Autotrophic Picoplankton of Cochin Backwater, their Seasonality and Ecological Efficiency

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Certificate

*This is to certify that the thesis entitled **"Autotrophic Picoplankton of Cochin Backwater, their Seasonality and Ecological Efficiency"** is an authentic record of the research work carried out by **Ms. Sooria. P. M,** under my supervision and guidance in the Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Marine Biology of Cochin University of Science and Technology, and no part thereof has been presented for the award of any other degree, diploma or associateship in any University. I also certify that all the relevant corrections and modifications as suggested by the audience during the pre- synopsis seminar and recommended by the Doctoral committee have been incorporated in this thesis.*

Prof. Dr. A. V. Saramma
Supervising Guide

Declaration

I hereby declare that the thesis entitled ***"Autotrophic Picoplankton of Cochin Backwater, their Seasonality and Ecological Efficiency"*** is an authentic work carried out by me under the supervision and guidance of Dr. A. V. Saramma (Retd.), Professor, School of Marine Sciences, Cochin University of Science and Technology, for the Ph. D degree in Marine Biology of the Cochin University of Science and Technology and no part thereof has been presented for the award of any other degree, diploma or associateship in any University.

Sooria. P. M

Cochin- 16
Date:

To my beloved mentor,
the Late. Prof. Dr. N.R. Menon
for guiding me from the milieu of fragmented knowledge
to the world of wisdom….

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List of Abbreviations

APP	- Autotrophic Picoplankton
HPP	- Heterotrophic Picoplankton
ANP	- Autotrophic Nanoplankton
HNP	- Heterotrophic Nanoplankton
HNF	- Heterotrophic nanoflagellate
MZP	- Microzooplankton
MSP	- Mesozooplankton
DO	- Dissolved Oxygen
DOC	- Dissolved Organic Carbon
POC	- Particulate Organic Carbon
TOC	- Total Organic Carbon
DCM	- Deep Chlorophyll Maximum
HNLC	- High Nutrient Low Chlorophyll Region

Chapter I

General Introduction

1.1. The Food Web

All life forms in our little blue planet – from bacteria to blue whale -have its own story and the stories never end till the great circle of life moves through the infinite time and space with its tremendous resilience. Food webs are the fundamental representation of this great circle which is driven by the energy source so called sun and regulated by the mechanism of eating and being eaten. Charles Darwin referred the food web as an “entangled bank”, and in most basic form, it reveals to us something about feeding relationship among the various functional components in an ecosystem.

Charles Elton (1927) who explained the ‘pyramid of numbers’ was the pioneer figure in food web research. Later, Raymond Lindeman emphasized on the successive energy loss at each trophic level in his classic paper (Lindeman, 1942). Thus, by using energy as the currency of ecosystem he quantified and explained Eltonian pyramid. Later, a different approach ruled in community ecology was initiated by May (1973) and pursued by Pimm (1982); this approach was based on the hypothesis that too much interaction destabilizes the food web. More recently Stephen Carpenter and James Kitchell have become leaders in aquatic food web research. Their theory regarding the trophic cascade in aquatic food webs has been central to the current debate on ‘top down’ and ‘bottom up’ control of populations (Carpenter & Kitchell, 1988; Carpenter & Kitchell, 1992). The present scenario of food web research involves the development of ecosystem simulation models using highly resolved food webs as a tool. Now food web approaches have taken hold in many applied management endeavours, such as fisheries and conservation biology by encouraging a more dynamic, interaction driven view of ecosystems (Zavaleta *et al.*, 2010). Adopting a food web perspective will provide valuable insight in to ecological restoration that would not otherwise be attained from a more static community-based approach. Thus, the present study tries to unveil the trophic role of aquatic food web component called autotrophic picoplankton (APP) in a nutrient rich coastal environment based on an ecosystem perspective.

1.2. Trophic Status of Autotrophic Picoplankton

Before 1970s marine food web structure was a simple linear model as described in ‘classical text book representation of pelagic marine food web based on plankton and feeding habits of herring in the North Sea' (Hardy, 1924). This simplified depiction was called as 'classic food chain' which include algae as primary producers, zooplankton as secondary producers and fish as teritiory producers. Later a paradigm change was introduced by Lawrence Pomeroy in 1974. He argued that classic food chain is only a small part of the energy flow in aquatic ecosystems, since the presence of microorganism, dissolved organic matter and non-living particles in the sea suggest the occurrence of other pathways through which a major part of the available energy may be flowing (Pomeroy, 1974). After that Williams (1981) and Azam *et al.* (1983) have brought a change in conceptual framework by introducing the presence of a feedback loop called 'microbial loop' in pelagic food web. According to them dissolved organic carbon (DOC) present in water column is utilized by bacteria and pumped back into the classic food chain through protozoans (bacterivores), an alternative food source of mesozooplankton. Thus, over the past two decades we accept microbial dominance of the ocean metabolism as a well-established fact and classical plankton community concept exists only as a caricature (Landry, 2002). As their size range is like the wavelength of visible light, most marine bacterioplankton were invisible to ordinary microscopy and could not be counted directly until the development of epifluorescent microscope (Francisco *et al.,* 1973; Hobbie *et al.,* 1977). Their metabolic impact on ocean was also underestimated till the development of tracer methods (Azam & Hodson, 1977; Fuhman & Azam, 1980). Later, a cyanobacterium called *Prochlorococcus*, which is found in high abundance in oligotrophic oceans, was discovered by Chishlom *et al.* (1988). This autotrophic unicellular form was having a size range of 0.2µm to 2µm.Thus a new episode has started in pelagic food web research. Now this small size fraction of phytoplankton or APP is considered as the major contributor to the total primary productivity of open ocean, rather than the larger fraction.

Autotrophic picoplankton is a ubiquitous and diverse component of marine and freshwater ecosystems (Waterbury *et al.,* 1979; Johnson & Sieburth, 1979; Chisholm *et al.,* 1988; Stockner *et al.,* 2000). Cyanobacterial genera such as *Synechococcus* and *Prochlorococcus* are known to comprise a large proportion of the autotrophic picoplankton community. Recent studies have demonstrated that eukaryotic picophytoplankton may also contribute significantly as well (Worden *et al.,* 2004). It has now been well established that autotrophic picoplankton biomass is constantly utilized by higher trophic levels of pelagic foodweb. Like bacteria, the relative constancy of their populations in temperate, tropical and subtropical oceans, implies that their population control is by predation or 'Topdown control' (Johnson *et al.,* 1981; Iturriaga & Mitchell, 1986; Campbell *et al.,* 1994). On the basis of literature reports, heterotrophic nanoplankton (HNP) and microzooplankton (MZP) appear to be the principal predators of autotrophic picoplankton in both marine (Perkins *et al.,* 1981; Landry & Kirchman, 2002) and freshwater ecosystems (Caron *et al.,* 1985; Fahnenstiel *et al.,* 1986; Callieri & Stockner, 2002) which are in turn consumed by mesozooplankton (MSP). Some mixotrophic flagellates are capable of direct ingestion of this algal picoplankton (Porter *et al.,* 1985; Landry, 2002). Ciliates also appear to be significant grazers of algal picoplankton in marine waters (Iturriaga & Mitchell, 1986; Sherr *et. al.,* 1992). Rotifers can also utilize autotrophic picoplankton because of their ubiquity and rapid grazing rates (Caron *et. al.,* 1985; Stockner, 1988). Autotrophic picoplankton have been found in the guts and fecal pellets of both marine and freshwater copepods, but they appear to be undigested and viable (Silver & Alldredge, 1981; Caron *et al.,* 1985). *Synechococcus* has been observed in Cladocerans too (Stockner & Antia, 1986). Other metazoan filterfeeders like bryozoans, pelagic larval stages of marine invertebrates, bivalves and sponges can potentially retain autotrophic picoplankton and the heaviest grazing by these metazoans would likely occur in estuaries and in nearshore waters due to the great abundance and biomass of picoplankton in these ecosystems (Gast, 1985; Glover, 1985; Stockner, 1988). Autotrophic picoplankton are at an advantage relative to larger phytoplankton cells in avoiding damage from eukaryotic parasites, and losses from sedimentation. However, viruses and small grazers can attack autotrophic picoplankton, just as viruses and larger grazers can attack larger phytoplankton (Raven *et al.,* 2005). Thus autotrophic picoplankton act as the primary producers of the microbial food web (even if the mesozooplankton cannot utilize them directly) and pump biogenic carbon to the higher trophic level through microzooplankton as a link (APP → HNF→ MZP→ MSP→ FISH).

