Composition of zooplankton off the southeast coast of India

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation entitled "Composition of zooplankton off the southeast coast of India" is based on the results of investigations carried out by me in the Department of Marine Sciences at the School of Earth, Ocean and Atmospheric Sciences, Goa University under the supervision of Dr. Sheryl Oliveira Fernandes and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations / experimental or other findings given the dissertation.

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COMPLETION CERTIFICATE

This is to certify that the dissertation entitled "Composition of zooplankton off the southeast coast of India" is a bonafide work carried out by Dr. Sheryl Oliveira Fernandes under my supervision in partial fulfilment of the requirements for the award of the degree of Master of Science in Marine Sciences at the School of Earth, Ocean and Atmospheric Sciences, Goa University.

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PREFACE

The genesis of this dissertation emerged from a fervent curiosity about the identification and composition of zooplankton is a topic sensitive to environmental changes, including temperature and nutrient levels. Studying zooplankton helps elucidate complex trophic interactions and energy flow within aquatic ecosystems. This study undertakes a thorough exploration, focusing on the Composition of zooplankton off the southeast coast of India

Sampling expeditions conducted during the post-monsoon season along the offshore of Chennai to Amaravati, Bay of Bengal unveiled intriguing insights into the identification and composition of zooplankton within these regions. Notably the region with more freshwater influx showed higher dominance of zooplankton.

This study transcends mere scientific curiosity; it underscores the urgent need to understand and to estimate the dominant groups of zooplankton and the reason for their dominance by unraveling the composition of zooplankton in the east coast of India

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Lastly, I would like to thank the Almighty and my family for their permission and support that helped me in the completion of this project.

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ABBREVIATIONS USED

Entity	Abbreviation
Bay of Bengal	BOB
Particulate Organic Carbon	POC
Carbon Dioxide	CO^2
Nitrous Oxide	N_20
Summer Monsoon Current	SMC
West India Coastal Current	WICC
High Density Polyethylene Bottle	HDPE
Sea Surface Temperature	SST
Millimetre	mm
Micrometer	µm
Normal Cubic Meter	N m-3
Degree Celsius	°C
Percentage	%

ABSTRACT

The study focuses on the identification and population diversity of zooplankton in the south east coast of India, offshore of Chennai BOB. Zooplankton play a crucial role in ecosystem dynamics, serving as both primary consumers and important prey for higher trophic levels. Through a combination of microscopic analysis, the study identifies various zooplankton groups and investigates their abundance and distribution patterns across different habitats. Understanding zooplankton population diversity and population dynamics provides valuable insights into ecosystem health, trophic interactions, and responses to environmental changes. This research contributes to the broader understanding of aquatic biodiversity and informs management strategies for maintaining ecosystem resilience and functionality.

Our analysis revealed the presence of nine groups of zooplankton in coast of Chennai to Amaravati, including copepods, Amphipoda, Appendicularia, Chaetognatha, Cladocera, Mollusca, Ostracoda, Decapoda, Echinoderm , Fish egg and fish larvae.

Based on our comprehensive study on zooplankton, at the south east coast of India, offshore of Chennai reveals that the population of zooplankton groups vary at different stations and the Highest abundance of zooplankton was recorded in stations were there is an influx of more fresh water.

CHAPTER 1

GENERAL INTRODUCTION

1.General Introduction

1.1 Introduction

A thorough comprehension of an animal group's variety and distribution in a dynamic environment is a fundamental aspect of ecological research. The basis of ecological study is an understanding of the diversity and distribution of animal groupings within changing ecosystems. Understanding species relationships, ecosystem dynamics, and the effects of environmental change all depend on this information, which may supplement other disciplines like conservation biology and biogeochemistry. In an environment where each species plays a distinct role and depends on the others for food and shelter, biodiversity promotes ecosystem production. Every species in an ecosystem has a specific ecological niche that it occupies and plays a role in maintaining the ecosystem's health. Enhanced resilience and productivity of ecosystems are frequently correlated with higher biodiversity levels. The functioning of an ecosystem can be significantly impacted by the extinction of a single species. Increased species variety guarantees the sustainability of the natural world for all living things. Numerous studies have shown that environments with high biodiversity are more adaptable and able to withstand a variety of environmental shocks. Similarly, environments with lower biodiversity are more susceptible because changes in the environment that affect one or two species might result in significant danger and the extinction of the entire species.

The aquatic environment provides homes for a diverse range of species, including fish, mammals, phytoplankton, and zooplankton. Aquatic environments are essential for maintaining biodiversity. In addition to providing food and shelter for many creatures, these ecosystems are crucial for a number of ecological functions, including the generation of oxygen, the cycling of nutrients, and the regulation of temperature. However, aquatic organisms experience less temperature variation due to the high specific heat capacity of water, which means it takes a lot of energy to change the temperature of water (Portner et al., 2017). Aquatic ecosystems are both highly valued economically and aesthetically, and they play a major role in maintaining the general health of the environment. However, because of human activity and the effects of climate change, the loss of biodiversity in aquatic habitats has become an increasingly urgent problem. The functioning of these ecosystems is further threatened by invasive alien species and the startling rates of species loss, which emphasises the critical need for conservation efforts and sustainable management.

Zooplankton, often called the "drifters of the sea," are a varied and vital component of aquatic environments. These microscopic organisms live in freshwater and marine habitats. They range in size from small crustaceans to gelatinous creatures and the larval stages of bigger species. Even though they are tiny, zooplankton are extremely important to the dynamics of ecosystems. With their ability to both graze on phytoplankton and organic debris and act as prey for bigger creatures like fish, marine mammals, and birds, they are the foundation of many aquatic food webs. Zooplankton are essential for the exchange of energy and the cycling of nutrients in aquatic environments because of their complex web of interactions (Hays et al., 2003). Additionally, because their populations serve as markers of changes in ecosystem conditions and water quality, they can offer important insights on the health of the environment.

The dynamics of zooplankton are primarily governed by many environmental conditions. Any change in ambient water quality significantly affects the zooplankton population, which in turn can affect larval survival and, consequently, the fishery

(Greenwood et al., 2001). Prey availability, grazing preference, competition, and predation play an important role in zooplankton community shifts (Sailley et al., 2015). Furthermore, zooplankton dynamics may be impacted in the short and long term by environmental changes brought on by pollution. The Bay of Bengal (BoB) gets a significant amount of freshwater from rivers, with a peak quantity during the south-west monsoon season (Chaitanya et al., 2015). Due to the significant influence of freshwater in the bay, salinity and temperature oscillations play pivotal roles in determining zooplankton distribution and diversity (Rakhesh et al., 2006).

The dynamics of the marine food web and biogeochemical cycling depend heavily on zooplankton (Castonguay et al., 2008). According to D'Alelio et al. (2016), zooplankton mostly consumes phytoplankton, which produces food for species at higher trophic levels. In determining the fish supply, the spatio-temporal distribution of phytoplankton is a significant component. So, a decrease in the zooplankton population might have an impact on how well an ecosystem functions. The dynamics of zooplankton are primarily governed by many environmental conditions. Therefore, any alteration in the overall water quality can have a major impact on the zooplankton population, which in turn influences larval survival and, consequently, the fishery (Greenwood et al., 2001). The mechanism of seasonal plankton succession is primarily controlled by salinity and temperature (Lawrence et al., 2012). With regard to zooplankton, factors such as predation, competition, grazing preference, and availability of prey are crucial.

Zooplankton comprise a highly diverse group of marine organisms that are classified based on their taxonomy, size, and duration of planktonic life. In marine waters, zooplankton communities are usually dominated by a number of faunal species, such as chordates, arthropods, molluscs, annelids, protozoans, and cnidarians. The size classes of zooplankton, known as micro- and mesozooplankton, are determined by the volume displacement method. In this method, the zooplankton sample is filtered through a 200-µm mesh screening. The interstitial water between the organisms is removed with the blotting paper. The filtered zooplankton is then transferred with a spatula to a measuring cylinder with a known volume of 4% buffered formalin. The displacement volume is obtained by recording the volume of fixative in the measuring jar displaced by the zooplankton (Goswami, 2004). It can be further classified into different size categories, such as picoplankton, which are the tiniest plankton, measuring between 0.2 and 2 micrometres. They contain certain bacteria and extremely small protists. Nanoplankton typically ranges from 2–20 micrometres; it comprises small protists such as certain types of flagellates and ciliates. Microplankton are larger than nanoplankton, ranging from 20 to 200 micrometres; they include dinoflagellates, diatoms, and some small crustaceans (Wieland et al., 1998). Mesozooplankton are significant consumers of phytoplankton, with sizes ranging from 0.2 to 20 millimetres. This size class includes the larval stages of many marine organisms, such as fish, mollusks, and crustaceans. Thus, they are the largest organisms that are of primary interest for global biogeochemical models of the marine carbon cycle (Buitenhuis E et al., 2006). Macroplankton are the largest size class of plankton, typically ranging from 20 to 200 millimetres; they include large visible organisms such as jellyfish, ctenophores, and some larger larval stages of marine organisms like fish and crustaceans (Sardou et al., 1996). Megaplankton are those floating organisms that exceed 20 cm in length. They are represented by large jellyfish, salps, and certain squid species (Edwards Martin G. et al., 2001).

Zooplankton feeding behaviour encompasses a wide range of strategies and mechanisms employed by these tiny aquatic organisms to acquire food. From aggressive ambushing to passive suspension feeding, zooplankton display a broad range of eating habits. This variety is a reflection of the various ways that zooplankton have evolved to get food in aquatic settings. Because they are heterotrophic organisms, zooplankton are an essential component of freshwater and marine ecosystems as primary consumers that rely on organic carbon for energy. Many zooplankton species are filter feeders, drawing small particles out of the water by means of specialised appendages or structures.

The role of zooplankton in controlling the efficiency of the Biological Carbon Pump is often overlooked, with greater focus on factors such as biominerals for ballasting (De La Rocha and Passow, 2007) or microbial respiration (Herndl and Reinthaler, 2013). Nevertheless, zooplankton have the potential to significantly impact the biological carbon pump as they can consume and completely transform particles (Lampitt et al., 1990) Further, zooplankton can undergo diel vertical migration, feeding on particles at night in the surface and egesting them at depth during the day (Wilson et al., 2013).

Marine zooplankton are useful indicators of environmental changes because of their sensitivity to numerous environmental conditions and role in aquatic food webs (Beaugrand et al., 2014). Changes in zooplankton populations can indicate changes in water temperature, nutritional availability, ocean acidification, pollution levels, and other environmental factors (Richardson et al., 2009). Environmental cues like temperature, light, and food availability can influence zooplankton life cycle events such as reproduction, growth, and diapause, which is a dormant state. Changes in the frequency or timing of these occurrences may be indicative of changes in ecosystem dynamics or environmental conditions. Environmental conditions and processes, including stratification, mixing, and grazing, impact the composition, abundance and productivity of phytoplankton (Deppeler et al., 2017) and subsequently the zooplankton.

