société Royale des Sciences de Liège 86: 78 – 87.

Lathika CT, Padmakumar KB, Smitha BR, Asha CR Devi S, Bijoy Nandan, Sanjeevan VN (2013) Spatio-temporal variation of microphytoplankton in the upwelling system of the south-eastern Arabian Sea during the summer monsoon of 2009.Oceanologia 55 (1):185-204.

Lawson TJ (1976) Community interactions and Zoogeography of the Indian Ocean Candacidae (Copepoda, Calanoida) Diss Abstr Int (37(3):1068-1069.

Lawson TJ (1977) Community interactions and Zoogeography of the Indian Ocean Candacidae (Copepoda, Calanoida) Mar Biol Berl 43(1):71-92.

Lee CE (2000) Global phylogeography of a cryptic copepod species complex and reproductive isolation between genetically proximate populations, Evolution, vol 54(6): 2014–2027.

Lee CE, and Frost BW (2002) Morphological stasis in the *Eurytemora affinis* species complex (Copepoda: Temoridae)., Hydrobiologia., 480:111-128.

Leis JM (1982) Nearshore distributional gradients of larval fish (15taxa) and planktonic crustaceans (6 Taxa) in Hawaii.Mar Biol 72:89–97.

Lubbock John Esq FRS FLS (1860) On the Distribution of the Tracheæ in Insects. 23(1):23-50.

Lubbock J (1853) On two new subgenera of Calanoida. Ann Mag Nat Hist 11(2):202–209.

Luo J, Peter BO, David FD, and Shailer RC (1998) Diel vertical migration of zooplankton and meso pelagic fish in the Arabian Sea. International Council for the Exploration of the Sea. 1-26.

Madhupratap M (1978) Studies on ecology of zooplankton of Cochin backwaters. Mahasagar Bull Nat Inst Oceanogr 11: 45-56.

Madhupratap M (1979) Distribution, community structure and species succession of copepods from Cochin Backwaters. Indian J Ma Sci 8: 1-8.

Madhupratap M (1987) Status and strategy of zooplankton of tropical Indian estuaries: A review. Bull Plank Soc Jpn 34: 65-81.

Madhupratap M (1999) Free living copepods of the Arabian Sea, Distribution and Research Perspectives. I J Mar Sci 146-149.

Madhupratap M and Haridas P (1986) Epipelagic calanoid copepods of the northern Indian Ocean. Oceanologica Acta 9(2):105-117.

Madhupratap M and Haridas P (1992) New species of *Pseudodiaptomus* (Copepoda): Calanoida) from the salt pans of the Gulf of Kutch, India and a comment on its speciation. J Plankton Res 14(4):555-562.

Madhupratap M Nair SSR, Haridas P and Padmavathi G (1990) Response of zooplankton to physical changes in the environment: coastal upwelling along the central west coast of India. J Coastal Res.6: 413-426.

Madhupratap M, Achuthankutty CT and Sreekumaran Nair SR (1991) Zooplankton of the Lagoons of The Laccadives: diel patterns and emergence. J Plankton Res 13: 947-958.

Madhupratap M, Achuthankutty CT, Nair SSR, Nair VR (1981) Zooplankton abundance of Andaman Sea. Indian J Mar Sci 10: 258–261.

Madhupratap M, Gauns M, Ramaiah N, Prasanna Kumar S, Muraleedharan PM, DeSousa, S N, Sardessai S, Muraleedharan UD (2003) Biogeochemistry of the Bay of Bengal: physical, chemical and primary productivity characteristics of the central and western Bay of Bengal during summer monsoon 2001. Deep-Sea Res Part II 50(5): 881-896.

Madhupratap M, Gopalakrishnan TC, Haridas P, and Nair KKC (2001) Mesozooplanktonic biomass, composition and distribution in the Arabian Sea during the fall intermonsoon: Implications of oxygen gradients., Deep Sea Res Part II 48: 1345–1368.

Madhupratap M, Gopalakrishnan TC, Haridas P, Nair KKC, Aravindakshan PN, Padmavati G, Paul S (1996) Lack of seasonal and geographic variation in mesozooplankton biomass in the Arabian Sea and its structure in the mixed layer. Curr Sci 71:863-868.

Madhupratap M, Haridas P, Ramaiah N, Achuthankutty CT (1992) Zooplankton of the southwest coast of India: abundance, composition, temporal and spatial variability in 1987. In: Desai, B.N. (Ed.) Oceanography of the Indian Ocean Oxford & IBH, New Delhi, 99–112.

Madhupratap M, Nair SSR, Haridas P and Padmavathi G (1990) Response of zooplankton to physical changes in the environment: coastal upwelling along the central west coast of India. J Coast Res 6: 413-426.

Madhupratap M, Sreekumaran Nair , Achuthankutty CT, Vijayalakshmi RN (1981) Major crustacean groups & zooplankton around Andaman –Nicobar islands. J Mar Sci 266-269.

Madhupratap M, Wafar MVM, Haridas P ,Narayanan B, Gopala Menon P, Sivadas P (1977) Comparative Studies on the Abundance of Zooplankton in the Surrounding Sea and Lagoons in the Lakshadweep. Indian J Mar Sci.6:138-141.

Mantha g, Moorthy MSN, Altaff K, Dahms HU, Sivakumar K, and Hwang JS (2012) Community Structure of the Harpacticoida (Crustacea: Copepoda) on the Coast of Chennai, India. Zool Stud 51(4): 463-475.

Manwell C, Baker CMA, Ashton PA, Corner EDS (1967) Biochemicl differences between *Calanus finmarchicus* and *C.helgolandicus*. Jour mar boil Ass UK 47: 145-169.

Margalef R (1958) Information theory in Ecology., General systems. 3: 36-71pp.

Marichamy R (1983) Zooplankton production in coastal waters. In: Alagarswami K (Ed.), Mariculture potential of Andaman and Nicobar islands - an indicative Survey., Bulletin CMFRI 34: 33-35.