The small size of autotrophic picoplankton gives many adaptive advantages that have likely contributed to their widespread abundance and distribution. Small cells have a greater surface area to volume ratio than larger cells, allowing for more resource (light and nutrients) acquisition area relative to internal cell structure. Small cells also have a thinner diffusive boundary layer surrounding their surface, allowing for more efficient nutrient uptake, and which is thought to be advantageous in low nutrient environments (Raven, 1986). Photon absorption rates are also higher for smaller cells, and hence autotrophic picoplankton is able to efficiently utilize photons for photosynthesis and growth especially in low light environment (Raven, 1986). According to the current belief these adaptive advantages contribute to the overwhelming dominance of autotrophic picoplankton in low nutrient, low light environments.

1.3. Rationale for the Study

Autotrophic picoplankton can be responsible for a dominant proportion of the total phytoplankton biomass (Landry *et al.,* 1996; Marañón *et al.,* 2001) and primary production (Platt *et al.,* 1983; Bell & Kalff, 2001) in oligotrophic open ocean systems. Their relative contribution is, however, thought to decrease in more eutrophic waters where the higher nutrient uptake rates of larger phytoplankton species may lead them to outcompete smaller cells when nutrients are plentiful (Riegman *et al.,* 1993). Hence, most researches on the smaller phytoplankton size fraction has focused on open-ocean systems, and the potential importance of autotrophic picoplankton in eutrophic waters has not until recently been realized. But some of the recent studies indicate widespread occurrence of autotrophic picoplankton in eutrophic coastal ecosystems as well (Marshall & Nesius, 1996; Philips *et al.,* 1999; Marshall, 2002). Despite the fact that autotrophic picoplankton numerically dominates in many estuarine systems, their relative small contribution to the total biomass leads to the widely held assumption that the importance of picoautotrophs decreases with increase in total system biomass. This conventional approach is quite unconvincing because of the following rationale.

1. It is proven that compared with larger cells smaller cells would be slower in converting nutrients into biomass (Marañón *et al.,* 2013) and as a result they achieve lower maximum growth rate. Therefore, even if small sized producers are numerically abundant, their total biomass will be very low unless they attain a very high growth rate compared to larger producers. Thus, it is likely that they become conspicuous only in systems where larger cells rarely survive.
2. Population dynamics of larger phytoplankton is found to be controlled by bottom up mechanisms (nutrient factors) and that of smaller ones is by top down mechanisms (grazing)

3. As size difference itself acts as a niche partitioning mechanism in plankton community, smaller phototrophs are preferred by smaller grazers and the larger ones by larger grazers. i.e. the predation pressure exerted on both communities differs in different environments.
4. When larger phytoplankton act as the base of a transport pathway (classic food web), autotrophic picoplankton are the producers of a recycling pathway (microbial food web), even if both food chains are linked at certain trophic level.
5. As autotrophic picoplankton are able to utilize photons efficiently in low light environment (Raven, 1986), they might be contributing to the production of highly turbid and highly dynamic coastal waters too.

Hence, as both plankton communities are regulated by different mechanisms it appears to be more logical to evaluate the significance of autotrophic picoplankton based on their ecological role rather than their biomass contribution perspective. Tight coupling between growth rates and loss by grazing have helped to explain why this smallest planktonic size fraction do not appear to respond as strongly as larger cells when growth conditions are favourable for both size fractions (Barber & Hiscock, 2006). Consequently, the fate of carbon fixed by the small size fraction (Fixation, export and sequestration) also becomes important in coastal environments. Hence, the proposed study adopts a combined approach of biogeochemistry and community ecology to reveal the significance of autotrophic picoplankton -an uncharted food web component of eutrophic waters.

1.4. Objectives and Perspectives

Autotrophic picoplankton plays an important role in the microbial food web by forming the base of food chain and serving as food for many protists and small invertebrate species (Pomeroy, 1974; Azam, *et al.*, 1983). Carbon transfer through microbial food web creates the important connection between these microscopic autotrophs and higher trophic levels (Chiang *et al.,* 2013). Several studies on phytoplankton have been conducted in estuarine region encompassing a wide salinity range. These studies suggest that salinity plays an important role in the spatial distribution of autotrophic picoplankton groups (Ray *et al.*, 1989; Murrell & Lores, 2004) and highlights that they are the major component of the phytoplankton community contributing substantially to the total biomass and primary production in estuarine region of subtropics (Sin *et al.,* 2000) and temperate waters (Ning *et al.,* 2000). In tropical estuarine regions studies have mostly focused on larger phytoplankton wherein hydrology and nutrients were indicated as the major dynamic factors influencing the phytoplankton biomass and composition (Costa *et al.,* 2009). However, there are a few preliminary studies on autotrophic picoplankton in tropical estuarine and coastal environments (Murrell & Lores, 2004; Lin *et al.,* 2010; Qiu *et al.,* 2010; Mitbavkar *et al.,* 2015). Apart from this, works related to various grazers of autotrophic picoplankton and the carbon turnover from this particular trophic level are more or less absent.

Estuaries are the transition zone of river and sea and mediate carbon flux between terrestrial and marine ecosystems. They are dynamic primarily due to short-term changes caused by tide and the seasonal changes induced by the regional climate (Madhupratap & Rao, 1979; Iriarte & Purdie, 1994). In the tropics, estuaries influenced by monsoon support very productive fisheries, which, is inturn, sustained via a healthy food chain supported by phytoplankton. Some findings show that increase in freshwater discharge influences the autotrophic picoplankton growth (Lin *et al.,* 2010; Qiu *et al.,* 2010). As Cochin backwater is profoundly affected by monsoon it serves as a good model ecosystem for studying autotrophic picoplankton dynamics in spatial and temporal scales.

In spite of many ecological studies on autotrophic picoplankton in the oceanic waters of the Pacific (Campbell & Vaulot, 1993; Binder *et al.,* 1996; Liu *et al.,* 2002) the Atlantic (Olson *et al.,* 1990a; Li, 1995; Buck *et al.,* 1996), the Mediterranean Sea (Vaulot *et al.,* 1990), and the Arabian Sea (Campbell *et al.,* 1998), only a few works are addressing the importance of autotrophic picoplankton in coastal ecosystems (Murrell & Lores, 2004; Mitbavkar *et al.,* 2011). Such studies are still less in tropical estuaries as compared to their ecological importance. However, it is evident that in Cochin estuary, there is a qualitative shift in phytoplankton composition during extremely low saline conditions and small forms contribute to most of the standing stock and production all through the year (Menon *et al.,* 2000; Qasim, 2003). According to the reports of ICMAM (2007) the net primary production of Cochin estuary is around 1343 mgC/m^2/day and the estimated consumption by mesozooplankton is up to 50 – 90 mg C/ m^2/day only. Thus ‘where does the remaining carbon go?’ remains as an unresolved question. Some authors have clearly stated that most of the studies have been overlooking the production and consumption of lower size fraction (Menon *et al.,* 1971; Gopinathan, 1975; Menon *et al.,* 2000). The preliminary observations on the trophic dependency of microzooplankton grazers on smaller phytoplankton (Jyothibabu *et al.,* 2006; Sooria *et al.,* 2015) also point towards the importance of quantification of carbon flow from autotrophic picoplankton to its grazers.