Numerous research institutes and organisations have studied zooplankton in the Indian Ocean to learn more about the variety, abundance, and ecological importance of these microscopic creatures in the marine environment (Patel et al., 2020). As key consumers, zooplankton is essential to marine food webs and its quantity and makeup can provide information about the health of marine ecosystems.

The zooplankton are sampled from the South East Coast of India (BOB), and receive a substantial amount of freshwater from rivers. Pulicat Lake is a saline backwater lake located on the Coromandel Coast of the South Indian state of Tamil Nadu and the northeastern part of the Andhra Pradesh state in India (Dhinamala et al., 2015). It is the second-largest brackish water lake in India and covers an area of about 720 square kilometres. The lake is separated from the Bay of Bengal by the barrier island of Sriharikota, which is home to the Satish Dhawan Space Centre, Pulicat Lake provides a diverse habitat for various species of zooplankton. Its brackish water conditions, influenced by both freshwater inflows and tidal movements from the Bay of Bengal, create a suitable environment for different types of zooplankton to thrive (Dhinamala et al., 2015).

In this study identification and composition of major zooplankton groups offshore of Chennai, South East coast of India was determined. The research aims to improve understanding of the distribution and identification of zooplankton in the study area.

1.2 Objectives

The present study was carried out to achieve the following objectives:

- To assess the composition of zooplankton from representative locations off Chennai, Pulicat, Amaravati south east coast of India.

CHAPTER II

LITERATURE REVIEW

2.Literature review

2.1 Significance of zooplankton in marine ecosystem

Zooplankton are essential components of marine ecosystems, holding a pivotal position in ecological processes and the health of aquatic habitats. Serving as primary consumers, they play a fundamental role in connecting phytoplankton with higher trophic levels, thereby facilitating the transfer of energy throughout marine food webs (Doubek et al., 2019). Zooplankton is directly related to higher trophic levels. Therefore understanding how their distribution affects the overall ecosystem and interactions with other planktonic species may be useful in understanding ecological models connected to other planktonic taxa (Pinel-Alloul et al., 1988). Consumption of phytoplankton helps to regulate population levels, preventing harmful blooms that can disrupt marine environments (Turner et al., 2019). Zooplankton play an important role in energy transmission between pelagic and benthic ecosystems (Richardson et al., 2009). Zooplankton excrete nutrient-rich waste such as nitrogen and phosphorus. These nutrients are essential for the growth of phytoplankton and other primary producers, completing the nutrient cycling loop in aquatic ecosystems (Alcaraz et al., 2010).

Zooplankton presence influences ecosystem dynamics (Bruce et al., 2009). Zooplankton have a position as grazers for algae and bacteria, influencing their community population but they also provide phytoplankton with nitrogen and phosphorous (Urabe et al., 1995; Hudson and Taylor, 1996; Lehman and Sandgren, 1985; Hudson et al., 1999; Sterner, 2009) having a perfect cycle of nutrient cycling. Zooplankton have a crucial role in the efficiency of the Biological Carbon Pump (BCP) that regulates the atmospheric carbon dioxide levels (Kwon et al., 2009, Parekh et al., 2006). Zooplankton grazing causes POC to either pass through the colon and be egested as a fecal pellet, be respired as CO_2, or be split into smaller particles by sloppy feeding

(Lampitt et al., 1990). Furthermore, zooplankton can undergo diel vertical migration, grazing on particles at night at the surface and ingesting them deep during the day (wilson et al 2013). Zooplankton fecal pellets play a crucial role in the marine ecosystem by contributing significantly to the export of (POC) particulate organic carbon to deeper ocean layers (Turner et al., 2015). The fraction of the projected total sinking particulate carbon flux provided by recognized zooplankton fecal pellets is extremely variable (<1->100%) with most of the values <40% (Dubischar and Bathmann, 2002, Ducklow et al., 2001, Fortier et al., 2002). These fecal pellets are formed when zooplankton consume phytoplankton and other organic substances in the water column and subsequently excrete waste in the form of pellets. Despite their variability, zooplankton fecal pellets are recognized as a key mechanism for transporting organic carbon from surface waters to deeper depths of the ocean. This process, known as the biological pump, helps sequester carbon dioxide from the atmosphere into the deep ocean, playing a vital role in regulating Earth's climate (Steinberg et al., 2017). Zooplankton has a considerable influence on biomass stocks of other planktonic groups. In fact, zooplankton may modify the concentration of prey populations by consuming and by predator populations (being consumed), consequently having effects on fish biomass (Vanni, 2002).

Zooplankton species are commonly used as live feed for farmed fish, particularly in the larval stages when the fish are small and require highly nutritious and easily digestible food. Zooplankton such as copepods and rotifers are popular choices due to their small size and high nutritional value. Copepods are an essential alternative live-feed in marine fish production because they enhance the survival, growth, and development of fish larvae, due to their biochemical profile and size range

(Hansen, 2017). Fish feed represents one of the primary expenses in aquaculture operations (Lupatsch et al., 2009).

2.2 Identification of zooplankton

Zooplankton are classified into two types: holoplankton, which are permanent plankton that spend their whole life in the water column, and meroplankton, which are transitory members (Slotwinski et al., 2014). Zooplankton groups encompass a diverse array of organisms found in aquatic ecosystems. They can be classified into various groups based on different criteria such as taxonomy, ecological roles, or behavioural characteristics (Johnson and Allen, 2005). Copepods (0.2-10mm) are microscopic crustaceans that constitute one of the most abundant groups of zooplankton. Calanoida, Cyclopoida and Harpacticoida are the most abundant orders that usually have a small, cylindrical body with a rounded or beaked head (Slotwinski et al., 2014).

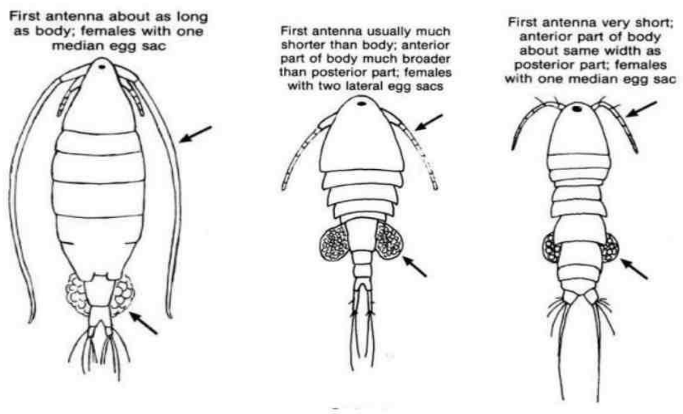


Fig. 2.2.1. Copepods (Slotwinski et al., 2014)

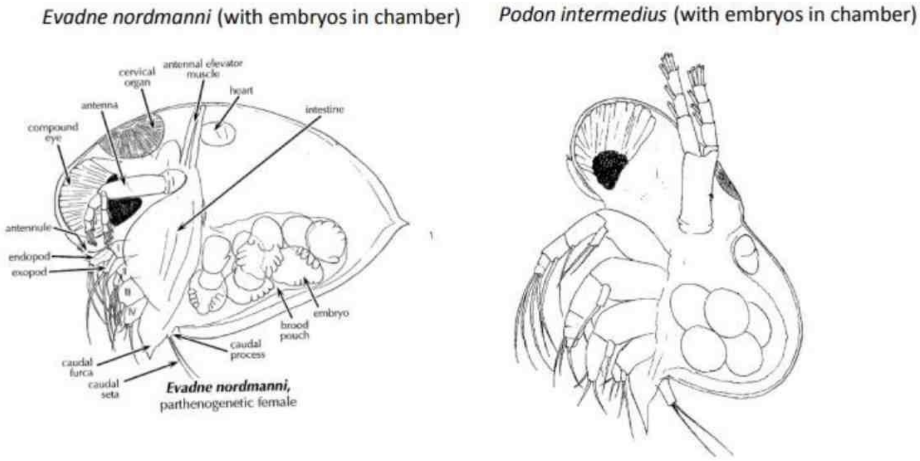


Fig. 2.2.2. Cladocera (slotwinski et al., 2014)

Cladocera order of small (0.2-5mm) crustaceans (Lynch, 1980) commonly known as ‘water fleas’. Most have an anterior, single and large compound eye. Typically, the head bears enormous, segmented, and branching antennas (Slotwinski et al., 2014). Ostracoda are microscopic crustaceans that range in length from 5 to 0.3 mm the carapace entirely covers their body (Zwair, 2023) have a clam-like shell with a tip (or rostrum) at one end.

The Decapoda are among the most explored animal families, owing to their prevalence in aquatic habitats (Vogt, 2012).The decapoda larvae (>3 mm) have huge eyes, numerous segmented appendages, spines, and typically a separate 'head' and 'tail' (Slotwinski et al., 2014). Isopoda comprises around 10,300 species, which include both marine and freshwater species (Wilson, 2008). Isopoda are rare in plankton and tend to be large (>5 mm), dorsoventrally compressed, and with non sessile eyes on their carapaces (Slotwinski et al., 2014). Amphipods lack shells and generally have bodies that are laterally compressed. Amphipods are relatively large (>5 mm) and laterally compressed, often with large eyes and sometimes chelae (Slotwinski et al., 2014). Chaetognaths are large (>5 mm), unsegmented, and resemble worms with enormous hooks on their heads. Echinoderm are ciliated and resemble trochophore stages in molluscs and annelids; however, others have arms, are bilaterally symmetrical, and are more distinct. Appendicularia look like tadpoles, with a distinct head and tail. Fish eggs are typically spherical and bigger (~1 mm) than other planktonic eggs, whereas larvae are elongated with distinct eyes, mouth, and fins (Slotwinski et al., 2014).