Markhaseva EL, Renz J (2015) A new genus, *Peniculoides* (Copepoda, Calanoida), from deep waters of the North Atlantic with notes on the definition of Clausocalanidae. Crustaceana. 88(9):1031-1047.

Marshall SM and Orr AP (1955) The biology of a marine copepod. Oliver and Boyd, Londen.

Mathew CV, and Gopakumar G (1986) Observation on certain environmental parameters in relation to surface tuna fishery at Minicoy Island Lakshadweep J Mar Biol Ass lndia. 28(1 & 2): 163-168.

Mathew KJ and Solomon K (1996) Distribution and abundance of zooplankton in the northern Arabian Sea with reference to oil spill in the Gulf waters. In: Second workshop on scientific results of FORV Sagar Sampada, 15-17 February 1994, Kochi.

Mauchline J. (1998) The biology of calanoid copepods. Adv Mar Biol Vol 33: 1-710.

Maud JL, Andrew GH, Angus A, Penelope KL, and Andrea JM (2018) Mortality of *Calanus helgolandicus*: Sources, differences between the sexes and consumptive and nonconsumptive processes. Limnol Oceanogr doi: 10.1002/lno.10805.

Mayer A (1914) The effects of temperature on tropical marine animals. Carnegie Institution of Washington Publication, 183: 1-24.

Mayor DJ, Matthews C, Cook K, Zuur AF, and Hay S. (2007) CO2-induced acidification affects hatching success in *Calanus finmarchicus*. Mar Ecol Prog Ser 350: 91-97.

McConville K, Halsband C, Fileman ES, Somerfield PJ, Findlay HS, and Spicer JI (2013) Effects of elevated CO2 on the reproduction of two calanoid copepods. Mar Pollut Bull 73: 428-434.

McGowan A, and Walker, PW (1979) Structure in the copepod community of the North Pacific central gyre. Ecol Monographs 49: 195-226.

McKinnon AD (1991) Community composition of reef associated copepods in the lagoon of Davies Reef, Great Barrier Reef, Australia. Bull. Plankt. Soc. Japan 467–478.

McKinstry CAE, and Campbell RW (2018) Seasonal variation of zooplankton abundance and community structure in Prince William Sound, Alaska, 2009–2016. Deep-Sea Res P II 147: 69–78.

Menon KS (1931) A preliminary account of Madras Plankton Rec Ind Mus VoL XXXIII, Part IV, 489-S16.

Menon MA (1945) Observation on the seasonal distribution of the plankton of the Trivandrum coast. Proc Ind Acad Sci. 22: 31-62.

Minxiao W, Song S, Chaolun L, and Xin S (2011) Distinctive mitochondrial genome of Calanoid copepod *Calanus sinicus* with multiple large non-coding regions and reshuffled gene order: Useful molecular markers for phylogenetic and population studies. BMC Genomics. 12:73 1-21.

Mishra S and Panigrahi RC (1999) Zooplankton ecology of Bahuda estuary (Orissa) east coast of India. Indian J Mar Sci 297-301.

Mishra S and Panigrahy R C (1996) Copepods of Bahuda estuary (Orissa), east coast of India. Indian J mar Sci 25(2): 98-102.

Mollmann C and Koster FW (2002) Population dynamics of calanoid copepods and the implications of their predation by clupeid fish in the central Baltic Sea. J plankton res 24:959-977.

Moon SY, Lee W, Soh HY (2010) A new species of Bestiolina (Crustacea: Copepoda: Calanoida) from the Yellow Sea, with notes on the zoogeography of the genus. P Biol Soc Wash 123: 32-46.

Mori T (1964) The pelagic Copepoda from the neighboring waters of Japan. The Soyo company inc Japan 90-91.

Mulyadi (1997) Three new species of Pontellidae (Copepoda: Calanoida) from coastal waters of Java. Crustaceana 70:653-675.

Mulyadi (2000) New records and taxonomy of the genus Pontella (Crustacea: Copepoda: Calanoida) with notes on its distribution in Indonesian waters. Raffles Bull Zool 48: 181-200.

Mulyadi (2002) The calanoid copepod family Pontellidae from Indonesian waters, with notes on its species-groups. Treubia 332:1-167.

Mulyadi (2003) Three new species of Pontella (Copepoda, Calanoida) from Indonesian waters, with notes on their species groups.Crustaceana 76:385-402.

Mulyadi (2011) New records of species of Pontella Dana, 1849 and Ivellopsis Claus, 1893 and a re-examination of these genera (Copepoda, Calanoida) around some small Islands in Indonesian waters. Crustaceana 84: 1511-1535.

Mulyadi, Nishida S and Ohtsuka S (2017) Seven new species of *Tortanus* (*Atortus*) (Copepoda, Calanoida, Tortanidae) from North Sulawesi, Indonesia. *Crustaceana,* 90: 77-99.

Murty CS and Varadachari VVR (1968) Upwelling along the east coast of India. Bulletin of National Institute of Sciences.India, 36 (1):80- 86.

Nair KKC (1976) Distribution and relative abundance of Paraphronimidae,HyperiIdae , Amphlpoda in the Indian Ocean. Proceedings of the Symposium on warm water zooplankton, Dona paula,Goa,India,Oct.14-19: 155-167.

Nair KKC, Jacob PO and Kumaran S (1973) Distribution and abundance of planktonic amphlpods In the Indian Ocean. Zeitzschel,Bernt(Ed.) Ecological studies. Analysis and synthesis, vol.3. The Biology of the Indian Ocean. Symposium. Kiel, West Germany, March 31-April 6: 349-356.

Nair SRS, Nair VR, Achuthankutty CT and Madhupratap M (1981) Zooplankton composition and diversity in the western Bay of Bengal. J Plank Res 3:493-508.

Nair V R, Panampunnayil SU, Pillai HUK, and Gireesh R (2008) Two new species of Chaetognatha from the Andaman Sea, Indian Ocean. Mar Biol Res 208-214.

Nair VR (1978) Zooplankton from the nearshore waters of Karwar. Indian J mar.Sci 7(4): 283-287.