Considering the ecological importance of autotrophic picoplankton (a major carbon source for the higher trophic levels in the microbial food web) and the scarcity of information available in this realm, the proposed study was primarily targeted to generate scientific information about autotrophic picoplankton and their grazers in Cochin Backwater. The trophic interactions at the base of marine pelagic food web have large implications on global carbon flux. In India, an ecosystem approach to analyze pelagic food webs is increasingly valued to develop predictive whole ecosystem simulation models; although efforts in this area are in infancy. Owing to its high fishery potential and dynamism, Cochin estuary of west coast of India is one of the tropical estuarine areas which have been undergoing meticulous research regarding food web dynamics. It is well known that Cochin backwater support wide range of planktonic ciliates, protozoans and zooplankton larvae which in turn support the commercial fishery (Madhupratap, 1987; Jyothibabu *et al.,* 2006). All these consumers are widely known as the grazers of both bacteria and autotrophic picoplankton. Therefore, autotrophic picoplankton might be an important alternative source of carbon for the higher trophic levels of Cochin backwater. Thus, the major objectives of the study are: -

- To define the structure and seasonality of food web of Cochin Backwater
- To study the trophic status and seasonal dynamics of autotrophic picoplankton community of the food web
- To describe the major grazers of autotrophic picoplankton in Cochin Backwater
- To delineate the role of autotrophic picoplankton in the carbon biogeochemistry of the system

Information gathered from the study might be valuable for the assessment of other similar estuarine systems and anticipate some inputs for the future ecosystem models.

Chapter II

A Historical Review of Autotrophic Picoplankton Research

2.1. Introduction

The discovery of autotrophic picoplankton named *Prochlorococcus* by Chishlom *et al.* in 1988 opened a new episode in marine food web research. Now it is well known that they play a crucial role in marine biogeochemistry. Therefore, in order to understand the complex interactions driven by autotrophic picoplankton, it is necessary to go through the evolution of pelagic food web research which led to the discovery of these tiny unicellular photoautotrophs. Hence the review is segregated in to the three following sections:

1. The evolution of food web research– from classic food chain to microbial loop
2. A chronological view of autotrophic picoplankton research
3. Autotrophic picoplankton as a pelagic food web component

2.2. The evolution of food web research –from classic food chain to microbial loop

John Bruckner, a Dutch Lutheran minister and author is considered as the early protagonist of food web concept. In his book, 'Théorie du SystèmeAnimale' (1767), he described nature as one continued web of life. Darwin in 1845 recognized a pelagic food chain but the earliest graphic depiction of a food web was given by Lorenzo Camerano in 1880, which has followed by Pierce *et al.* in 1912 and Victor Shelford in 1913. Later, two food webs about herrings were described by Victor Summerhayes and Charles Elton (1923) and Alister Hardy (1924). Charles Elton subsequently pioneered the concept of food cycles, food chains, and food size in his classic book "Animal Ecology"(1927). Elton's 'food cycle' was replaced by 'food web' in a succeeding ecological text and it became a central concept in the field of ecology which formed the basis for the trophic system of classification in Raymond Lindeman's landmark paper on trophic dynamics (Lindeman, 1942). Whereas, Hardy's simple linear model of food web as described in 'classical text book representation of pelagic marine food web based on plankton and feeding habits of herring in the North Sea' (Hardy, 1924) was identified as the simplified illustration of marine food web called as 'classic food chain' (algae →zooplankton → fish).

Even though a very early suggestion of the significance of microorganisms in the sea has come from Lohmann (1911), classic food chain concept dominated the marine food web research till 1970s. This was mainly due to the lack of technology to enumerate bacteria or to estimate their production. During most of the 20th century, microorganisms were thought to be significant only in regenerating nitrogen and phosphorous but not in terms of carbon flux in marine food web. As their size is smaller than the wavelength of visible spectrum, most marine bacterioplankton were invisible to conventional light microscopy and could not be counted directly until the development of Epifluorescent microscopy (Francisco *et al.,* 1973; Hobbie *et al.,* 1977). Lawrence Pomeroy in 1974 noticed the possibility of occurrence of an alternative pathway of energy flow which involves microorganism, dissolved organic matter and non-living particles in the sea. Azam *et al.* (1983) and Williams (1984) introduced a change in conceptual framework, by bringing out the existence of a feedback loop called 'microbial loop' in pelagic food web. According to them, dissolved organic carbon present in water column is utilized by bacteria and pumped back into the classic food chain through microzooplankton (bacterivore protozoans), an alternative food source of mesozooplankton. Even if the studies on microzooplankton have started in the first decade of 20th centuary (Lohmann, 1911), a deep interest on these protozoans was established only after the demonstration of the metabolic impact of them on food web using tracer method by Azam, Hodson and Fuhrman (Azam & Hodson, 1977; Fuhman & Azam 1980). During the same period Landry and Hasset (1982) developed an *insitu* dilution technique for estimating the microzooplankton grazing impact on natural communities of marine phytoplankton. This was based on the major assumption that the probability of a phytoplankton cell being consumed is a direct function of the rate of encounter of consumers with prey cells. Even then the immense significance of microorganisms in oceanic system has not been shared by many fisheries scientists (Cohen & Newman, 1988; Cury *et al.,* 2000 etc.). They acknowledged the existence of microbial food web but denied its implications on the higher trophic levels including fishes. However, in 2002, Michael Landry in one of his reviews published in the journal 'Hydrobiologia' emphasized on the necessity of integrating classic and microbial food web concepts based on the observations from tropical Pacific Ocean (Landry, 2002). He stated that *"over the past two decades we accept microbial dominance of the ocean metabolism as a well-established fact and classical plankton community concepts exists only as a caricature"* (Landry, 2002). Meanwhile, evidences were accumulating for the existence of a population of minute unicellular photosynthetic organisms collectively called picoplankton which contributed substantially to the phytoplankton biomass of tropical and subtropical oceans (Platt *et al.*,1983). Platt *et al.* presented the first data on photosynthetic characteristics of autotrophic picoplankton collected at sea and argued that picoplankton contains a significant, metabolically-active, autotrophic component, capable of supplying about 60% of the total primary production in an open-ocean ecosystem. Later, a cyanobacterium called *Prochlorococcus*, which is found in high abundance in oligotrophic oceans, was discovered by Chishlom *et al.* (1988) and thus a new epoch has started in pelagic food web research. Now autotrophic picoplankton is considered as a ubiquitous and diverse component of marine and freshwater ecosystems (Waterbury *et al.*, 1979; Johnson & Sieburth 1979; Chisholm *et al.* 1988; Stockner *et al.* 2000). Currently the small size fraction of phytoplankton is considered as the major contributor to the total primary productivity of open cean, rather than the larger fraction.

2.3. A chronological view of picophytoplankton research

2.3.1. Discovery, Enumeration and taxonomy

The occurrence of tiny cells in the ocean had been suspected long before the term picoplankton was established. More than 150 years ago, N¨ageli (1849) described the tiny green alga *Stichococcus bacillaris*. At the beginning of the 20th century, Lohmann (1911) realized that organisms still smaller than net plankton were present in the oceans. One of the first descriptions of a 'pico' cyanobacterium, *Synechocystis salina*, appeared in 1924 (Wislough, 1924). In the early 1930s, the importance of very small cells in the food chain was recognized when Gaarder (1932) found small green algae (1–3 mm) to be the main food source of oyster larvae on the West Coast of Norway. In 1938, Ruinen described the heterotrophic *Cafeteria minuta* and in 1952, Butcher described the ubiquitous *Micromonas pusilla*. Knight-Jones (1951) calculated the abundance of ultra and nanoplankton in British coastal waters using the serial dilution method and found that smaller species like *Micromonas pusilla* and *Hillea marina* could be present in large numbers. However, it was only in the late 1970s that the use of epifluorescence microscopy (Hobbie *et al.*, 1977) led to the realization of the abundance of bacteria in all marine systems. Seiburth defined picoplankton as those cells whose size lies between 0.2 and 2 µm (Sieburth *et al.*, 1978) and the photoautotrophs coming under this size fraction was called 'picophytoplankton' or autotrophic picoplankton. This was soon followed by the discovery of very small primary producers (Johnson & Sieburth, 1979; Waterbury *et al.,* 1979; Johnson & Sieburth, 1982) which changed our view of marine ecosystems and shifted the scientific emphasis from the larger to the smaller sized organisms. Meanwhile freshwater ecosystems were also explored for the presence of autotrophic picoplankton. Rodhe in 1955 described a group of algae of minute size found in subarctic Swedish lakes and called them as the "μ-algae" (Rodhe, 1955). Algae in this size range also have been described as "little round green things" (LRGT) or small Coccoid or *Chlorella* like cells (Pearl, 1977). All these reports invoked intense research activities across the world. Many investigators believed that this discovery can provide an answer for the controversial carbon supply/demand question in the world ocean (Banse, 1974; Johnson *et al.,* 1981) and that it added credibility to the emerging new paradigm that focused on the significance of microbial food webs in energy transfer, carbon recycling, and nutrient release in aquatic ecosystems (Pomeroy, 1974; Azam *et al.,* 1983; Williams, 1984; Caron *et al.,* 1985).