2.3 Indian Ocean

The Indian Ocean is the third largest ocean in the world, covering an area of approximately 70.56 million square kilometres (27.24 million square miles). It has a maximum length of 10,000 kilometres between Antarctica and the Bay of Bengal, and a width of 7,600 kilometres between Australia and Africa's southern tip (Moffet, 2024). The Indian Ocean plays a significant role in global ocean circulation patterns, contributing to the flow of heat, nutrients, and marine life around the world (Smith, 2020). The Indian Ocean experiences seasonal monsoons, which are characterised by strong, reversing winds (Shetye, 1998). During the summer monsoon (June to September), southwesterly winds bring moist air and heavy rainfall to the Indian subcontinent and Southeast Asia. In contrast, during the winter monsoon (December to February), winds move northeast, resulting in drier weather (Schott, 2001). During the summer monsoon, the West India Coastal Current (WICC, Shetye, 1998) travels southward and meets the eastward Summer Monsoon Current (SMC), The SMC transports high-salinity water (Arabian Sea High Salinity Water) into the Bay (Wyrtki, 1973, Murty, Sarma, Rao and Murty, 1992, Gopalakrishna, Pednekar and Murty, 1996, Han and McCreary, 2001). The salinity of the Bay of Bengal (BOB) is exceedingly diverse, both horizontally and vertically. A downward rise of 5 units (on the PSS-78 scale) over the upper 20 m of the water column is fairly unusual in the open Bay (Vinayachandran and Kurian, 2007). The Bay of Bengal (BOB) experiences substantial river water discharge (⁾1.6 X1012 m3 y-1) from the Indian subcontinent during the southwest monsoon, resulting in fresher surface waters and less favourable conditions for high-density water mass development (Manuel et al., 2006). Despite the low salinity levels, the BOB supports rich biological productivity, driven by nutrient inputs from river discharge and coastal upwelling (Kumar et al., 2002). The low salinity of surface waters promotes phytoplankton development, which serves as the base of the marine food web (Jyothibabu et al., 2018). The abundance of primary producers sustains diverse fish populations and supports important fisheries in the region(Hossain et al., 2019). Low salinity and weak winds at the surface in the Bay of Bengal reduces upward pumping of CO_2 (George et al., 1994) and N_2O (Naqvi *et al*., 1994). Therefore, surface concentrations of CO_2 and N_2O are lower than in the Arabian Sea. Biological productivity triggered by river and atmospheric nutrient depositions makes the BOB a seasonal sink for atmospheric CO_2 (Kumar et al., 1996).

2.4 Distribution of zooplankton in the Indian Ocean.

In recent years, there has been an increasing number of research on interannual variability in the tropical Indian Ocean (Perigaud and Delecluse, 1993; Masumoto and Meyers, 1998). With increasing interest and description of Indian Ocean Dipole (IOD) phenomena (Behera et al., 1999; Vinayachandran et al., 1999; Yu and Rienecker, 1999; Saji et al., 1999; Webster et al., 1999; Chambers et al., 1999; Xie et al., 2002). The Bay of Bengal (Northeastern Indian Ocean) is one of the most important regions in the world to study land-ocean interaction since it gets abundant riverine input from major rivers such as the Ganges, Brahmaputra, Godavari, Mahanadi, Cauvery, Irrawaddy, and Krishna Compared to its nearby basin, the Arabian Sea (Tanabe et al, 1993). The abundance and distribution of these zooplankton species varies depending on the season, depth, and geographical location within the bay (Vinayachandran et al., 2003). During the fall inter-monsoon, severe stratification in the top 50 metres of the water results in sea surface salinity as low as 28 and sea surface temperature ≥ 28℃ (Prasanna Kumar et al., 2016). Temperature, salinity, and food supply are some of the main elements known to influence geographic variations in zooplankton populations (Prasanna Kumar et al., 2016). All of these parameters, such as salinity, nutrients, and terrestrial organic matter, are considerably altered by river discharge, which has a direct impact on the abundance and diversity (Siokou-Frangou et al., 1998) additionally in the distribution of zooplankton (Habib, 1998). Zooplankton biomass and abundance has been reported to vary from 0.02 to 0.21 ml m^{-3} and 52 to 1745 numbers (N m^{-3}) on the coast off Andhra Pradesh (Venkataramana, 2017). It was reported that the copepod group was the dominating group within the mixed layer, accounting for 81% of the overall abundance in the northern Bay of Bengal (16°–20°N) during early winter monsoon (Sabu et al., 2015).

A study was carried out by Baliarsingh, Srichandan, Loltliker and Kumar in 2018 on the distribution of zooplankton on the North-Western Bay of Bengal. Zooplankton distribution in the northern BOB exhibits significant seasonal fluctuation, which is connected to variations in monsoon-driven hydrodynamics and nutrient dynamics. The study enhanced understanding of zooplankton diversity and distribution in coastal waters around Gopalpur, north-western BoB. Higher abundance was recorded during specific years. Copepods emerged as the most dominant group >50% of total population. Occurrence of low saline copepod species signified estuarine influence on the distribution of plankton community. It further revealed that zooplankton fauna of the region is susceptible to change under the influence of different environmental parameters such as salinity, chlorophyll a and nutrients of the ambient medium, rather than salinity resulting heterogeneity in species composition, population size and abundance of zooplankton. Seasonality was evident in the makeup of zooplankton communities, particularly during pre-monsoon and monsoon periods. Environmental factors such as sea surface temperature, chlorophyll content, and oceanographic features (e.g. coastal currents, eddies) influence zooplankton distribution patterns in the northwestern Bay of Bengal.

Comparing the diversity of zooplankton between the Arabian Sea and the Bay of Bengal (BoB) would involve considering various factors such as oceanographic conditions, temperature, salinity, and nutrient levels. The Arabian Sea is characterised by its unique oceanography, influenced by the Indian monsoon system. During the southwest monsoon, nutrient-rich waters are brought up from the depths, leading to increased productivity and a diverse range of zooplankton (Hood et al., 2024). Higher biological production during and following the southwest monsoon could also be supported by influx of atmospheric and river water discharges of nitrogen released by anthropogenic activities, primary agriculture (Durand et al., 2013). The Bay of Bengal experiences a different set of oceanographic conditions compared to the Arabian Sea. It is influenced by the northeast monsoon, which brings nutrient-rich waters from the Bay of Bengal to the northern Indian Ocean (Kumar et al., 2013). The Bay of Bengal is known for its high productivity, driven by nutrient inputs from river discharges, upwelling, and monsoonal currents; this high productivity supports a diverse array of zooplankton species (Hood et al., 2023).

CHAPTER III

MATERIALS AND METHODS

3. Materials and Methods

3.1 Study area

The Indian Ocean covers approximately 20% of the Earth's total ocean surface area. The eastern boundary of the Indian Ocean is formed by the western coastlines of Australia and the eastern coastlines of the Indian subcontinent and Southeast Asia (Hood et al., 2024). The Bay of Bengal is the northeastern extension of the Indian Ocean that is bordered by India and Sri Lanka to the west, Bangladesh and Myanmar to the north, and Thailand and Malaysia to the east (Alpers, 2014). It covers an area of almost 2.17 million square kilometres.

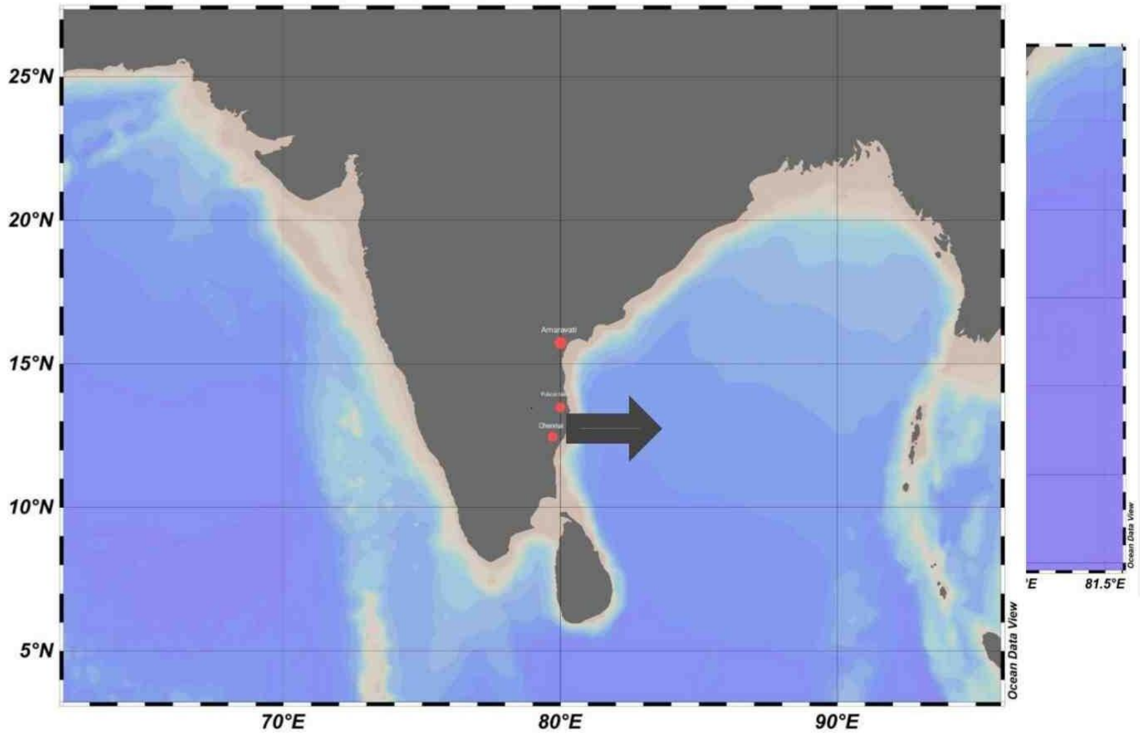


Fig 3.1.1. Map showing sampling locations off Chennai, Pulicat, Amaravati, Bay of Bengal.

The samples for the present study were from eighteen stations, off Chennai of Bay of Bengal, (13° 10.554089’N- 80°24.628811’E) to the north coast of Andhra Pradesh (Amaravati) (15°39.150’N - 80°43.6597’E) from 9th to 13th October 2022. It is the

transition period between the Southwest monsoon and the Northeast monsoon, causing a substantial change in weather patterns and ocean conditions (Sengupta, 2001). It brings heavy rainfall to the region from June to September, the Northeast monsoon starts gaining strength toward the end of October or early November (Goswami et al., 2001). This study area is influenced by fresh water flow through Pulicat lake covering an area of approximately 450 square kilometres. It is situated about 60 kilometres north of Chennai, the capital city of Tamil Nadu. The lake is separated from the Bay of Bengal by the barrier island of Sriharikota, which is home to the Satish Dhawan Space Centre (Goswami et al., 2001).

3.2 Sampling

The zooplankton samples for present study were collected (≅34 m depth) by horizontal towing of a Heron-Trenter net (mesh size 200 µm; net opening 0.25 m2) for 15 minutes at eighteen locations along the coast of Bay of Bengal in the Indian Ocean. The zooplankton sample was transferred into a 500 mL High Density Polyethylene Bottle (HDPE) and then fixed with formaldehyde (4% v/v), using siphoning tube the sample was concentrated to 60 ml and stored at room temperature for further laboratory analysis. Identification and enumeration of zooplankton in subsample was carried out using a Stereozoom microscope (Olympus; model no: SZX16).