Nair VR and Rao TSS (1973) The Biology of Indian Ocean (Eds) Zeizschel B and Geleach SA, Springer verlag Berlin 293-317.

Nair VR, and Rao TSS (1973) Chaetognaths of the Arabian Sea. In The Biology of the Indian Ocean, pp. 293–318. Ed. by B. Zeitzschel. Springer-Verlag, New York.

Nair, V. R. 1977. Chaetognaths of the Indian Ocean. In Proceedings of the Symposium on Warm Water Zooplankton, National Institute of Oceanography, Goa, Indiapp. 168-195.

Nashad M, Sijo PV, Swapnil SS and Pratyush D (2018) New Records of Four Parasitic Copepods (Crustacea, Siphonostomatoida) from Andaman and Nicobar Waters, India. J Fish Environ. 42(2): 1-11.

Nasser AKV, Siraimeetan P and Aboobaker PM (1998) Zooplankton abundance and distribution at Minicoy lagoon, Lakshadweep. Indian Journal of Marine Science. 27: 346-350.

Newell GE and Newell RC (1973) Marine Plankton – A Practical Guide., Hutchinson Educational Ltd. London. 244 pp.

Nishida S, Anandavelu I and Padmavati G (2015) Two new species of *Tortanus* (*Atortus*) (Copepoda, Calanoida, Tortanidae) From the Andaman Islands. *Crustaceana,* 88: 216-230.

Nishida S, and Cho N (2005) A new species of *Tortanus* (Atortus) (Copepoda, Calanoida, Tortanidae) from the coastal waters of Nha Trang, Vietnam. Crustaceana 78: 223-235.

Ohtsuka S (1985) A note on the feeding habit of a calanoid copepod, *Pontellopsis yamadae* Mori. Publs Seto Mar Biol Lab 30:145-149.

Ohtsuka S and Nishida S (2017) Copepod Biodiversity in Japan: Recent Advances in Japanese Copepodology. DOI: 10.1007/978-4-431-56432-4_22.

Ohtsuka S, and Kimoto K (1989) Tortanus (Atortus) (Copepoda: Calanoida) of southern Japanese waters, with description of two new species, *T. (A.) digitalis* and *T. (A.) ryukyuensis*, and discussion on distribution and swarming behavior of Atortus. J Crust Biol 9: 392-408.

Ohtsuka S, and Reid JW (1998) Phylogeny and zoogeography of the planktonic copepod genus *Tortanus* (Calanoida: Tortnidae), with establishment of a new subgenus and descriptions of two new species. J Crust Biol 18: 774-807.

Ohtsuka S, El-Sherbiny MM, and Ueda H (2000) Taxonomy, functional morphology, and behavioural ecology of the planktonic calanoid copepod Tortanus (Atortus). Crustacean Research 29:1-11.

Ohtsuka S, Fleminger A, Onbé T (1987) A new species of Pontella (Copepoda: Calanoida) from the Inland Sea of Japan with notes on its feeding habits and related species. J Crustac Biol 7(3):554-571.

Ohtsuka S, Shimozu M, Tanimura A, Fukuchi M, Hattori H, Sasaki H, and Matsuda O (1996) Relationships between mouth part structures and in situ feeding habits of five neritic calanoid copepods in the Chukchi and northern Berings Seas in October 1988. Proceedings of the NIPR Symposium on Polar Biology, 9:153-168.

Omori M, Ikeda T (1984) Methods in marine zooplankton ecology, A Wiley Interscience Publication. Wiley, United States.

Othman BHR (1986) A new species of Labidocera (Copepoda, Calanoida) from Peninsular Malaysia. Malay Nat J 39:193-201.

Othman BHR (1987) Two new species of Tortanus (Crustacea, Copepoda) from Sabah, Malaysia. Malaysian Nature Journal 41:61-73.

Padmavati G and Goswami SC (1996) Zooplankton distribution in neuston and water column along west coast of India from Goa to Gujarat. Indian J mar Sci 25(2): 85-90.

Padmavati G, Haridas P, Nair KKC, TGopalakrishnan TC, Shiney P, and M. Madhupratap M (1998) Vertical distribution of mesozooplankton in the central and eastern Arabian Sea during the winter monsoon. J Plankt Res 20(2):343-354.

Padmavati GP, Haridas, Nair KKC, Gopalakrishnan TC, Shiney P and Madhupratap M (1998) Vertical distribution of mesozooplankton in the central and eastern Arabian Sea during the winter monsoon. J Plankton Res 20(2): 343-354.

Pagano M, Rodier M, Guillaumot C, ThomasnY , Henry K, Andrefouet C (2017) Ocean-lagoon water and plankton exchanges in a semi-closed pearl farming atoll lagoon (Ahe, Tuamotu archipelago, French Polynesia). Estuar Coast Mar Sci 191:60-73.

Paine MA, McDowell JR, and Graves JE (2007) Specific identification of western Atlantic Ocean scombrids using mitochondrial DNA cytochrome c oxidase subunit I (COI) gene region sequences. Bull Mar Sci 80(2): 353-367.

Panikkar NK (1970) IIOE,Plankton Atlas Vol.1 Fasc1.,Maps on total zooplankton biomass in the Arabian Sea and Bay of Bengal., CSIR,New Delhi.

Panikkar NK and Rao TSS (1973) Zooplankton investigation in Indian water and the role of the Indian Ocean Biological Centre'. Handbook to the IIOE Collections, 5, NIO, CSIR, India.

Patil MR and Ramamirtham CP (1963) Hydrography of the Laccadives offshore waters a study of the winter conditions. J Mar Biol Ass India Vol. V No. 2.

Perumal P, Rajkumar M, and Santhanam P (2009) Biochemical composition of wild copepods, *Acartia spinicauda* and *Oithona similis*, from Parangipettai coastal waters in relation to environmental parameters. J EnviroN Biol 30(6):995-1005.