Epifluorescence microscopy which helped in the enumeration of picoplankton was rather a simple technology. Picocyanobacteria can easily be observed by epifluorescence microscopy under blue and green excitation. No fluorochrome stains were necessary for their enumeration because each cyanobacterial picoplankton has a unique auto fluorescent spectral signature, usually distinguishable from eukaryotic picoplankton because of their red auto fluorescence emitted by chlorophyll. However, some phycocyanin-rich cyanobacteria had emission and excitation wavelengths that may not be visually distinguishable from red fluorescing chlorophyll. Therefore, the complete separation of cells and their detailed study again remained undone. Later, various sophisticated technologies evolved during 1980s have contributed a lot to the picophytoplankton research. Electron microscopy (Johnson & Sieburth, 1982; Takahashi & Hori;1984), Flow cytometry (Olson *et al.,*1985; Chisholm *et al.,*1988), immunofluorescence techniques (Campbell & Iturriaga, 1988; Shapiro *et al.,*1989) and chromatographic analysis of pigments (Gieskes & Kraay,1983; Hooks *et al.,*1988), led to major advances in autotrophic picoplankton ecology, physiology and taxonomy. Thereafter, it was possible to quantify autotrophic picoplankton routinely, utilizing the natural auto fluorescence of phycobiliprotein pigments and chlorophyll. Two cell-types of picophytoplankton have been found: yellow autofluorescing phycoerythrin cells (PE) and red autofluoresceing phycocyanin cells (PC) displaying maximum pigment activities at 570 nm and 630 nm, respectively (Wood *et al.*, 1985, Callieri *et al.*, 1996). The fluorescent characteristics of picocyanobacteria, based on phycobiliprotein spectra, have proven to be an easy way for their classification (McMurter & Pick, 1994). For example, the difference between PE and PC containing *Synechococcus* sp. was evident from fluorescence emission spectra: PE showed an emission maximum at 578 nm when excited at 520 nm, while PC emitted maximally at 648 nm when excited at 600 nm (Ernst, 1991; Callieri *et al.*, 1996).

The use of flow cytometry led to the discovery of primitive, prokaryotic picocyanobacteria of the Prochlorophyta group (Chisholm *et al.*, 1988), with divinyl chlorophyll-*a* (chl-a_2) as the principal light-harvesting pigment, and divinyl chlorophyll-*b* (chl-b_2), zeaxanthin, alfa-carotene and a chl-c-like pigment as the main accessory pigments (Goericke & Repeta, 1993). The small coccoid prochlorophyte species *Prochlorococcus marinus* is abundant in the North Atlantic Ocean (Veldhuis & Kraay, 1990), the tropical and subtropical Pacific (Campbell *et al.*, 1994), the Mediterranean Sea (Vaulot *et al.*, 1990) and the Red Sea (Veldhuis & Kraay, 1993). In freshwater, only a filamentous form of prochlorophytes has been described from a eutrophic lake (Burger-Wiersma *et al.*, 1986, Burger-Wiersma, 1991). The other published occurrences of possible prochlorophytes in freshwaters (Stockner & Antia, 1986; Fahnenstiel *et al.*, 1991) were more likely PC-rich cyanobacteria and Chlorella-like eukaryotic cells.

Most recent techniques for the identification of autotrophic picoplankton involve the use of genetic tools. One method used for this procedure is the restriction fragment-length polymorphism (RFLP) of the DNA (Douglas & Carr, 1988; Wood & Townsend, 1990; Ernst *et al.*, 1995). An internal fragment of the gene is used as a probe; for example, the pbsA gene (refers to a protein of photosystem II) has been used successfully (Ernst *et al.*, 1995). The probe recognizes the homologous genes and provides information about regions of the genome. With this method, a high number of picocyanobacteria clones have been distinguished in Lake Constance, Germany (Postius *et al.*, 1996). The use of classical methods based on morphology in combination with molecular techniques based on molecular markers offer one of the best solutions to picocyanobacteria identification. Genetic fingerprinting techniques, such as denaturing gradient gel electrophoresis (DGGE) (Muyzer, 1999), provide a profile of community diversity based upon physical separation of unique nucleic acids. A polyphasic approach (Vandamme *et al.*, 1996), encompassing the isolation of morphotypes and their molecular characterization, can help in detecting species and strain succession in different environments.

Table 2.1. Some Prokaryotic and eukaryotic picoplankton from marine and freshwater ecosystems (given by Stockner 1988).

Prokaryote	Marine	Identified by	Fresh water	Identified by
Chroococcales	*Synechococcus*	Johnson& Sieburth, 1979; Waterbury *et al.*,1979	*Cyanodictyon reticulatum*	Cronberg & Weibull, 1981
(Cyanobacteria)				
	Synechocystis	Campbell *et al.*,1983	*Cyanonephrori styloides*	Hickel, 1981
			Synechococcus	Drews *et al.*, 1961
Eukaryote				
Chlorophyceae	Chlorella-like	Johnson & Sieburth, 1979; Joint & Pipe, 1984; Takahashi & Hori,1984	*Chlorella minutissima*	Fott & Novakova, 1969
	Chlorella nana	Andreoli *et al.*, 1978	*Stichococcus*	Butcher,1952; George1957,
	Nannochloris	Butcher, 1952; Sarokin & Carpenter 1982		
Prasinophyceae	*Micromonas pusilla*	Johnson & Sieburth, 1982		
	Pyramimonas	Takahashi & Hori,1984		
	Dolichomastix lepidota	Manton, 1977		
Eustigmatophyceae	*Nannochloropsis*	Turner &Gowen,1984		
Cryptophyceae	*Hillea marina*	Butcher, 1952	*Rhodomonas pygmaea*	Javornicky, 1976
unidentified		Takahashi& Bienfang, 1983		
chrysophytes				
unidentified		Takahashi & Hori,1984		

2.3.2. Investigations on the ecological aspects of autotrophic picoplankton from various oceans.

Numerous studies suggest that picoplankton is cosmopolitan in distribution in the surface waters of both freshwater lakes and the sea, with numbers of organisms commonly around 10^6 ml^{-1} for heterotrophic bacteria, 10^4 ml^{-1} for cyanobacteria (Fogg, 1986; Stockner, 1988; Kudoh *et al.*, 1990; Caron *et al.*, 1991; Nagata, 1994; Landry, 2002), 10^3 ml^{-1} for eukaryotes and up to 10^5 ml^{-1} for prochlorophytes (Campbell & Vaulot, 1993). Population densities do not usually vary very much but fluctuations of several orders of magnitude have been reported (Fogg, 1995).

Reports from Atlantic

In 1983, Li *et al.* showed that major part of the primary production of Atlantic Ocean was coming from organisms smaller than 2µm (Li *et al.*, 1983). Heterotrophic nanoplankton was identified as the major predators of these organisms (Davis & Seiberth, 1982). Later discovery of "prochlorophytes" by Chisholm *et al.* (1988) in the northern Atlantic confirmed the former hypothesis. After that Prochlorophytes have been shown to be extremely abundant in the North Atlantic (Zubkov *et al.*, 2000; Li & Wood, 1988; Neveux 1989; Li, 1995; Li, 1997). In Celtic Sea, a significant portion of primary production was found to be from autotrophic picoplankton (Joint *et al.*, 1986). In Sargasso Sea and Gulf Stream, the highest concentration was found in surface waters and towards the north of the Gulf Stream, the cells were found to be absent (Olson *et al.*, 1990). They appeared to bloom later than *Synechococcus* after the onset of seasonal stratification (Olson *et al.*, 1990). It is also proven that there is a shift in the concentration of autotrophic picoplankton pigment composition (divinyl chlorophyll *a*, chlorophyll *b* and xeaxanthin) according to the change in irradiance (Veldhuis & Kraay, 1990). In 1992 prochlorophytes was renamed as *Prochlorococcus marinus* (Chisholm *et al.*, 1992). There was also high incorporation of carbon into the cell protein than to lipid and nucleic acid in autotrophic picoplankton of North Sea and this was assumed to be a consequence of nutrient limitation (Howard & Joint, 1989). Li in 1994 quantified the cell specific range of productivity of autotrophic picoplankton in Atlantic and the values were found to be varying between 0.03 - 4 fg C $cell^{-1}$ h^{-1} (Li, 1994). Later he argued that intermediate disturbance shapes diversity through an equitable distribution of cells in different size classes (Li, 2002). In North Eastern Atlantic great abundance of autotrophic picoplankton was reported during less developed upwelling periods (Partensky *et al.,* 1996).