Table 3.2. Details of sampling locations

Sr.no	Station no.	Date	Time	Latitude (N)	Longitude (E)	SST(°C)	Depth(m)
1	1	9/10//2022	9:45	13 °10.554089′	80 °24.628811′	29.1	34
2	3	9/10/2022	11:20	13°12.787360′	80°28.354145′	29.1	59.8
3	5	9/10/2022	2:10	13°18.0837′	80°32.234′	30.1	151
4	6	9/10/2022	3:10	13°19.944′	80°32.875′	29.3	195
5	7	10/10/2022	9:20	13°33.728′	80°31.975′	28.4	255
6	8	10/10/2022	10:22	13°32.673′	80°32.901′	28.5	269
7	11	10/10/2022	12:23	13°38.276′	80°34.988′	29.7	454
8	12	10/10/2022	1:47	13°43.803′	80°32.841′	29.5	1013
9	16	10/10/2022	4:18	13°44.880′	80°39.705′	29	1369
10	18	11/10/2022	9:36	14°29.881′	80°16.233′	28.2	24.1
11	20	11/10/2022	10:34	14°33.288′	80°13.288′	29.1	14
12	24	11/10/2022	1:40	14°39.471′	80°13.403′	29.2	22.6
13	27	11/10/2022	3:40	14°41.29′	80°15.354′	29.5	58.8
14	28	12/10/2022	10:30	15°15.577′	80°24.476′	28.5	46.7
15	29	12/10/2022	11:00	15°17.314′	80°24.929′	28.2	46.5
16	32	12/10/2022	12:10	15°20.996′	80°28.221′	29.3	48.13
17	38	12/10/2022	3:35	15°30.624′	80°38.373′	30.3	37.57
18	39	13/10/2022	9:07	15°39.150′	80°43.6597′	29.8	13.3

CHAPTER IV

ANALYSIS AND CONCLUSION

4.1 Results and Discussion

4.1.1 Variability in sea surface temperature

At the end of monsoon season, the sea surface temperature varied between 28.2 °C and 30.3°C in the study area (Table 3.2),. Lowest sea surface temperature was in station no. 18 and 29 (Fig. 4.1.1). highest was in station no.38 (Fig. 4.1.1).

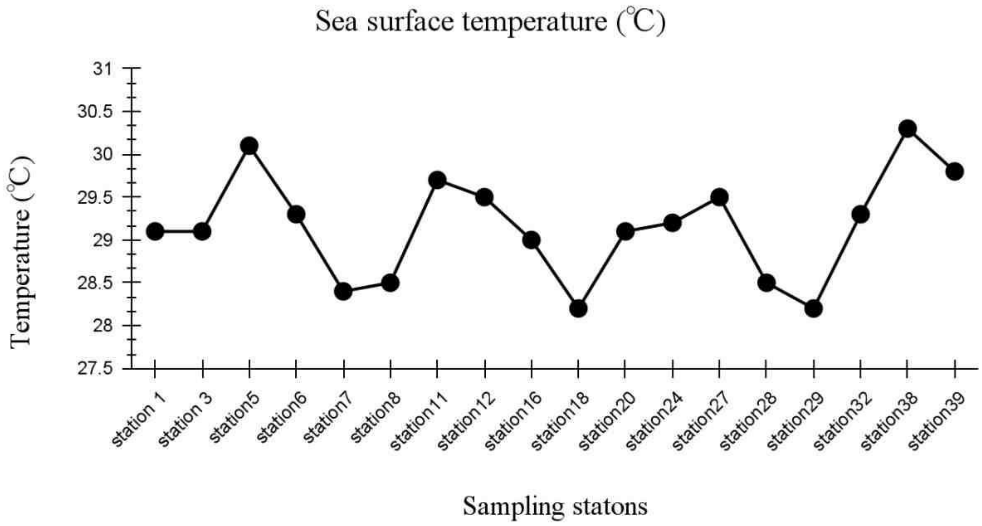


Fig. 4.1.1. Sea surface temperature at sampling stations

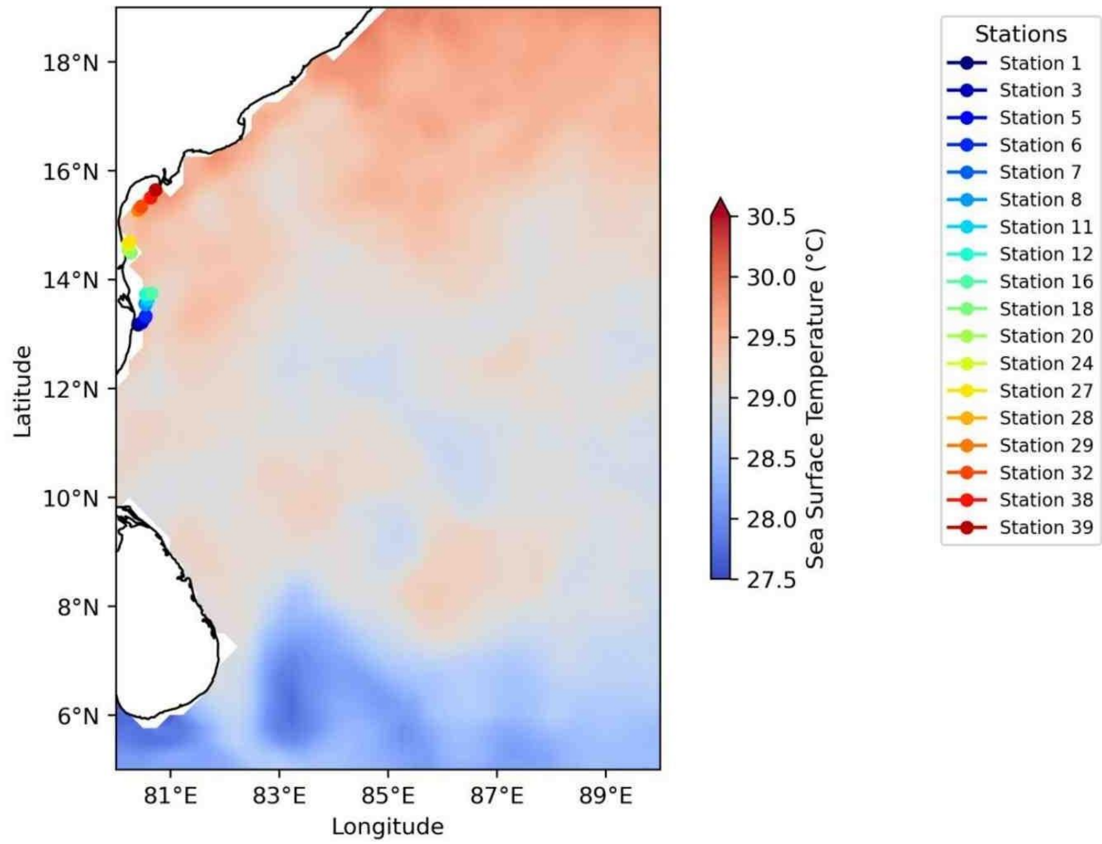
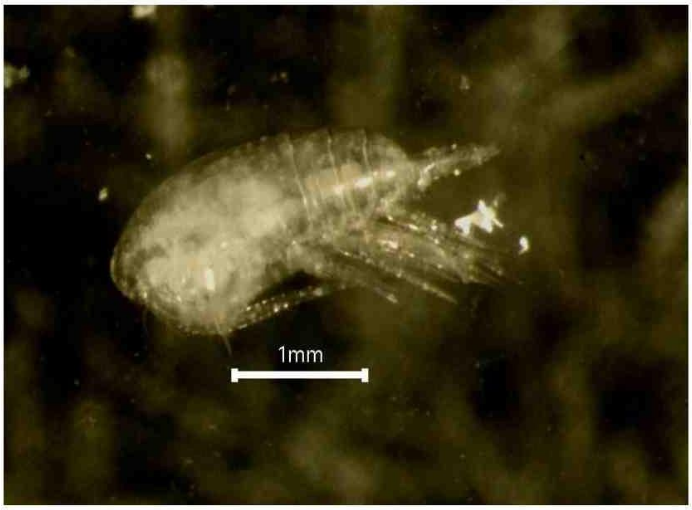


Fig. 4.1.2. Sea surface temperature at sampling stations along the east coast of India

.The graph was generated using the ERA5 Single Level Daily SST data-, focusing on the Bay of Bengal region during the sampling period. After selecting the specific area, the relevant data was downloaded. Subsequently, Python was utilized to plot the graph effectively.

4.1.2 Major zooplankton groups

Marine copepods are small crustaceans that range in size from 0.2 to 10 mm. Calanoida, Cyclopoida, and Harpacticoida are the most common orders. Copepods usually have a short, cylindrical body and a rounded or beaked head.



Phylum: Arthropoda

Subphylum: crustacea

Class: Maxillopoda

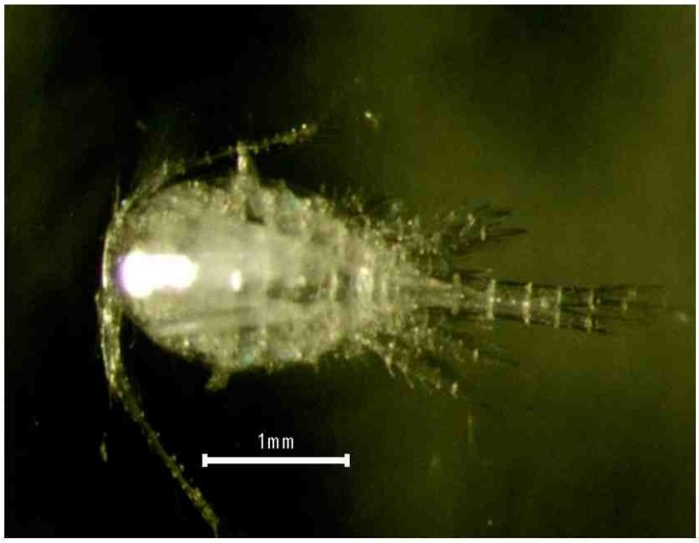
Subclass: Copepoda

Order: Calanoida

Kingdom: Animalia

Fig. 4.1.3 Order Calanoida

Calanoids are typically bullet-shaped of phylum arthropoda, subphylum crustacea; their body (prosome) is considerably larger and usually longer than the tail (urosome), and the antennae are around the length of the body. The primary antennas are typically long. Females often have five pairs of swimming legs, with the fifth leg being symmetrical but frequently smaller and less complicated than the other four. Males always have five pairs of legs, with the fifth pair being modified and asymmetrical to grip females during mating(Slotwinski et al., 2014).