Peterson WT and Bellantoni DC (1987) Relationships between water-coloumn stratification, phytoplankton cell size and copepod fecundity in Long Island Sound and off central Chile. South African J Mar Sci 5:411-421.

Pielou EC (1975) A general book on ecological diversity, Entropy based diversity measures (Models for distribution of species). Ecological diversity Newyork: Wiley.

Pillai HUK, Jayalakshmy KV, Biju A, Jayalakshmi KJ, Paulinose VT, Devi CBL, Nair VR Revichandran C, Menon NR, Achuthankutty CT, and Panampunnayil SU (2014). A comparative study on mesozooplankton abundance and diversity between a protected and an unprotected coastal area of Andaman Islands. Environ Monit Assess 186: 3305-3319.

Pillai HUK, Jayaraj KA, Rafeeq M, Jayalakshmi MK and Revichandran C (2011) Mesozooplankton distribution near an active volcanic island in the Andaman Sea (Barren Island) Author version: Environ Monit Assess vol: 176(1-4): 239-250.

Pillai PP (1971) Studies on the estuarine copepods of India. J Mar Biol Ass India, 13 (2): 162-172.

Pillai PP (1975) On the species of Pontella Dana and Pontellopsis Brady of the International Indian Ocean expedition collections (1960-1965). J mar Biol Ass India 17:129-146.

Pillai PP, Qasim SZ, Nair KK (1973). Copepod component of zooplankton in a tropical estuary. J mar boil Ass India 13 (1): 66-77.

Polovina J, Howell and Abecassis M (2008) Ocean's least productive waters are expanding. Geophys Res Lett 35: LO3618, doi:10.1029/2007GL031745.

Prabhakaran M.P. (2008) PhD Thesis. Cochin University of Science and Technology, 279pp.

Prasad TG (1997) Annual and seasonal mean buoyancy fluxes for the tropical Indian Ocean. Current Science 73: 667-674.

Prasannakumar SM, Madhupratap M, Dileepkumar P, Muraleedharan S, DeSouza Gauns M, and Sarma V (2001) High biological productivity in the central Arabian Sea during the summer monsoon driven by Ekman pumping and lateral advection, Current Science, 81(12): 1633-1638pp.

Pratap MM, Wafar MVM, Haridas P, Narayanan B, Menon PG and Sivadas P (1977) Comparative studies on the abundance of zooplankton in the surrounding sea and lagoons in the Lakshadweep. Indian J Mar Sci 6(2): 138-141.

Prestandrea N (1833) Su di alcuni nuovi crustacei dei mari di Messina. Effemeridi scientifiche e Letterarie per la Sicilia. 6: 3-14.

Prusova I, Sharon LS, and Elena P (2012) Calanoid Copepods of the Arabian Sea Region. Academic Publication Board, Sulthan Quaboos University Press 240 pp.

Purcell JE, Grover JJ (1990) Predation and food limitation as causes of mortality in larval herring at a spawning ground in British Columbia. Mar Ecol Prog Ser 9: 55-61.

Qasim S Z (1998) Pharmaceutical Potential of Marine Organisms. Advances in aquatic biology and fisheries 2. pp. 5-10.

Qasim SZ (1977) Biological productivity of the Indian Ocean. Indian J Mar Sci 6: 122- 137.

Qasim SZ and Sankaranarayanan VN (1970) Production of particulate organic matter by the reef on Kavaratti atoll (Laccadives). Limnol Oceanogr 15(4): 574-578.

Qasim SZ, and Sengupta R (1988) Some problems of coastal pollution in India. Mar Pollut Bull 12:295-301.

Qasim SZ, Bhattathiri PMA, Reddy CVG (1972) Primary production of an atoll in the Laccadive., Int Revue ges Hydrobiol Vol 57 : 207-225.

Qasim SZ, Gopinathan CK (1969) Tidal cycle and environmental features of Cochin backwaters (a tropical estuary). Proc Indian Acad Sci 69 (B):336-348.

Radhakrishna K, Bhattathiri PMA, and Devassy VP (1978) Primary productivity of Bay of Bengal during August- September, 1976. Indian J Mar Sci 7: 94–98.

Radhika R, Bijoy Nandan S, Harikrishnan M (2016) Morphological and molecular identification of marine copepod *Dioithona rigida* Giesbrecht, 1896 (Crustacea:Cyclopoida) based on mitochondrial COI gene sequences, from Lakshadweep sea, India. Mitochondrial Dna, part A. http: //dx.doi.org/10.1080/ 2470 1394.2016.1202941.

Radhika R, Bijoy Nandan S, Harikrishanan M (2014a).Redescription of female specimens of *Corycaeus(Corycaeus) crassiusculus* Dana and *Corycaeus (Onychocorycaeus) catus* Dahl (Poicilostomatoida : Corycaeidae) from Kavaratti Atoll, Lakshadweep Island ,India., Biosystematica., 8(1&2).

Radhika R, Bijoy Nandan S, Rithin Raj M, Sanu VF (2014b) Species assemblage an community patterns of cyclopoid copepods in Kavaratti atoll along the Indian coast. International J Cur Res 6(9): 8648-8657.

Rajthilak C, Perumal P, Murugan A, Jayaraj S, and Santhanam P (2010) Study on molecular variations among marine copepods (*Acrocalanus gracilis* and *Euterpina acutifrons*) isolated from Vellar estuary-South East coast of India. Global J Mol Sci 5: 7-11.

Rangarajan K and Marichamy R (1972) Seasonal changes in the temperature, salinity and plankton volume at Port Blair, Andamans. Indian J Fish 19: 60-69.

Rao and Ganapati PN (1958) Systematics and distribution in the waters oflf Visakhapatnam. Andhra Univ Mem Oceanogr 62,2 : 147-163.

Rao RR and Sivakumar R (2003) Seasonal variability of sea surface salinity and salt budget of themixed layer of the north Indian Ocean. J Geophys Res Biogeosci 108(C1) 3009. Doi: 10.1029/2001JC000907.

Rao TSS (1958) Studies on Chaetognatha in the Indian Seas. Part 2.