In Sargasso Sea, the abundance of *Synechococcus* was significantly correlated with the nitrate and chlorophyll maximum (Olson *et al.,* 1990). In Carribean Sea, eukaryotic nano- and picoplankters comprised a higher portion of the phytoplankton community in the deeper portions of the DCM (deep chlorophyll maximum) in the tropics (Mcmanus & Dawson, 1994). In Mediterranean Sea also, the proportion of chlorophyll in < 2 µ particles increased with depth between the surface and the DCM (Yacobi *et al.,* 1995). Total picoplankton biomass ranged from 11 to 99 pg C 1^{-1} in North Atlantic Ocean (Buck *et al.,* 1996). Temperature, light and nutrient gradient were found to be affecting the physiological and biochemical properties of autotrophic picoplankton cells (Veldhuis, 2005). Moran *et al.* (2010) have shown a higher contribution of autotrophic picoplankton in the warmer regions of Atlantic Ocean. In Northwest Mediterranean Sea waters, *Synechococcus* and picoeukaryotes were found to be growing during the light period and dividing at night while an opposite pattern was observed in *Prochlorococcus.* The diel patterns of the overall autotrophic picoplankton community structure were strongly disrupted by a wind change event with associated rainfall and increased turbulence, suggesting that the shift observed in community structure resulted from the imbalances between growth and loss processes (Lefort & Gasol, 2013).

Reports from Pacific Ocean

The first report on the occurrence of autotrophic picoplankton in Pacific was published in 1964 by G.C. Anderson (Anderson, 1964). He observed a well-developed subsurface chlorophyll maximum during summer in North Pacific Ocean. It appeared to be composed of photosynthetically active phytoplankton community well adapted to low light intensity. Later, it was found that more than 70 percentage of this chlorophyll was from autotrophic picoplankton which could pass through a 3-µm Nuclepore but retained on 0.22-µm Millipore filters. They were identified as *Chlorella* like coccoid green algae having a section size of 1.2 to 1.5 µm and cyanobacteria of 0.5 to 2 µm (Takahashi & Hori, 1984). In the western tropical pacific, El Niño Southern Oscillation events were observed as one of the reasons for sudden shifts in autotrophic picoplankton density. The cyanobacteria and microalgae populations were 4.7 and 3.2

times larger than that of the year before and were associated with the strong upwelling established after the return of non-ENSO conditions (Blanchot *et al.*, 1992). A flow cytometric analysis of autotrophic picoplankton distribution showed that nitracline and light intensity was found to be profoundly affecting the distribution of prochlorophytes of western Pacific Ocean (Shimada *et al.*, 1993). In central Pacific Ocean, *Prochlorococcus* was found to be the most dominant picoplankton population and were present even below euphotic zone (Campell *et al.*, 1994; Ishizaka, 1994; Blanchot & Rodier, 1996; Durand & Olson, 1996). For most of the subtropical and tropical central Pacific, they accounted for greater than fifty percentage of the total chlorophyll *a* (Ishizaka, 1994). At the same time Campell and Valuote observed that the biomass of autotrophic picoplankton always exceeds that of heterotrophic bacteria in Central North Pacific Ocean. Therefore, they suggested that the heterotrophic bacterial biomass dominance is not typical to all oligotrophic regions (Campell & valuote, 1993). The annual variability of autotrophic picoplankton taxa in the same region, showed a significant seasonal cycle with the dominance of *Prochlorococcus* in summer, *Synechococcus* in winter and picoeukaryotes in spring (Campell *et al.*, 1997). Autotrophic picoplankton are known to contribute to the major portion of the productivity and biomass of "High Nutrient low chlorophyll region" (HNLC) of equatorial Pacific (Platt *et al.*, 1983; Binder *et al.*, 1996; Landry *et al.*, 1996; Landry *et al.*, 1997). There is a general notion that iron regulation and grazing are complementary mechanisms, which together constrain production of all size fractions of phytoplankton including autotrophic picoplankton in the Central Equatorial Pacific (Cullen, 1991; Cullen *et al.*, 1992; Frost & Franzen, 1992; Martin *et al.*, 1994; Banse, 1995; Cullen, 1995; Landry *et al.*, 1996; Landry *et al.*, 1997). Binder *et al.* (1996) observed that the most dominant group *Prochlorococcus* showed changes in the fluorescence and light scattering properties as a physiological response to tropical instability wave. Specific growth rate of *Prochlorococcus* was estimated as one division per day. Cell division was highly synchronized but was not identical for three major populations of autotrophic picoplankton. *Synechococcus* divided first, followed 2 hours later by *Prochlorococcus* and 7 hours later by picoeukaryotes. At the same time growth processes occurred in parallel at the top and the bottom of the mixed layer, inducing uniform profiles for cell abundance (Valuot and Marie, 1999). Neveux *et al.* (1999) identified two new phycoerythrin spectral type cells of cyanobacteria from areas in the Tropical and Equatorial Pacific Ocean with undetectable amount of nitrates and ammonia and recordable level of phosphates. They suggested that these cells might be contributing to the new production of this region by nitrogen fixation. Andre *et al.* (1999) tentatively predicted primary production from the growth rates. *Prochlorococcus,* the picoeukaryotes, and *Synechococcus* contributed 57%, 33%, and 10% of the picoplankton total, and the predictions were consistent with the ^{14}C measurements during the time series observations. Blanchot *et al.* (2001) studied abundance, distribution and cellular characteristics of autotrophic picoplankton in the western warm pool and HNLC region of the Equatorial Pacific Ocean. In warm pool, *Prochlorococcus* was the dominant organisms in terms of abundance and biomass whereas in HNLC region their contribution was slightly less than *Synechococcus* and picoeukaryotes. According to Zhavo *et al.* (2010), picoeukaryotes were major contributors to the red fluorescence above the 100m in Western Pacific, whereas at a depth below 100m *Prochlorococcus* and *Synechococcus* dominated. Grob *et al.* (2007) studied the distribution of autotrophic picoplankton in the South Pacific Ocean. They showed that the abundance of *Synechococcus* and picoeukaryotes increased from oligo to eutrophic condition. Fabbri *et al.* (2011) studied picoeukaryotes phylogenetic diversity in the wind driven upwelling coastal sites of central Chile by cloning and sequencing of 18S rRNA. They found that *Ostreococcus* dominated the autotrophic picoplankton community numerically throughout the year and, thus, appears to be a key component of the upwelling picoplanktonic community in the Eastern South Pacific. Moran *et al.* (2010) showed an increasing importance of smaller phytoplankton in Warmer Ocean. In Northeast pacific, size fractionated particle export has studied by Mackinson *et al.* (2015) and found that there is a preferential export or sinking flux of microplankton which indicated a higher rate of particle export of smaller phytoplankton towards the higher trophic level.