Phylum: Arthropoda

Subphylum: Crustacea

Class: Maxillopoda

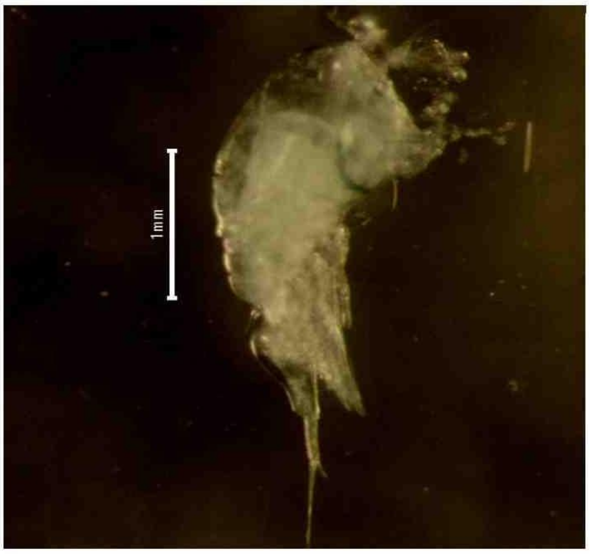
Subclass: Copepod

Order: Cyclopoida

Kingdom: Animalia

Fig. 4.1.4 Order Cyclopoida

Cyclopoids (1mm), Cyclepods are generally small, ranging from a few millimetres to a few centimetres in length, depending on the species. Typically have a cylindrical or elongated body shape, of which helps them move efficiently through water are smaller than calanoids, with a larger body (prosome) than the 'tail' (urosome), a comparatively lengthy urosome (similar to the prosome), and antennae shorter than the body. Consist of a large eye, which gives them a cyclops-like appearance. This eye is located in the centre of their head. Cyclepods are primarily filter feeders, using their feeding appendages to capture small particles, algae, and plankton from the water.



Phylum: Arthropoda

Subphylum: Crustacea

Class: Maxillopoda

Subclass: Copepod

Order: Harpacticoida

Kingdom: Animalia

Fig. 4.1.5. Order Harpacticoida

Harpacticoida (1mm),. Ranging from less than a millimetre to a few millimetres in length, with a compact body shape, are small copepods, with two pairs of antennae. Harpacticoida have a segmented body consisting of a head, thorax, and abdomen. Their bodies are adapted for both swimming and crawling. Less frequent than calanoids and cyclopoids. They have a body (prosome) that is identical in width to the 'tail' (urosome), resulting in little contrast between the two and very short antennae.

Phylum: Arthropoda

Subphylum: Crustacea

Superorder: Peracarida

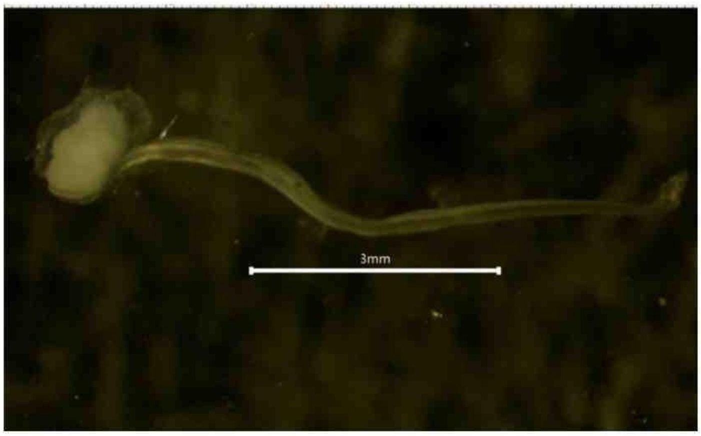
Order: Amphipoda

Domain: Eukaryota

Kingdom: Animalia

Fig. 4.1.6. Order Amphipoda

Amphipods (1mm), large eyes and occasionally with chelae. Amphipods lack a carapace and typically have laterally compressed bodies. The body is separated into thirteen segments, with the head fused to the thorax. They typically have a curved or somewhat flattened appearance, with a distinct head, thorax, and abdomen. The majority of amphipods are benthic(Bottom-dwelling)habitats, such as sandy or rocky substrates, as well as in planktonic environments.. They possess pairs of appendages, which vary in structure and function depending on the species and ecological niche. These include specialised appendages for walking, swimming, grasping, and feeding.



Phylum: Chordata

Subphylum: Tunicata

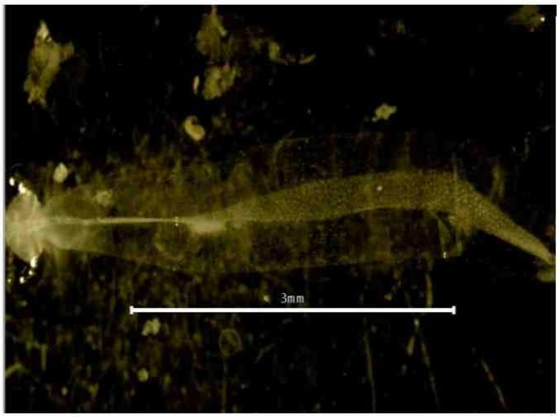
Class: Appendicularia

Order: Coplata

Kingdom: Animalia

Fig. 4.1.7. Class Appendicularia

Appendicularia (>5mm); also known as larvaceans or "sea squirts," (Gorsky and Fenaux, 1998), are small, free-swimming tunicates that belong to the class Appendicularia within the phylum Chordata, resembling tadpoles, with distinct 'head' and tail. They have a body plan similar to other tunicates, consisting of a gelatinous, transparent body called a "house" (Slotwinski et al., 2014). Within the house, there is a smaller, tadpole-like body known as the "trunk," which houses the vital organs such as the digestive system, nervous system, and reproductive organs. The body is separated into two regions: a trunk (the 'head' end) and a tail, which is often many times longer than the trunk and connects at 90° to the trunk.



Phylum: Chordata

Subphylum: Tunicata

Class: Appendicularia

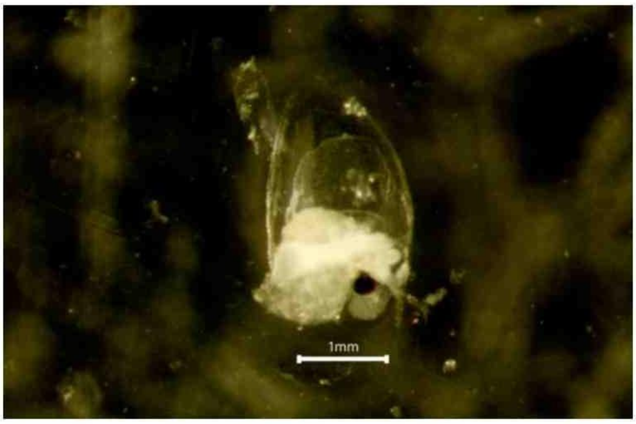
Order: Coplata

Kingdom: Animalia

Subkingdom: Eumetazoa

Fig. 4.1.8. Phylum Chaetognatha

Chaetognatha (>5mm), commonly known as arrow worms or chaetognaths, are a phylum of marine predatory worms characterised by their streamlined, arrow-shaped bodies. Chaetognaths have a slender, transparent, and cylindrical body that is bilaterally symmetrical and normally transparent or slightly opaque. The body is divided into three main regions: the head, trunk, and tail. The head is distinct and often bears sensory structures such as eyes and bristles (chaetae). The head of a chaetognatha is slightly rounded and equipped with specialised structures for capturing prey. This includes grasping spines or hooks and sensory organs like eyes, statocysts (for balance), and chemoreceptors. The trunk is the main body region where most of the internal organs are located. It contains the digestive system, reproductive organs, and parts of the nervous system. The tail of a chaetognatha is slender and tapers to a point. It assists in propulsion and steering during swimming.



Phylum: Arthropoda

Subphylum: Crustacea

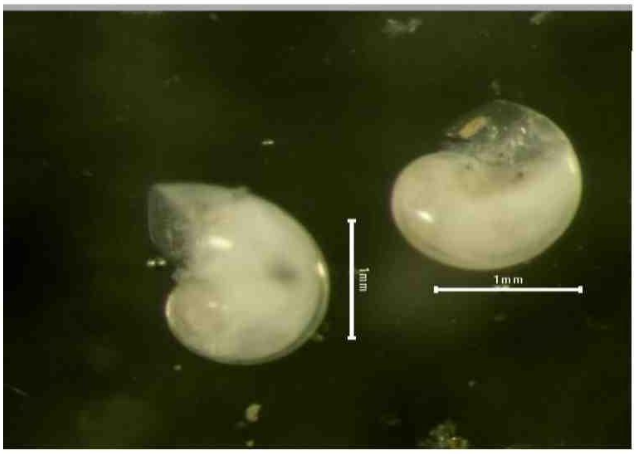
Class: Branchiopoda

Infraorder: Cladocera

Kingdom: Animalia

Fig. 4.1.9. Infraorder Cladocera

Cladocera (1mm) commonly known as water fleas, Cladocerans are typically small, ranging from less than 0.5 mm to a few millimetres in length. They have a distinct body structure consisting of a head, thorax, and abdomen. The head bears antennae and usually a single eye, while the thorax and abdomen may have appendages for swimming and feeding. Cladocerans often reproduce rapidly under favourable conditions through parthenogenesis (asexual reproduction) but can also reproduce sexually. They are known for their capability of producing resting eggs, which can survive harsh environmental conditions and hatch when conditions become favourable.



Phylum: Mollusca

Kingdom: Animalia

Domain: Eukaryota

Subkingdom: Eumetazoa

Fig. 4.1.10. Phylum Mollusca

Mollusca is a diverse phylum of invertebrate animals that includes holoplanktonic and meroplanktonic gastropods Some have ciliary bands on their tips, while others resemble mussels (meroplanktonic bivalve larvae) or small adult cephalopods. Mollusks typically have a soft body, though some have evolved hard shells for protection. The body may be covered by a mantle, which secretes the shell in species that have one. The body can be divided into, head with eyes or tentacles and muscular foot, used for various forms of locomotion. Most marine mollusks have a radula, a ribbon-like feeding organ covered with tiny teeth, which is used to scrape algae, detritus, or prey from surfaces. The radula is a key adaptation for obtaining food in marine environments. Bivalve (mussel) larvae, gastropods (snails), and cephalopod (squid and octopus) larvae are the three most prevalent molluscan groupings in plankton.

Phylum: Arthropoda

Subphylum: Crustacea

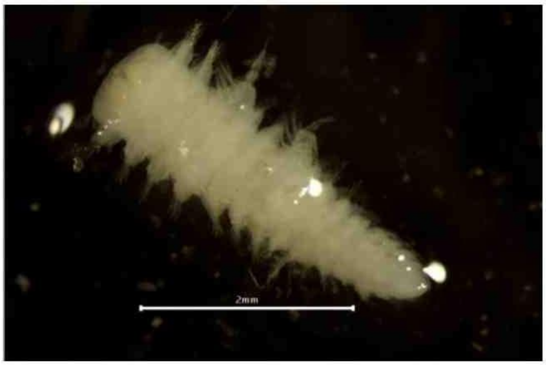
Domain: Eukaryota

Class: Ostracoda

Superclass: Oligostraca

Fig. 4.1.11. Class Ostracoda

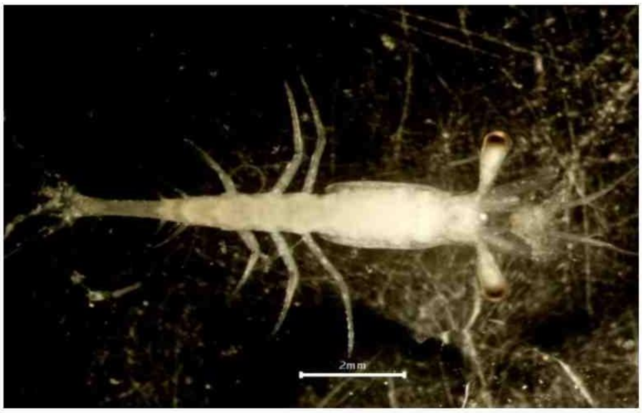
Ostracods (1mm) are typically very small, ranging from less than 1 mm to a few millimetres in size. They are bivalved crustaceans commonly known as seed shrimp. Ostracods contain a clam-like shell with a tip (or rostrum) at one end of it. The shell is made up of chitin, which covers their body. This shell is often transparent or translucent, allowing for easy observation of internal structures. The body is divided into two valves, with appendages protruding from between the valves. Most ostracods are filter feeders, using their appendages to capture small particles of food from the water column. Bivalve shell of ostracods encloses and protects the soft parts of their body, including their appendages and internal organs.