Rao, TSS (1979) Zoogeography of the Indian Ocean. In. Zoogeography and diversity of Plankton, Ed. Van der Spoel and A. C Pierrot Bults, Bunge Scientific Publishers, Utrecht, 254-292.

Rashiba AP (2010) Studies on Copepods from the EEZ of India- Bay of Bengal and Andaman Sea. PhD Thesis, Cochin University of Science and Technology.

Raymont J (1983) Plankton and productivity in the ocean .Vol.2.Zooplankton. Pergamont Oxford.824p.

Raymont JEG (1983) Plankton and Productivity in the Oceans. 2nd Edition. Volume 2–Zooplankton. 824 pp. Oxford/New York: Pergamon Press 1983. ISBN 0-08-024404-1.

Razouls C, Bovée F, Kouwenberg J, Desreumaux N. 2005-2018. Diversity and Geographic Distribution of Marine Planktonic Copepods. Available at http://copepodes.obs-banyuls.fr/en. Accessed 20 December 2018.

Redden AM, Kobayashi T, Suthers IM, Bowling L, Rissik D, Newton G (2008) Plankton process and the environment. In: Suthers, I.M., Rissik, D., (Eds.), Plankton: a guide to their ecology and monitoring for water quality. CSIRO Publishing, Collingwood, pp. 15-38.

Rissik D, and Suthers IM (2009) Plankton: A Guide to their Ecology and Monitoring for Water Quality CSIRO Publishing (Australia). 272 pp. ISBN: 9780643090583.

Robin RS, Pradipta R, Vishnu Vardhan K, Nagarjuna A, Nallathambi T, Rajanim KM, Balasubramanian T (2012) Planktonic communities and trophic interactions in the Kavaratti waters, Lakshadweep Archipelago India. Int J Ecosyst 2:5-18.

Rosamma Stephen (1988) Oncaeidae (Copepods: Poecilostomatoida) in the Indian Ocean with comments on the species of Lubbockia and Conaea. Mahasagar 21:35-43.

Runge JA and Ingram RG (1988) Underice grazing by planktonic, calanoid copepods in relation to a bloom of ice microalgae in southeastern Hudson Bay. doi.org/10.4319/lo.1988.33.2.0280.

Ryther JH, Hall JR, Pease AK, Bakeem Aand Jones MM (1966) Primary organic production in relation to the chemistry and hydrography of the western Indian Ocean. Limnol. Oceanogr 11: 371- 380.

Ryuji JM, Masaki UM, Matsumi N, Shuhei N (2002) Complete mitochondrial DNA sequence of Tigriopus japonicas (crustacea: copepoda). Mar Biotechnol 4:406–417.

Sabu P, Asha Devi CR, Lathika CT, Sanjeevan VN and Gupta GVM (2015) Characteristics of a cyclonic eddy and its influence on mesozooplankton community in the northern Bay of Bengal during early winter monsoon. Environ Monit Assess 187:3 30. DOI 10.1007/s10661-015-4571-x.

Sakaguchi S O and Ueda H (2011) Morphological divergence of *Pseudodiaptomus inopinus* Burckhardt, 1913 (Copepoda: Calanoida) between the Japan Sea and Pacific coasts of western Japan. Plankton Benthos Res 6(2): 124-128.

Sale PF, McWilliam PS, Anderson DT (1978) Faunal relationships among the near-reef zooplankton at three locations on Heron Reef, Great Barrier Reef, and seasonal changes in this fauna. Mar Biol 49:133–145.

Santhakumari V (1978). Distribution of scyphomedusae in the Indian Ocean. Mahasagar- Bull. Natl. Inst. Oceanogr. 11, 217–220.

Santhankumar J, Vinithkumar NV, Dharani G, Magesh PD et al (2010) Recent Trends in Biodiversity of Andaman and Nicobar Islands Edition: 1 Chapter 08 Zooplankton Abundance and Diversity in Andaman Nicobar Islands, India.

Santu KS, Bijoy Nandan S, and Athira K (2016) Occurrence of Mass Swarming of Family Acartiidae (Calanoid Copepods) (Zooplankton) in Ashtamudi Estuary, Kerala International J Mar Sci 6(30): 1-8.

Santu KS, Nandan SB, Cleetus RI, and Harikrishnan M (2017) Reassessing the species status of *Pseudodiaptomus malayalus* Wellershaus, 1969 and *P. binghami* Sewell, 1912 (Calanoida: Pseudodiaptomidae) from India based on morphology and mitochondrial cytochrome oxidase I gene sequences. Mitochondrial DNA Part A 29(6):885-896.

Sanu VF, Bijoy Nandan S, Deepak J, and Harikrishnan M (2016) Molecular identification and systematic assessment of *Labidocera madurae* A. Scott, 1909 (calanoid copepod) from Lakshadweep Archipelago, southwest coast of India, based on mitochondrial COI gene sequences. Mar Biodiv 46:95-103.

Sanu VF, Bijoy Nandan S, Rithin RM, and Radhika R (2014) Mesozooplankton Distribution in Kavaratti Atoll, Lakshadweep Archipelago, South West Coast of India with Special Reference to Calanoid Copepods. IOSR Environ Sci Tox And Food Technol 8: 69-78.

Sanu VF, Nishida S, Nandan SB (2018) Validation of Male *Pontella spinipes* Giesbrecht, 1889 (Copepoda: Calanoida: Pontellidae) Based on Morphological and Mitochondrial COI Gene Sequence Analysis. Zool Stud 57:16.

Saraladevi K, Stephen R, Rao TSS (1979) Distribution of Haloptilus (Copepoda : Calanoida) in the Indian Ocean, Indian J Mar Sci 8:159-165.

Saraswathy and Iyer (1986) Ecology of *Pleuromamma indica* Wolfenden (Copepod Calanoida) in the Indian Ocean. I JMar sci 15:219-222.