Reports from Polar waters

Picocyanobacteria is considered as an indicator organism for the advection of warm water masses into polar regions as the number of picocyanobacteria decreased from the warm Atlantic Intermediate Water (AIW) to the cold Polar Water (Gradinger & Lenz, 1989). Their cell abundance shows an inverse relationship with the latitude both in south and north poles (Marchant *et al.,* 1987). But the pico eukaryotic cells contributed 35% of the total chlorophyll *a* (Vanucci & Bruni, 1998). Distribution of autotrophic picoplankton especially that of *Prochlorococcus* in Southern Ocean was found to be determined by temperature and water masses (Ling *et al.*, 2012). The iron fertilization experiment LOHAFEX conducted in a cold-core eddy in the Southern Atlantic Ocean during austral summer shows the remarkable stability of the nano- and picoplankton community which points to a tight coupling of the different trophic levels within the microbial food web during LOHAFEX (Thiele *et al.*, 2014). In same latitude of Atlantic Ocean and Indian Ocean, picoplankton distribution and constitution were totally different, geographical location and different water masses combination would be the main reasons (Thiele *et al.*, 2014).

Reports from Indian Ocean

The vertical distribution pattern of autotrophic picoplankton in Arabian Sea was described in relation to the epipelagic structure by Jochem (1995). *Synechococcus* dominated phytoplankton in the upper mixed layer and *Prochlorophytes* at the bottom of the euphotic zone, in the lower part and below the deep chlorophyll maximum. Brown *et al.* (1999) investigated growth and grazing rates of autotrophic picoplankton populations and their contributions to phytoplankton community biomass and primary productivity in Arabian Sea during the Southwest Monsoon 1995. Even during intense monsoonal forcing in the Arabian Sea, picoeukaryotic algae appear to account for a large portion of primary production in the coastal upwelling regions, supporting an active community of protistan grazers and a high rate of carbon cycling in these areas. Picoplankton as a group accounted for 64% of estimated gross carbon production for all stations, and 50% at high-nutrient, upwelling stations. Prokaryotes (*Prochlorococcus* and *Synechococcus*) contributed disproportionately to production, relative to biomass at the most oligotrophic station, while picoeukaryotic algae were more important at the coastal stations. Microzooplankton grazing on four autotrophic picoplankton groups (*Prochlorococcus* sp., *Synechococcus* sp., and 2 picoeukaryotes) analysed by flow cytometry showed growth (p = 0.27 to 0.92 d^{-1}, mean 0.68 d^{-1}) and grazing mortality rates (0.26 to 0.73 d^{-1}, mean 0.67 d^{-1}) well in balance, with an average of 49% of the standing stock and 102% of the primary production grazed per day (Reckermann & Veldhuis, 1997). The effect of environmental forcing on the microbial community structure of Arabian Sea was investigated by Campell *et al.*, (1997). Average depth profiles for *Prochlorococcus* and *Synechococcus* displayed uniform abundance in the surface mixed layer with a rapid decrease below the mixed layer. However, there was a peak at the base of the mixed layer during spring Intermonsoon. But picoeukaryotes displayed a peak in surface during Monsoon. Landry *et al.* (1998) showed the dominance of autotrophic picoplankton in the oligotrophic systems and increased importance of large phytoplankton zooplankton grazing in coastal systems of Arabian Sea during Monsoon forcing. Growth rate was high in shallow depths than in deep waters (Liu *et al.,* 1998). In East China Sea *Prochlorococcus* were always more abundant in the summer than in the winter, the same was true to *Synechococcus* except for the oceanic region. In contrast, picoeukaryotes were more abundant in the winter than in the summer (Jiao *et al.,* 2005). Mitbavkar and Anil (2011) reported a lower contribution of picoplankton biomass in Arabian Sea than in Bay of Bengal. Distribution of picophytoplankton in eastern Indian Ocean was found to be primarily affected by temperature (Hong *et al.,* 2012). In Gulf of Mannar and Palk Bay picoeukaryotes, heterotrophic bacteria and autotrophic nanoplankton are positively correlated with salinity and nitrate, whereas *Synechococcus* and heterotrophic nanoplankton are positively correlated with turbidity, phosphate and dissolved oxygen (Jyothibabu *et al.,* 2013).

2.3.3. *Investigations on the ecological aspects of autotrophic picoplankton from Coastal ecosystems.*

Iriarte and Purdie (1994) studied photosynthetic picoplankton (> 1μm and < 3μm) in a Southern England estuary, and concluded that the contribution of autotrophic picoplankton decreases with increasing system biomass. According to their research, while autotrophic picoplankton in Open Ocean environments contribute more than 50% to total phytoplankton primary production, coastal system contribution could vary around 20% while their contribution in estuaries could be less than 10%. Badylak and colleagues (2007) observed that cyanobacterial picoplankton were numerically dominant in Tampa Bay Estuary but were not dominant in terms of overall phytoplankton biovolume. Additionally, Ning *et al.* (2000) reported cyanobacterial picoplankton was on average 15% of the total phytoplankton biomass in San Francisco Bay, and that their relative contribution decreased with increasing total phytoplankton biomass. Henceforth, while most of the researchers agreed on the assumption that the productivity contribution of picophytoplankton is significant only in the oligotrophic oceanic systems, some have shown that they are an important but ignored component of coastal ecosystems especially estuaries (Marshall & Nesius, 1996; Phlips *et al.,* 1999; Marshall, 2002). Additionally, they demonstrate that autotrophic picoplankton can attain high biomass and dominate the total phytoplankton biomass in estuaries during certain seasons and conditions (Ray *et al.,* 1989; Phlips *et al., 1*999; Badylak & Phlips, 2004, Murrell & Lores, 2004; Buchanan *et al.*, 2005). In Pensacola Bay, phytoplankton < 5µm averaged over 70% of the total phytoplankton community, with this trend being most significant during summer months (Murrell & Lores, 2004). Warm summer temperatures, along with periods of high residence times, also contributed to *Synechococcus* blooms in Florida Bay (Phlips *et al.,* 1999). Picoplanktonic cyanobacteria have also been shown to comprise a significant proportion of the phytoplankton biomass in the York River, a tributary of Chesapeake Bay (Ray *et al.,*1989). These studies suggest that high summer temperatures, periods of low river flow, and increased residence times are conditions favourable to high picoplankton abundance, particularly cyanobacterial species.

Schapira *et al.* (2010) observed the autotrophic picoplankton dynamics along a continuous gradient in south Australian coastal lagoon where salinity increases from 1.8% to 15.5%. They found that the autotrophic picoplankton cytometric-richness decreased with salinity and the most cytometrically diversified community (4 to 7 populations) was observed in the brackish-marine part of the lagoon (i.e. salinity below 3.5%). Picocyanobacteria were found to be the dominant component in eutrophic Mediterranean coastal lagoons and increase in nutrients was found to be giving competitive advantage for the picoeukaryotes (Bec *et al*., 2011). In the central Adriatic Sea autotrophic components (*Prochlrococcus, Synechococcus* and picoeukaryotes) made a greater contribution to picoplankton biomass in mesotrophic and eutrophic areas (Santic *et al.,* 2013). In the northern South China Sea, coastal upwelling waters, was dominated by *Synechococcus* within the euphotic zone. *Prochlorococcus* dominated the picophytoplankton community in the euphotic zone in the non-upwelling region (Wu *et al.,* 2014).

Reports from Indian coastal waters and estuaries

In India, studies associated to the ecological importance of autotrophic picoplankton in coastal ecosystems are still in its infancy. In 2015 Mitbavkar *et al.* observed eight autotrophic picoplankton abundance peaks comprising *Prochlorococcus*-like cells, picoeukaryotes, and three groups of *Synechococcus* in Dona Paula Bay. The chlorophyll biomass and abundance were negatively influenced by reduced solar radiation, salinity and water transparency due to precipitation and positively influenced by the stabilized waters during precipitation break/non-monsoon periods. Responses to environmental conditions differed with autotrophic picoplankton groups, wherein the presence of *Synechococcus*-PEI (phycoerythrin) throughout the year suggested its ability to tolerate salinity and temperature variations and low light conditions. Appearance of *Synechococcus*-PEII toward monsoon end and non-monsoon during high water transparency suggested its tidal advection from offshore waters.