Phylum: Annelida
Scientific name: Polychaeta
Class: Polychaeta
Domain: Eukaryota
Kingdom: Animalia

Fig. 4.1.12. Class Polychaeta

Polychaeta (2mm) is a class within the phylum Annelida, they are often referred to as polychaete worms or bristle worms, are marine annelids characterised by their numerous chaetae (bristles) along the length of their body. Polychaetes typically have elongated, segmented bodies. Each body segment usually bears a pair of fleshy protrusions called parapodia, which bear bundles of chaetae used for locomotion and anchorage (Sclotwinski et al., 2014). Polychaetes possess various sensory structures such as eyespots, tentacles, and sensitive appendages to detect changes in their environment (Rouse et al., 2001). Polychaete larvae are often part of the meroplankton, which refers to planktonic organisms that only spend part of their life cycle as plankton before settling to the seafloor as adults.



Phylum: Arthropoda

Subphylum: Crustacea

Class: Malacostraca

Superorder: Eucardia

Order: Decapoda

Domain: Eukaryota

Kingdom: Animalia

Fig. 4.1.13. Order Decapoda

Decapoda (2mm); it includes crabs, lobsters, crayfish, shrimp, and prawns. Decapod larvae are relatively large, typically measuring over 3 millimetres in length and often have large compound eyes. The larvae possess numerous segmented appendages, which are usually used for swimming, capturing food, and sensing their environment. These appendages are often well-developed and may exhibit specialised structures depending on the larval stage and species. Decapod larvae typically have a distinct head region, which contains their sensory organs, mouthparts, and appendages for feeding and swimming. The tail region often includes structures like the telson and uropods, which are used for propulsion and steering during swimming.

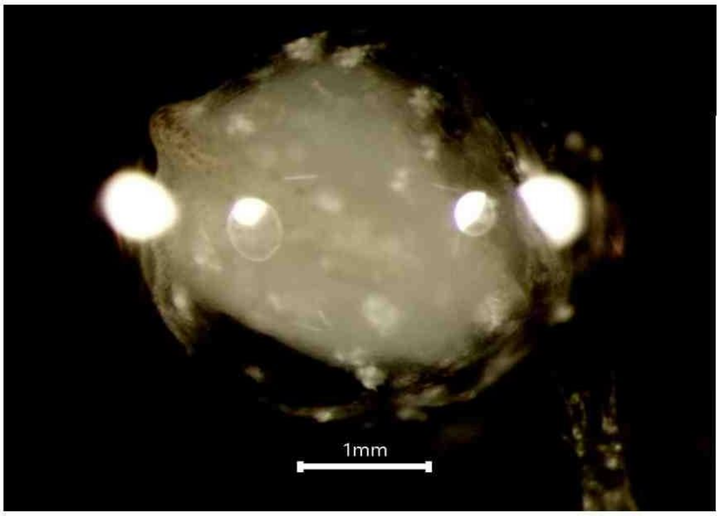
Phylum: Chordata

Subphylum: Vertebrata

Superclass: Osteichthyes

Fig. 4.1.14. Fish Larvae

Fish larvae are typically small in size, ranging from a few millimetres to a few centimetres in length. Many fish larvae have transparent or semi-transparent bodies, allowing for easy visualisation of internal organs and structures. This transparency aids in camouflage and protection from predators by making them less visible in the water column. Fish larvae typically have elongated bodies, which are adapted for swimming in the water column. Fish larvae have well-developed eyes, specialised jaws or mouthparts adapted for feeding on small planktonic organisms such as zooplankton or phytoplankton, typically possessing fin structures that aid in swimming and manoeuvring.



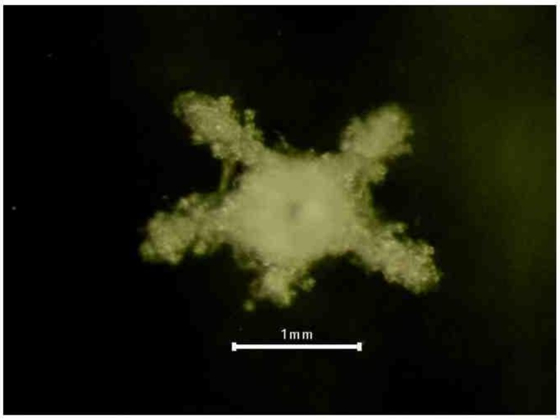
Phylum: Chordata

Domain: Eukaryota

Kingdom: Animalia

Fig. 4.1.15. Fish egg

Fish eggs are typically spherical and larger in size compared to other planktonic eggs and larvae. They can vary in size depending on the species, but they are generally around 1 millimetre in diameter or larger. Fish eggs are fertilised externally or internally, depending on the species. After fertilisation, the embryo develops within the egg, nourished by the yolk contained within it. Development time varies widely among fish species and can range from a few days to several weeks or even months.



Scientific name: Echinodermata

Phylum: Echinodermata

Domain: Eukaryota

Kingdom: Animalia

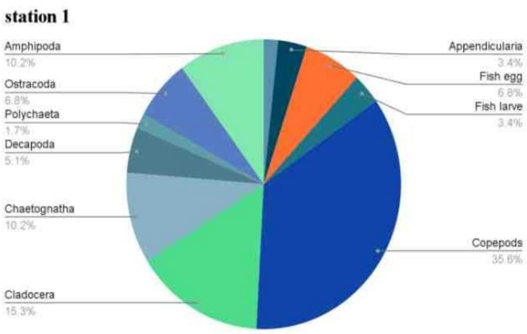
Subkingdom: Eumetazoa

Superphylum: Deuterostomia

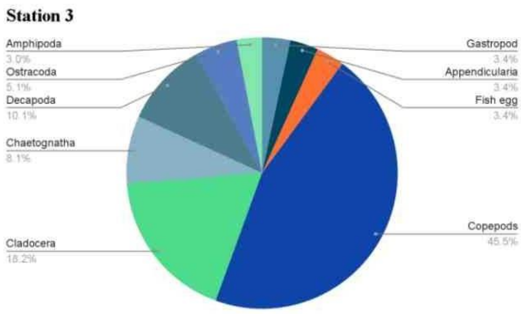
Fig. 4.1.16. Phylum Echinodermata

Echinoderm larvae exhibit a fascinating diversity of forms. Some, like the auricularia larvae of sea stars, are ciliated and resemble trochophore larvae, which are characteristic of certain mollusks and annelids. These larvae typically have a simple, bilaterally symmetrical body plan. Echinoderm larvae possess ciliated bands or rows of cilia that are used for locomotion, feeding, and sensory functions. These ciliary bands are typically arranged in specific patterns along the larval body and play a crucial role in larval swimming and feeding behaviours.They have transparent or semi-transparent bodies, which allows for easy observation under a microscope. This transparency facilitates the study of larval morphology, behaviour, and developmental processes in laboratory settings. The adult echinoderms typically exhibit pentaradial symmetry, meaning their bodies are organised around a central axis into five equal parts, the larvae initially possess bilateral symmetry.

4.1.3 Composition of zooplankton



(a)



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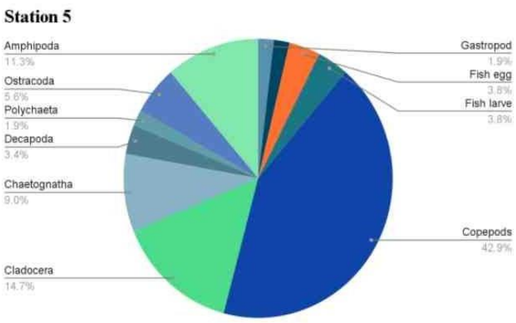

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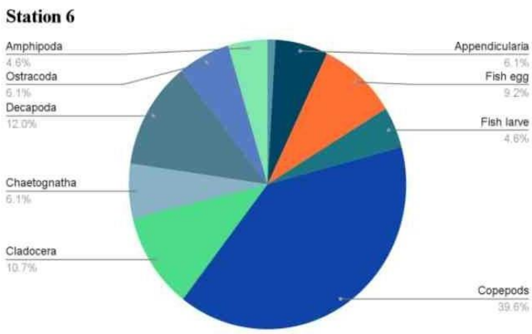

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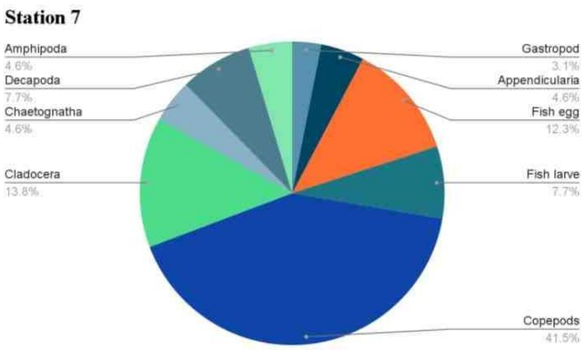

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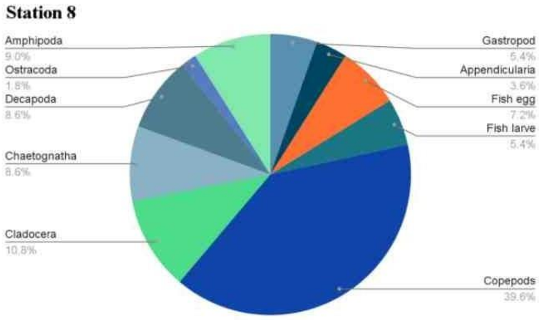

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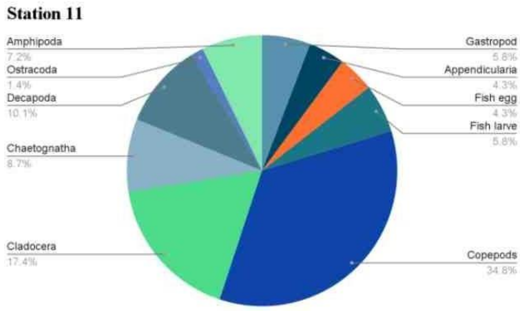