Saraswathy M (1973) Distribution of Gaussia (Copepoda, Metridiidae) in Copepoda Calanoidae upper 200 m in the Indian Ocean. In: B. Zeitschel, ed., The Biology of the Indian Ocean 4. 10: 335-338.

Saraswathy M (1982) Siphonostomes (Copepoda-Cyclopoida) from the Indian Ocean. J Plankton Res 4 (3): 633-641.

Saraswathy M (1986) *Pleuromamma* (Copepoda - Calanoida) in the Indian Ocean. Mahasagar 19 (3): 185-201.

Sarkar SK, Singh BN and Choudhury A (1986) Seasonal distribution of copepods in Hoogly esturary, northern Bay of Bengal. Indian J mar Sci 15(3): 177- 180.

Sars GO (1902) Copepoda Calanoida, Parts V & VI, Scolecithricidae, Stephidae, Tharybidae, Pseudocyclopiidae. An Account of the Crustacea of Norway, with short descriptions and figures of all the species. Bergen Museum 4: 49-72, pls. 33-48.

Sars GO (1903) An account of the Crustacea of Norway with short descriptions and figures of all species . Volume IV. Copepoda, Calanoida. Bergman Museum 171pp.

Sars M (1846) Fauna littoralis Norvegiae oder Beschreibung und Abbildungen neuer oderwenig bekannter Seethiere, nebst Beobachtungen über die Organisation,Lebensweise und Entwickelung derselben. 1-194.

Satapoomin S, Nielsen TG, and Hansen PJ (2004) Andaman Sea copepods, spatio-temporal variations in biomass and production and role in the pelagic food web. Mar Ecol Prog Ser 274: 99–122.

Savolainen V, Cowan RS, Vogler AP, Roderick GK, and Lane R (2005) Towards writing the encyclopaedia of life: An introduction to DNA barcoding. Phil. Trans R Soc Lond B 360:1805–1811.

Scott A (1909) The Copepoda of the Siboga Expedition. 1. Free- swimming, littoral and semi-parasitic Copepoda. Siboga- Expeditie, no.29a: 1-323, pls. 1-69.

Scott T (1894) Report on Entomostraca from the Gulf of Guinea, collected by John Rattray, B.Sc. Transactions of the Linnean Society of London, Series 2, Zoology. 6(1):1-161.

Scott T (1902) Notes on gatherings of Crustacea collected by the Fishery Steamer "Garland" and the steam trawlers "Star of Peace" and "Star of Hope", of Aberdeen, during the year 1901. Rep Fishery Bd Scotl 20 (3): 477-484.

Sell DW, and Evans MS (1982) A statistical analysis of subsampling and an evaluation of the Folsom plankton splitter. Hydrobiologia 94(3): 223-230.

Sewell RBS (1912) Notes on the biological work of the R.I.M.S.S. "Investigator" during survey seasons, 1910-11 and 1911-1912. J. Proc. Asiat. Soc. Beng., n. ser. 9: 329-390.

Sewell RBS (1914) Notes on the surface Copepoda of the Gulf of Mannar. Spolia zeylan., 9: 191-262.

Sewell RBS (1929) The Copepoda of Indian Seas. Calanoida. Mem. Indian Mus., 10: 1-221.

Sewell RBS (1932) The Copepoda of Indian seas. Calanoida. Memmoirs of the Indian Museum 10: 223-407.

Sewell RBS (1948) The free swimming planktonic copepod. Geographical distribution. Scientific Reports of the John Murray Expedition, 1933-34, zoology .8, 317-592.

Sewell RBS (1947) The free-swimming planktonic Copepoda. Systematic account., Scient Rep John Murray Exped 8 (1), 1-303.

Shannon CE and Weaver WW (1963) The mathematical theory of communications. University of Illinois Press, Urbana, 117 p.

Sherman K (1963) Pontellid Copepod distribution in relation to surface water types in the Central North Pacific. Limnol Oceanogr 8(2):214–227.

Sherman K (1964) Pontellid copepod occurrence in the central South Pacific. Limnol Oceanogr 9:476–484.

Sherman K (1967) A redescription of the calanoid copepod, pontellavalidadana, from the central South Pacific. Crustaceana 13(1):20–30.

Shetye, S.R., Gouveia, A.D., Shenoi, S.S.C., Sundar, D., Michael, G.S., Nampoothiri, G (1993) The Western boundary current of the seasonal subtropical gyre in the Bay of Bengal., Journal of Geophysical Research., 98 (C1), 945–954.

Shiganova T , Stupnikova A, and Stefanova K (2015) Genetic analyses of non-native species *Oithona davisae* Ferrari F.D. & Orsi, 1984 in the Black Sea. Bio Invasions Records 4(2): 91-95.

Silas EG and Pillai P (1976) The calanoid copepod family Pontellidae from the Indian Ocean. J mar boil Ass India 15 (2): 771-858.

Silas EG and Pillai PP (1967) *Labidocera pseudacuta*, a new pontellid copepod from the Indian Ocean, with remarks on the related species *Labidocera acuta* (Dana). J mar biol. Ass India 9(2): 346-364.

Silas EG and Pillai PP (1973) The calanoid copepod family Pontellidae from the Indian Ocean. J mar boil Ass India 15(2): 771-858.

Simpson EH (1949). Measurement of Diversity.,Nature.163:688pp.

Sivakumar K, Anandan R, Muthupriya P, Gopikrishna M and Altaff K (2013) Phylogenetic Analysis of Thermocyclops decipiens with Reference to 18S rDNA. Indian J Sci Technol 6(12): 5585–5592.

Skjoldal HR, Wiebe PH, Postel L et al. (2013) Intercomparison of zooplankton (net) sampling systems: Results from the ICES/GLOBEC sea-going workshop. Prog in Oceanogr 108: 1-42.

Smith J, Richter C, Fabricius KE and Cornils A (2017) Pontellid copepods *Labidocera Spp.* Affected by ocean acidification ; A field study at natural CO2 seeps. PLOS one. 12(5): e0175663. https://doi.org/10.1371/journal. pone. 0175663.