In Cochin Estuary, it is evident that there is a qualitative shift in phytoplankton composition during extremely low saline conditions and small forms contribute to most of the standing stock and production all through the year (Menon *et al.*, 2000, Qasim, 2003). Sincy (2005) have done an extensive study on the diversity, distribution and ecology of cyanobacteria in Cochin estuary. From the results it is evident that the ecological conditions of Cochin Backwater support a rich cyanobacterial fauna including unicellular forms. A total number of 75 species of cyanobacteria from 24 genera across 7 families and 4 orders of the class Cyanophyceae were recorded and 31 of these were unicellular colonial forms. Premonsoon was characterized by high density of organisms whereas cell counts were less in Monsoon. The preliminary observations on the trophic dependency of microzooplankton grazers on smaller phytoplankton by Jyothibabu *et al.* (2006) point towards the importance of quantification of carbon flow from autotrophic picoplankton (lower trophic level) to its grazers. Sooria *et al.* (2015) showed that autotrophic picoplankton acts as a major carbon source for the higher trophic level in the Cochin estuary especially in the mesohaline regions even during the monsoon. Rajaneesh *et al.* (2015) reported that *Synechococcus* can be considered as an indicator organism of eutrophication in Cochin estuary. The flowcytometer analysis shows the dominance of picoeukaryotes > *Synechococcus* > Nanoautotrophs > with *Prochlorococcus* very low or entirely absent (Arya *et al.*, 2016).

The general deduction from all these reports emphasize on the importance of autotrophic picoplankton not only in the oceanic ecosystem but also in the coastal marine environments.

2.4. Autotrophic picoplankton as a pelagic food web component

Currently autotrophic picoplankton is thought to play a major role in the carbon biogeochemistry of aquatic ecosystems. Carbon biogeochemistry of an aquatic ecosystem refers to the study of cycling of carbon through the living and non-living components of the system. Different trophic levels of an aquatic food web act as the compartments through which carbon is transported within the biotic community. Whereas three key processes called production, export and sequestration facilitate the flux of carbon between the biotic community and non-living compartments of an ecosystem. In marine ecosystem, production denotes carbon fixation by primary producers (unicellular algae and macrophytes) and export refers to the flux of biogenic material from surface to depth. On the other hand, sequestration concerns the removal of dissolved inorganic carbon from the atmosphere and the surface waters by downward transport of biogenic dissolved and particulate carbon followed by burial in sediments (Legendre & Fevre, 1995). Export pathway is known as the biological pump since the carbon supply from the atmosphere is mainly taken by photosynthesis and transported through the food chain. Different size fractions of marine phytoplankton fix the atmospheric carbon dioxide and pump it to the higher trophic level. Most of the early workers believed that the classic food chain is the only pathway through which major carbon export take place (Hardy, 1959; Raymont, 1963; Gross, 1972; Sumich, 1976; Garrison, 1993). But the modern view had been profoundly influenced by the microbial paradigm (Pomeroy, 1974; Azam *et al.*, 1983; Landry, 2002). The discovery of *Prochlorococcus* (Chisholm *et al.*, 1988), the major primary producer especially in the iron limited high nutrient low chlorophyll region (Morel *et al.* 1991, Landry & Kirchman, 2002) lead to the intense research revealing their role in biogeochemistry. Recently, new data concerning the primary production of phytoplankton has been enlarged which can have enormous impact on the energy mass balance of the marine biosphere. Current measurements indicate that the role of autotrophic picoplankton is extremely significant. The number of them in one cubic metre equals 10 million which may be equalent to a mass of about 10 micrograms per cubic meter of oceanic water. In spite of this, it has been suggested that autotrophic picoplankton could be responsible for 20 to 80 percentage of primary production of the world ocean. Viral lysis of cyanobacteria, of course, releases dissolved organic matter provides a major pathway for carbon flow back into the bacteria (Heldal & Bratbak, 1991). Recently, Barber and Hiscock (2006) put forward a hypothesis called 'rising tide' hypothesis which states that diatoms and picophytoplankton assemblages equally respond to the elevated nutrient levels, but diatoms accumulate more biomass than the quantity mesozooplankton grazers can consume whereas, autotrophic picoplankton shifts to higher growth rate and biomass levels, however, grazing also increases and so a balance is maintained, and accumulation of biomass reduces. Thus, it can be concluded that not only larger cells, smaller cells like autotrophic picoplankton are also found to be playing a major role in the biogeochemistry of nutrient rich waters. Hence, the present study tries to analyse their significance in nutrient rich coastal ecosystems.

Chapter III

Seasonal Dynamics of Plankton Food Web in a Monsoonal Estuary and the Significance of Mesohaline Region

3.1. Introduction

Estuary, the transition zone of river and sea, facilitates carbon flux between terrestrial and marine ecosystems. They are dynamic principally due to short-term changes caused by tide and the seasonal changes brought by the regional climate (Madhupratap & Rao, 1979; Iriarte & Purdie, 1994). Tide causes changes in salinity and nutrients distribution, which potentially impact the spatial distribution of biological components (Madhupratap, 1987; Iriarte & Purdie, 1994; Kimmerer *et al.,* 1998). On the other hand, due to seasonal changes, an estuary can exhibit significant variations in the distribution of physicochemical as well as biological components (Madhupratap, 1987; Jyothibabu *et al.,* 2006). India has about 25 estuaries located along its 7500-km coastline (Qasim, 2003) of which those heavily influenced by the Southwest Monsoon (June–September) rainfall are referred to as monsoonal estuaries (Vijith *et al.,* 2009). Out of the monsoonal estuaries of Indian western coast, Cochin backwater is the largest and considered as a unique tropical ecosystem due to its highly dynamic nature. The backwater is constantly influenced by mixed semidiurnal tide with a maximum range of about 1m and all the environmental parameters fluctuate according to this. Magnitude of variation is not consistent and depends up on time of the year (Qasim & Gopinathan, 1969).

The two pronounced seasons in the ecosystems of tropical continental margins are spring intermonsoon (dry period) and south west monsoon (wet period). As a tropical ecosystem Cochin estuary is also controlled by the same seasonal contrast. Low freshwater inflow from rivers allows active salinity incursion in to the estuary from adjacent Arabian Sea during spring intermonsoon (Madhupratap, 1987). During monsoon the backwater transforms into a freshwater lake except near the inlet region due to the heavy fresh water input (Madhupratap, 1987; Qasim 2003). The heavy rainfall causes drastic changes in hydrography as the total fresh water inflow becomes several orders of magnitude larger than the estuarine volume and hence the name monsoonal estuary (Vijith *et al.,* 2009).

The current hypothesis related to the food web dynamics of Cochin Backwater is that there is a general weakening of food web in monsoon due to the low relative abundance of grazers in the fresh water dominated system (Jyothibabu *et al.,* 2006, Jyothibabu *et al.,* 2015) and there is a substantial amount of unconsumed carbon at primary level owing to the reduction in phytoplankton grazers (Madhu *et al.,* 2007). Studies also confirm that monsoonal flooding wipes out most of the organisms which thrives in high salinity and only a few organisms tolerant to low salinity are able to thrive in the middle and upper reaches (Madhupratap & Haridas 1975; Madhupratap *et al.,* 1987). But when we carefully examine, these studies lead us towards an inevitable re-evaluation of the current hypothesis. On land and off shore sediments in the Laccadive basin indicate that Cochin estuary was originated during tertiary and quaternary period (Menon *et al.,* 2000). It is also proven that endemic species and cosmopolitan species occurring in mixohaline areas could develop 'physiological races' through evolution (Kinne, 1964; Menon & Nair, 1967). Therefore, estuary must harbour various organisms which are highly adapted to its current hydrological characteristics and hence weakening of food web during monsoon has to be re-examined.

Moreover, marine ecosystems function studies are prone to ecological fallacies due to the highly dynamic nature of system and the limitations in the currently available methodologies (Weisse *et al.,* 2016). In order to avoid this, a passable data analysis of all the ecological components in both spacial and temporal scale is essential. The literature on the hydrobiology of Cochin backwater consists of isolated studies on heterotrophic bacteria, phytoplankton, microzooplankton, and mesozooplankton (Madhupratap, 1987; Jyothibabu *et al.*, 2006; Madhu *et al.*, 2007; Thottathil *et al.,* 2008). But integrated information on various functional components of the plankton food web is absent. Hence it is necessary to check the existing hypothesis in a time series manner which provides a continuous picture of spatial and temporal variation in the food web. Considering this, the present chapter provides a complete analysis of comprehensive seasonal time series data of plankton food web of Cochin backwater. Accordingly, the objectives of the chapter can be outlined as:

- To characterize the dynamics and distribution of different functional component of plankton food web of Cochin backwater during two major contrasting seasons – Spring Intermonsoon and Southwest monsoon.