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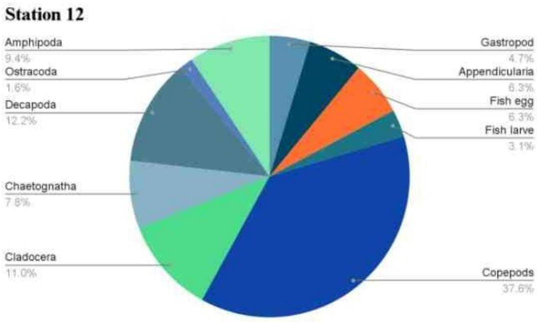

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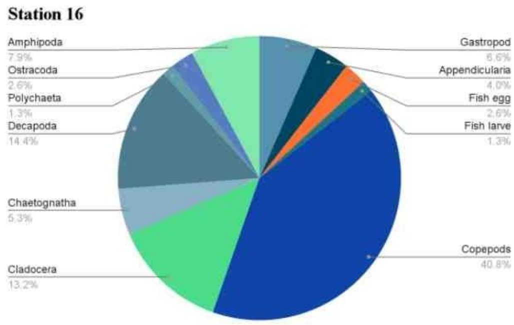
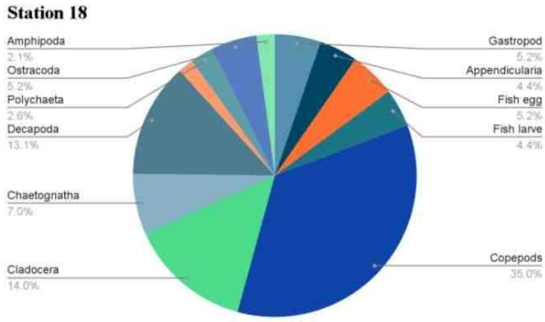
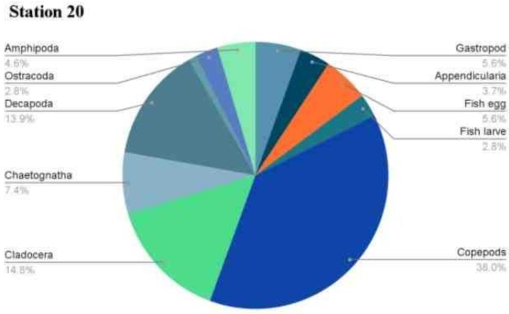


(i)

Fig. 4.1.17 (a-i) Percentage of major zooplankton groups off Chennai



(j)



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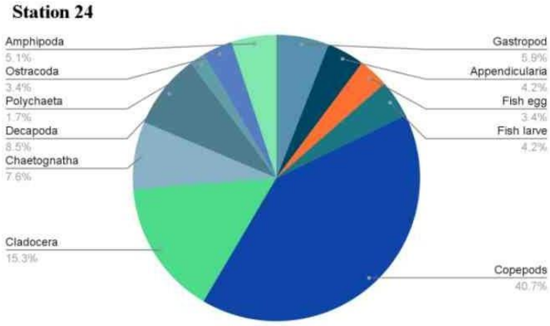
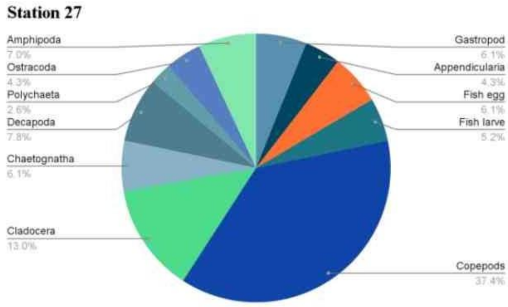
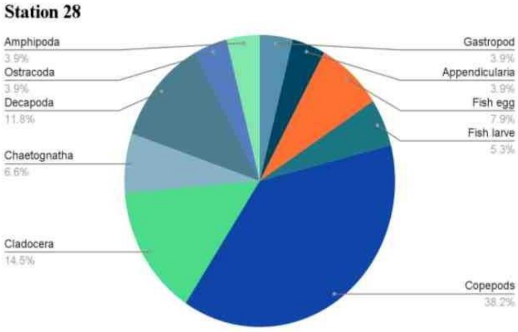


(l)

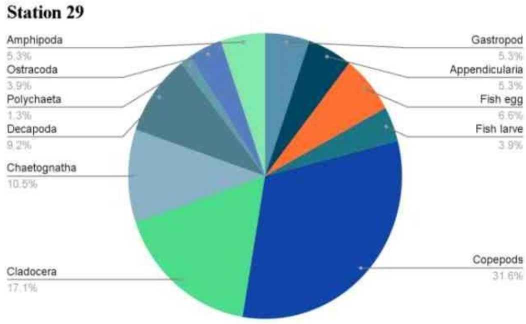


(m)

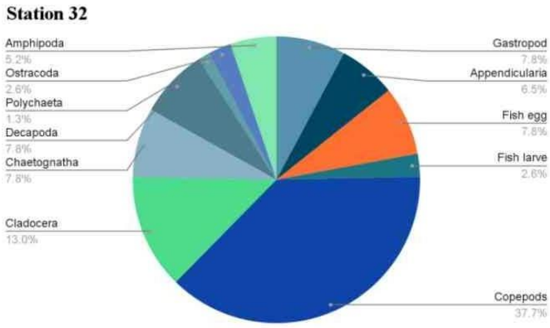
Fig.4.1.18 (j-m) Percentage of major zooplankton groups off Pulicat



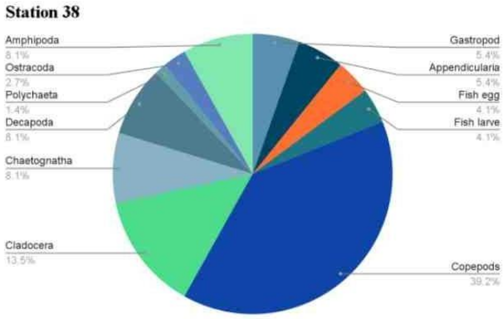
(n)



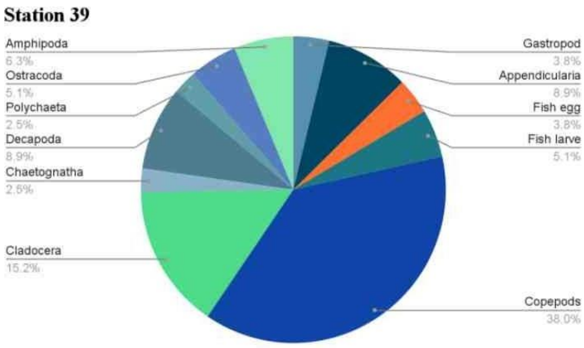
(o)



(p)



(q)



(r)

Fig.4.1.19 (n-r) Percentage of major zooplankton groups off Amaravati

In terms of zooplankton groupings throughout all samples, crustacea dominated in all stations represented by copepods followed by cladocera Fig. 4.1.17 (a-i), Fig. 4.1.18 (j-m) & Fig. 4.1.19 (n-r). Copepods, namely Calanoida, Cyclopoida and Harpacticoida were the dominant zooplankton group across all sites studied . Calanoid copepods were more as compared to Cyclopods and Harpacticoid (Fig. 4.1.20). The Decapods group, Chaetognatha, Amphipoda, Appendicularia, Fish egg and Fish larvae were also recorded in all stations.

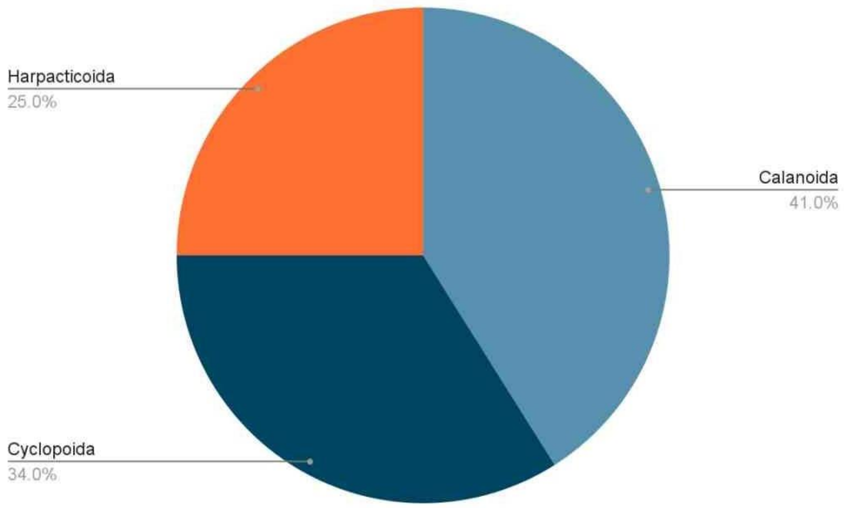


Fig.4.1.20. Percentage contribution of Calanoida, Cyclopoida and Harpacticoida for all samples

Off Chennai (Stations 1, 3 and 5), Copepods remained dominant (Fig. 4.1.21.) followed by Cladocera and the minimum number of Copepods and Decapods were recorded at this region (stations 1 and 5) (Fig. 4.1.21.).

Off Pulicat (stations 18, 20, 24 and 27), maximum number of Copepods, Cladocera, Decapoda were recorded in this region (Fig. 4.1.21.). Chaetognatha was maximum at stations 20 and 24 (Fig. 4.1.21). Fish egg, Fish larvae and Appendicularia were abundant at stations 24 and 27 (Fig. 4.1.22). Amphipods, Ostracoda and Polychaeta were maximum at stations 18 and 27 (Fig. 4.1.23). Echinoderm was only recorded at station 18 (Fig. 4.1.23).

In the northern stations i.e. Off Amaravati, stations 32, 38 and 39 showed maximum number of Copepods per sample analyzed followed by Cladocera (Fig. 4.1.21). The minimum number of Chaetognatha was also recorded in this region at stations 38 and 39 (Fig. 4.1.21). The maximum number of appendicularians were recorded at station 39 (Fig. 4.1.22). Compared to the southern sampling locations, the number of Copepods, Cladocera and Decapods numbers were higher off Amaravati (Fig. 4.1.21).