Smith JN, Glenn D, Claudio R, Astrid C, Jason MH and Katharina EF (2016) Ocean acidification reduces demersal zooplankton that reside in tropical coral reefs.Nature climate change DOI: 10.1038/NCLIMATE3122.

Soh HY, Kwon SW, Lee W, Yoon YH (2012) A new *Pseudodiaptomus* (Copepoda, Calanoida) from Korea supported by molecular data. Zootaxa 3368:229–244.

Steedman FH (ed) (1976) Zooplankton fixation and preservation. Monographs on Oceanographic Methodology. 4; UNESCO, Paris.

Stephen R (1984) Distribution of calanoid copepods in the Arabian Sea and Bay of Bengal. Mahasagar, Goa Volume: 17(3):161-171.

Stephen R (2001) Biodiversity and density of zooplankton on the decline in Kavaratti atoll (Lakshadweep, Arabian Sea) A multidecadal Study. Proceedings of Workshop on Scientific Database of Lakshadweep Islands: 6-7 December 1995: Kochi, India. Geological Survey of India, Special Publication No. 56:133-138.

Stephen R, (1998) Geographical variation in the distribution of different calanoid species in the Indian Ocean. Pelagic Biogeography, ICOPB II, IOC Workshop Report 142: 338-344.

Stephen R, and Iyer HK (1979) Species composition and coexistence of calanoid copepods in the shelf waters of Cochin. Mahasagar-Bulletin of the National Institute of Oceanography 12: 227-238.

Stephen R, and Saraladevi K (1973) Distribution of *Haloptilus acutifrons* (Copepoda,Calanoida) in the Indian Ocean with a description of the hitherto unkown male .Handbook to the International zooplankton collections, Indian ocean Biological center 5: 172-179.

Stephen R, Rao TSS (1980) Distribution of the bathypelagic family Arietellidae (Copepoda : Calanoida) in the upper 200m inthe Indian Ocean, J Plank Res 2: 239-247.

Stephen R, Saraladevi K, Meenkshikunjamma PP, Gopalakrishnan TC, and Saraswathy M (1992) Calanoid Copepods of the International Indian Ocean Expedition Collections Proc. of the Oceanography of the Indian Ocean, pp. 143-156.

Stephen R. (1992) Copepod composition along southwest and southeast coasts of India. Oceanography of the Indian Ocean. Ed. by: Desai, B.N., 121-127.

Strickland JDH and Parsons TR (1968) Practical Handbook of Seawater Analysis. Bull Fish Res Board Can Ontario. 167:311 pp.

Strickland JDH, and Parsons TR (1972) A practical handbook of seawater analysis. Bull Fish. Res Bd Can 2nd Edn 167: 310pp.

Suchismita S, Baliarsingh SK, Prakash S; Panigrahy RC, Sahu KC (2018) Zooplankton Research in Indian Seas: A Review. J Ocean Uni China. 17(5):1149-1158

Suresh VR and Mathew KJ (1997) Zooplankton ecology in Kavaratti Atoll, Lakshadweep, India., Indian J. Fish., 44 (3): 271-277.

Tait RV (1981) Elements of marine ecology. Third edition, Butterworths London des especesnovuvelles. Bull Instoceanogr Monaco.

Tamura K, Peterson D, Peterson N, Stecher G, Nei M, Kumar S (2011) MEGA5: molecular evolutionary genetics analysis using maximum likelihood, evolutionary distance, and maximum parsimony methods. Mol Biol Evol 28:2731-2739.

Tanaka O (1964) The pelagic copepods of the Izu region, middle Japan systematic account XII Families Arietellidae, Pseudocyclopidae, Candaciidae and Pontellidae. Publ Seto Mar Biol Lab 12(3):231-271.

Tanaka O (1965) The pelagic copepods of the Izu region, middle Japan systematic account XIII Parapontellidae, Acartidae and Tortanidae. Publications of the Seto Marine Biological Laboratory 12: 71-82.

Tanaka O (1973) On Euchaeta (Copepoda, Calanoida) of the Indian Ocean. Handbook to the International collections, Indian Ocean Biological Centre 4: 126-149.

Thompson IC (1900) Report on two collections of tropical and more northerly plankton. Proc Trans Lpool boil Soc 14: 262-294.

Thompson IC, and Scott A (1903) Report on the Copepoda collected by Professor Herdman, at Ceylon, in 1902 In: Herdman, W.A. (ed.). Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Manaar Volume: 1, suppl. 7: 227-307, text-fig. 1, pls. 1-20.

Thompson JD, Gibson TJ, Plewniak F, Jeanmougin F, and Higgins DG (1997) The ClustalX windows interface: flexible strategies for multiple sequence alignment aided by quality analysis tools. Nucleic Acids Res 25:4876-4882.

Thum RA, and Harrison RG (2009) Deep genetic divergence among morphologically similar and parapatric Skistodiaptomus (Copepoda: Calanoids: Diaptomidae) challenge the hypothesis through of Pleistocen speciation. Biol J Linn Soc 96: 150-156.

Todd CD, and Laverack MS (1991) Coastal marine zooplankton: a practical manual for students. Cambridge University Press, Cambridge.

Tranter D J and George J (1969) Nocturnl abundance of zooplankton at Kavaratti and Kalpeni, two atolls in the Laccadive archipelago. Proc. Symp. Corals and Coral reefs, Mandapam camp.

Tranter DJ (1973) Seasonal studies of a pelagic ecosystem (meridian 110°E). The biology of the Indian Ocean (B. Zeitschel, ed) Chpman and Hall Ltd, Londen 487-520.

Tranter DJ, and Abraham S (1971) Coexistence of species of Acartidae (Copepoda) in the Cochin Backwaters, a monsoonal estuarine lagoon. Mar Biol 11:222-241.

Ummerkutty ANP (1960) Studies on Indian copepods. 1. *Paralepeopsyllus mannarensis*, a new genus and species of cyclopoid copepod from the Gulf of Mannar. J Mar Biol Ass India. 2: 105-114.