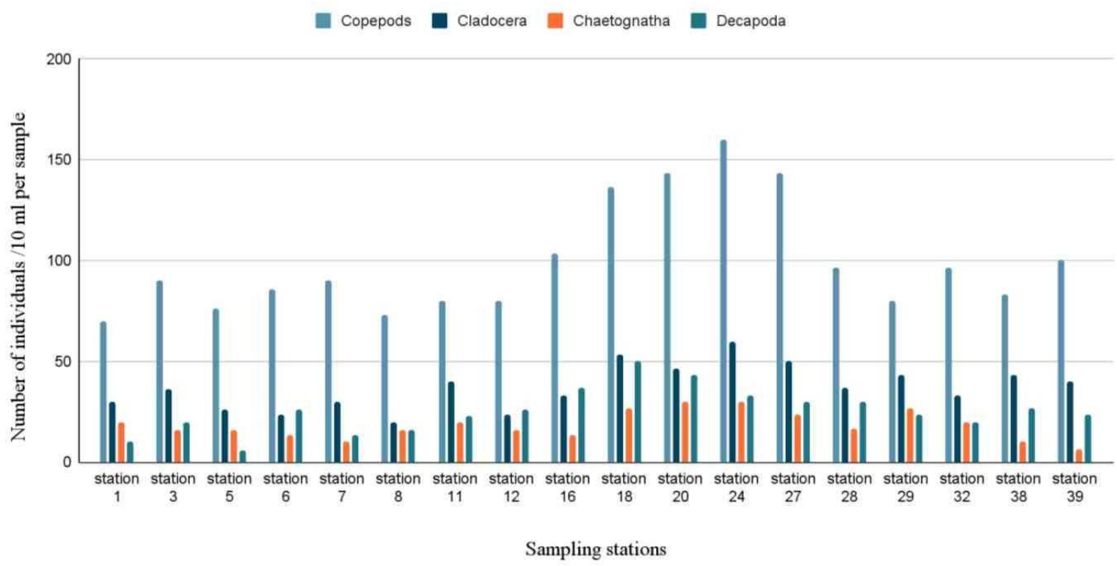


Fig. 4.1.21. Variation in number of Copepods, Cladocera, Chaetognatha, Decapoda at sampling stations

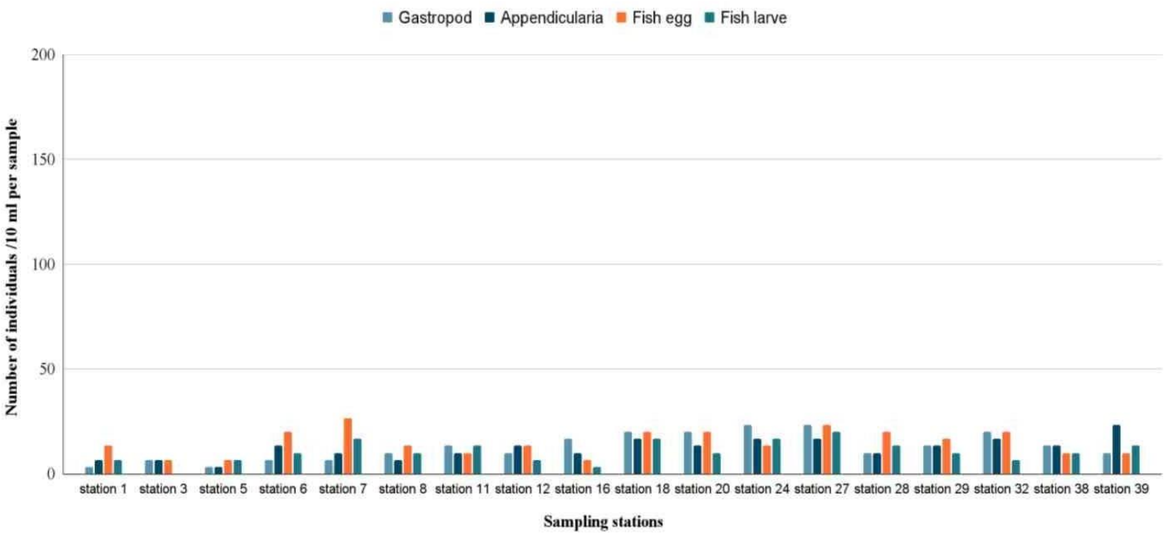


Fig. 4.1.22. Variation in number of Gastropod, Appendicularia, Fish egg and Fish larvae at Sampling stations

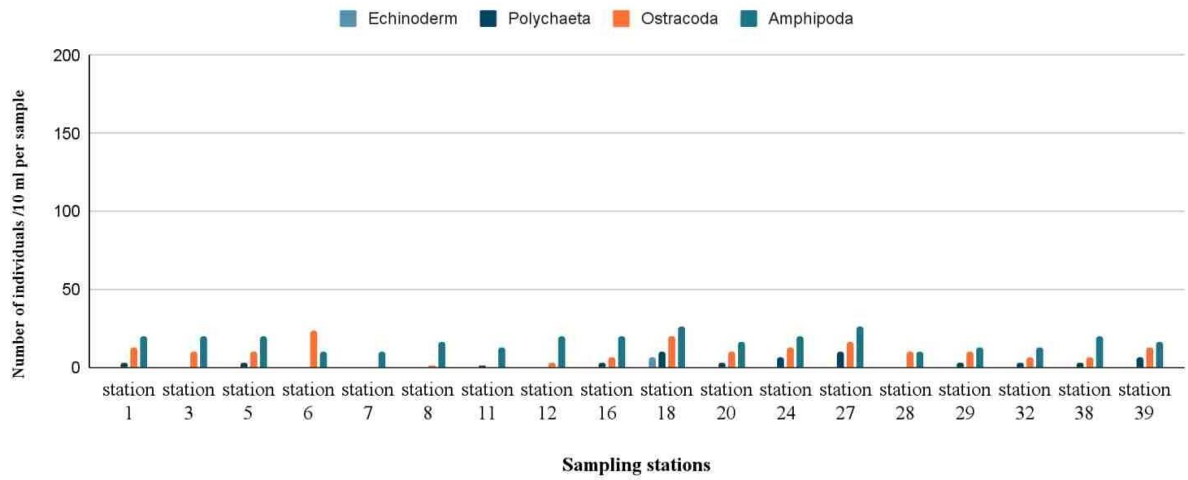


Fig. 4.1.23. Variation in number Echinoderm, Polychaeta, Ostracoda, Amphipoda at sampling stations

4.2 Discussion

Identification of zooplankton is a fundamental aspect of ecological studies, providing insights into community composition, population dynamics, and ecosystem health. However, the vast diversity of zooplankton species, ranging from microscopic protozoans to larger crustaceans. In this study, there were 11 groups of zooplankton. We employed a combination of morphological and ecological approaches to enhance the accuracy and efficiency of zooplankton identification. The bulk of zooplankton identification still relies on microscopes and taxonomic guides, but recent advances in imaging technology and computer software may offer significant gains in speed and precision (Benfield et al. 2007). In this study, morphological identification served as the foundation for species recognition, enabling us to distinguish between different zooplankton taxa based on distinctive anatomical structures such as appendages, body shape, and pigmentation patterns conceptualized by (Slotwinski et al., 2014). Zooplankton identification is integral to ecological studies investigating biodiversity, trophic interactions, and ecosystem functioning, zooplankton identification to environmental variables, such as temperature, salinity, and nutrient concentrations, to elucidate ecological patterns and processes (Carstensen et al., 2019).

Considering that temperature is essential drivers of zooplankton distribution (Hirst and Bunker, 2003), one might have expected the zooplankton communities to differ at different stations. In the present study, no such relation was observed.

In the present study, the number of zooplankton varied according to the topography of the sampling site. Our data showed the dominance of copepods at each sampling station The reason for this can be; Copepods are known for their rapid reproductive rates, with some species capable of producing multiple generations in a short period under favourable conditions (Kiorboe, 2013). Also the ability of copepods to utilise resources and adapt to changing environmental conditions contributes to their dominance in aquatic habitats. Cladocera was the second most dominant zooplankton; their dominance can occur under specific conditions that favour the rapid reproduction and population growth of cladocerans. Cladocerans are known for their rapid reproductive rates under favourable conditions. Many species of cladocerans are parthenogenetic, meaning they can reproduce without fertilisation, leading to exponential population growth (Larsson and Lampert, 2011).

Maximum number of zooplankton was recorded at the stations 18, 20, 24 and 27. There is an influx of more fresh water in this region from Pulicat lake. The main source of freshwater is land runoff through three small seasonal rivers that open into the lake viz., Arani, Kalangi and Swarnamukhi (Dhinamala et al., 2015). Minimum number of zooplankton was recorded at, off Chennai stations 1 and 5. Human activities such as coastal development, dredging, and habitat destruction can disrupt the natural habitat of zooplankton. Loss of suitable habitat can lead to a decline in their numbers (Halpern et al., 2008). Zooplankton are highly sensitive to changes in water quality, and pollutants can directly affect their abundance and distribution (Halpern et al., 2008). However, the zooplankton communities at all the stations were abundant, except for order Echinoderm which showed the distribution only at station 18. The low abundance of Echinoderm larvae can be influenced by various factors related to their reproductive biology, environmental conditions, and ecological interactions. Echinoderms often exhibit synchronous spawning events, where adults release their gametes into the water column simultaneously. If spawning synchrony is disrupted due to environmental factors such as temperature fluctuations or changes in water quality, it can result in reduced larval abundance (Young et al., 2009).

4.3 Summary

The present study was carried out to analyze zooplankton composition at 18 stations along the south east coast of India, during October, 2022.

- ❖ The sea surface temperature at sampling stations varied between 28.2 °C (station no. 18 and 29) off Pulicat and 30.3 °C off Amaravati (station no. 38.).
- ❖ Composition of zooplankton

The number of individuals per sample were maximum, off Pulicat stations possibly influenced by freshwater from the Pulicat lake (Dhinamala et al., 2015). Number of individuals per sample was minimum, off Chennai stations 1 and 5. This can be attributed to the effect that zooplankton are highly sensitive to changes in water quality, and pollutants can directly affect their abundance and distribution (Halpern et al., 2008). Off Amaravati, the number of Appendicularians were higher at station 39, due to favorable environmental conditions such as nutrient availability, temperature, and water currents. Additionally, local ecological interactions and biological factors could also influence their population dynamics, such as predation pressure or competition with other planktonic organisms (Sakai et al., 2018).

4.4 Conclusion

The current study on zooplankton, off Chennai BOB reveals that Crustacea dominated at all stations represented by Copepods followed by Cladocera. Off pulicat showed maximum number of zooplankton followed by those collected off Amaravati. Pulicat lake plays a major role in the abundance of zooplankton in the region. The minimum number of zooplankton were recorded off Chennai and number of Appendicularians were higher off Amaravati it reveals that human activities can affect the abundance of zooplankton. The present study will act as a baseline study for the identification and composition of zooplankton in the BOB region. Moreover, studying zooplankton populations in the Bay of Bengal region provides valuable insights into broader ecological patterns and can inform conservation and management strategies aimed at preserving the health and productivity of this vital marine environment. The data can help to assess the impact of anthropogenic activities on zooplankton composition and overall ecosystem health. Future studies could be focussed on assessing the biomass, diversity and influence of prevailing environmental conditions on the zooplankton community.

CHAPTER V

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5. References

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