Ummerkutty ANP (1963) Studies on Indian Copepods – 7. On two Calanoid copepods, *Ridgewayia typica* Thompson and Scott and R. krishnaswamyi n. sp. Bull Dept Mar Sci Univ Cochin1: 15-26.

Ummerkutty ANP (1966) Studies on Indian Copepods - 16. On some rare and interesting copepods from south east coast of India. J mar boil Ass India 8(2): 302-319.

Ummerkutty, ANP (1964). The post-conbryonic development of two calanoid copepods, *Pseudodiaptomus aurivilli* Cleve and *Labidocera bengalensis* Krishnaswamy. J mar biol Ass India 6(1): 48-60.

Uye SI, and Kayano Y (1994) Predatory feeding behaviour of Tortanus (Copepoda: Calanoida): life- stage differences and the predation impact on small planktonic crustacean. Journal of Crustacean Biology 14: 473-473.

Varghese M, George RM, Jasmine S, Laxmilatha P, Sreenath KR, Behera PR, Thomas VJ, and Kingsley J (2015) Zooplankton abundance in Amini and Kadmat islands of Lakshadweep. J Mar Biol Ass India. Vol 57 (1).

Varghese M, Jasmine S, Sreenath KR, Ranjith L, and Thomas VJ (2018) Plankton productivity in lagoons of Agatti and Bangaram atolls of Lakshadweep archipelago India. Fish Tech 55: 149-151.

Vargis D (2005) Macro-benthos of Minicoy Island, Lakshadweep. PhD Thesis. Cochin University of Science and Technology, 141pp.

Vijayalakshmi GS and Venugopalan VK (1973) Diurnal variation in the physico-chemical and biological properties in Vellar estuary. Indian J Mar Sci 2: 19-22.

Vineetha G, Kusum KK, Raveendran TV, Idrees Babu, Riyas C, Muhsin MI, Shihab BK, Cheruvathoor Simson and Anil P (2018) Responses of the zooplankton community to peak and waning periods of El Niño 2015–2016 in Kavaratti reef ecosystem, northern Indian Ocean. Environ Monit Assess 190:465 https://doi.org/10.1007/s10661-018-6842-9.

Vinogradov ME and Voronina NM (1961a) The distribution in the Indian Ocean of some copepod species .Doki Akad Nauk SSR 140(1):219-222.

Vinogradov ME and Voronina NM (1961b) The influence of oxygen deficit upon the plankton distribution in the Arabian Sea. Okeanologiya 1(4):670-678.

Voronina (1962) On the distribution of the macroplankton in the northern half of the Indian Ocean. Okeanologiya 2(1): 118-121.

Voronina NM (1962) On the surface plankton of the Indian Ocean. Traudy Inst Okeanol 58:67–79.

Wallershaus (1969) On the taxonomy of planktonic Copepoda in the Cochin Backwater (a South Indian Estuary). Veroff Inst Meeresforsch Bremerh 12 : 235-286.

Walter TC, and Boxshall GA. (2018) World of copepods database, available online at http://www.marinespecies.org/copepoda (accessed 20 December 2018).

Walters K, and Bell SS (1994) Significance of copepod emergence of benthic, pelagic, and phytal linkages in a subtidal seagrass bed. Mar Ecol Prog Ser 108:237–250.

Watanabe T, Chikara K, and Shiro F (1983) Nutritional values of live organisms used in Japan for mass propagation of fish: A review. Aquaculture 34: 115-143.

Wiebe PH, Ann Bucklin, and Mark Benfield (2017) Marine Plankton: A Practical Guide to Ecology, Methodology, and Taxonomy, Chapter: 10Publisher: Oxford University PressEditors: C. Castellani and M. Edwards.

Wilson CB (1950) Copepods gathered by the United States Fisheries Steamer "Albatross" from 1887 to 1909, chiefly in the Pacific Ocean. Bull US Natn Mus 100:141-441.

Wishner KF Gelfman C, Gowing MM, Outram DM, Rapien M , and Williams RL (2008) Vertical zonation and distributions of calanoid copepods through the lower oxycline of the Arabian Sea oxygen minimum zone. Prog Oceanogr 78: 163-191.

Wishner KF, Gowing MM, and Gelfman C (2000) Living in suboxia: Ecology of an Arabian Sea oxygen minimum zone copepod. Limnol Oceanogr 45(7): 1576–1593..

Wolfenden RN (1905) Plankton Studies: preliminary notes upon new or interesting species. Part 1. Copepoda. Rebman Limited, London & New York. [The original edition was withdrawn by Wolfenden and an amended edition was being circulated. Vide: Farran, G.P., 1939.] :1-24, pls. 1-7.

Wolfenden RN (1906) Notes on the collection of copepoda. In: Gardiner, J.S. (Ed.),The Fauna and Geography of the Maldive and Laccadive Archipelagoes., Vol. 2. Cambridge University Press. Cambridge 894-1040.

Wolfenden RN (1911) Die marinen Copepoden der Deutschen Südpolar Expedition 1901-1902. II. Die pelagischen Copepoden der Westwinddrift und des südlichen Eismeers met Beschreibung mehrerer neuer Arten aus dem Atlantischen Ozean. Dt. Südpol. -Exped., 12 Zool. 4: 181-380.

Yamani FY, and Prusova I (2003) Common copepods of the North Western Arabian Gulf: Identification Guide. Kuwait Institute for Scientific Research. 162pp.

Young RG, Abbott CL, Therriault TW, and Adamowicz SJ (2016) Barcode-based species delimitation in the marine realm: a test using Hexanauplia (Multicrustacea: Thecostraca and Copepoda). Genome 60: 169-182.

Zeitschel B (1973) The biology of the Indian Ocean' 'Ecological studies', 3, Springer Verlag, Berlin, Heidelberg, New York, 549 pp.

Zheng Z , LI S, LI SJ, and Chen B (1982) Marine planktonic copepods in Chinese waters: 1-162. (Shanghai Scientific and Technological Press, Shanghai).

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