- To understand the variation in food web existing in different ecological regions of backwater based on a comprehensive seasonal time series data

3.2. Materials and Methods

3.2.1. Study Area

The Cochin backwater is a complex shallow estuary (average depth 4 m), located parallel to the coastline of India between 9° 30′–10° 10′ N and 76° 15′–76° 25′ E (Fig: 3. 1). It extends around 75 km along the coastline and has two permanent inlets to the Arabian Sea — the southern inlet located at Kochi and the northern at Azhikode. There are seven rivers bringing water to the estuary out of which the major ones are Periyar and Muvatupuzha.

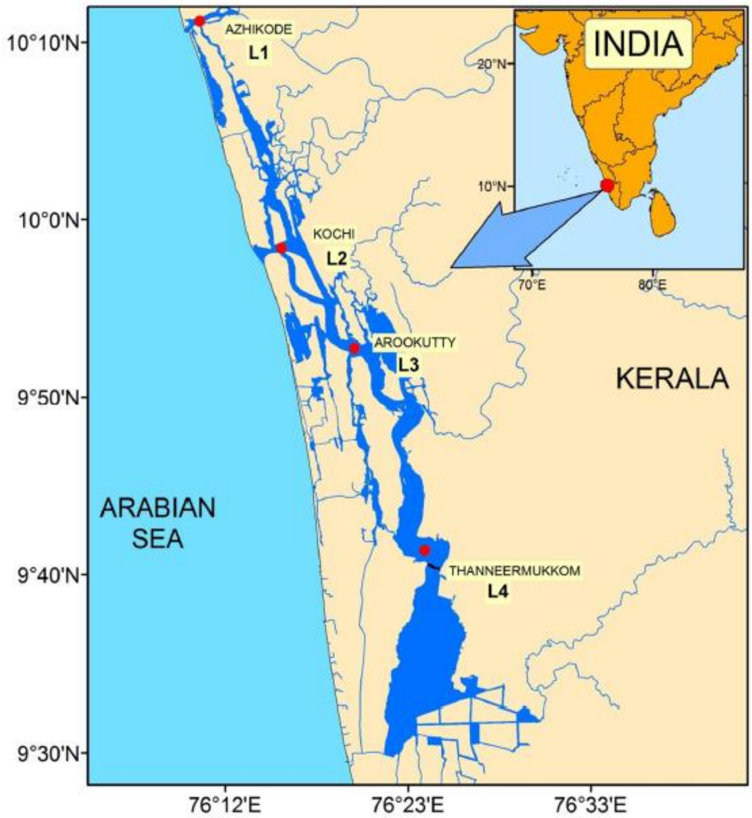
3.2.2. Sampling strategy

Three hourly time series sampling was conducted in four locations in the Cochin backwater during the spring intermonsoon (March 2009) and the southwest monsoon (September 2009) periods. Out of four sampling locations along the salinity gradients in the Cochin backwater (L1 to L4), two locations each represented the downstream (L1- Azhikode and L2- Kochi) and the upstream (L3- Arookkutty and L4- Thanneermukkom) regions (Fig: 3.1). During the seasonal sampling, field measurements began at 0900 hours and ended at 0900 hours the next day (24 h). Water samples for various environmental and biological parameters were collected every three hours from the surface waters (0.5 m) using a Niskin sampler.

3.2.3. Physico-chemical parameters

Tide in all the four time series locations was measured using tide gauges, and readings were taken at every 10 min. Surface salinity was measured using a digital salinometer (Make TSK). Dissolved oxygen was estimated by the Winkler's method. Dissolved inorganic nutrients nitrate (NO_3), phosphate (PO_4), and silicate (SiO_4) were measured following standard colorimetric techniques (Grasshoff *et al.*, 1983).

Fig: 3.1. The study area (Cochin backwaters) with the time series locations indicated in red circles. Azhikode (L1) and Kochi (L2) were situated in downstream, whereas, Arookutty (L3) and Thannermukkom (L4) were in upstream. Three hourly time series measurements were carried out in these locations for 24 h during the Spring Intermonsoon (dry season) and Southwest Monsoon (wet season)



3.2.4. Biological parameters

Picoplankton

Water samples (10 ml) were preserved in glutaraldehyde and processed for estimating picoplankton. Samples prefiltered through 3-µm sterile glass filters, to remove larger particles, were used to quantify autotrophic and heterotrophic picoplankton (Porter & Feig, 1980). The heterotrophic picoplankton (HPP) or heterotrophic bacteria sample was stained with 4’6-diamidino-2-phenylindole (DAPI) whereas autotrophic picoplankton (APP) samples were processed without any staining.

The samples (2ml) for autotrophic and heterotrophic picoplankton were separately passed through 0.2 µm black nucleopore filters and mounted in immersion oil. The slides were examined under an Olympus BX 53 epifluorescence microscope equipped with an image analyzer (progRes Capture Pro 2.6) under UV excitation for DAPI and blue excitation for phototrophic components. The microscopic analysis was carried out as soon as the slide was prepared and, in any case, not later than a few hours of its preparation (Bloem *et al.,* 1986). This approach ensured the preservation of autofluorescence of photosynthetic pigments in the samples. The carbon biomass of autotrophic and heterotrophic picoplankton was estimated based on the conversion factors presented by Garrison *et al.* (2000).

Nanoplankton

Water samples (15ml) preserved in glutaraldehyde were very gently pre-screened through 20 µm bolting silk to discard particles >20µm size. The filtrate was stained with 1.65 µg ml^{-1}proflavin hemisulfate and filtered through 0.8 µm pore sized Nucleopore filter (Haas, 1982). This filter is mounted in immersion oil and analysed under epifluorescence microscope not later than a few hours of its preparation (Bloem *et al.,* 1986). All organisms between 2 and 20 µm body sizes that fluoresced green under blue illumination were considered as heterotrophic nanoplankton (HNP) or heterotrophic nanoflagellates. The phototrophs were separated from the heterotrophs by the presence of red or red-orange auto fluorescence of photosynthetic pigments. The counts of heterotrophic (HNP) and autotrophic nanoplankton (ANP) were taken using the uys0\image analyzer. The carbon biomass of these components was measured based on their body dimensions using the image analyzer and their biovolume calculated by assuming appropriate geometrical shapes (Garrison *et al.,* 2000). The mean biovolume was extrapolated to the total counts at each location to obtain the total biovolume of the nanoplankton fraction. The conversion of biovolume to organic carbon was carried out based on the numerical conversion factors of Garrison *et al.* (2000).

Microzooplankton and mesozooplankton

Water samples (1L) for microzooplankton were gently pre-filtered through a 200µm bolting silk, preserved in acid Lugol's and stored in black polythene bottles. After 48 h of gravity settling, the water sample was concentrated to ~100 ml and again allowed to settle under gravity in a settling chamber for 48 h. The settled samples were observed under an inverted microscope with an image analyzer (Olympus IX 51). The microzooplankton community was broadly grouped into ciliates, heterotrophic dinoflagellates, and crustacean larvae. Ciliates and heterotrophic dinoflagellates were identified up to the species level based on available literature (Kofoid & Canmpbell, 1939; Subrahmanyan, 1971; Maeda, 1986; Krishnamurty *et al.,* 1995). The mesozooplankton was collected using a working party net (mesh size 200 µm, mouth area 0.28 m^2). The net was towed horizontally just below the water surface for 10 min. A digital flow meter (Hydro Bios, model 438110) was attached across the net opening to estimate the amount of water filtered to collect the sample. The mesozooplankton biomass was measured following the standard displacement volume method after removing large detrital particles (Harris *et al.,* 2000). The displacement volume of zooplankton was converted into dry weight using a factor of 0.075 g dry wt.ml^{-1} and then to carbon biomass following the standard conversion factor of Madhupratap *et al.* (1981).

3.2.5. Statistical treatments

Analysis of variance

Standard statistical treatments were used to analyse the significance of tidal as well as seasonal variation on various hydrographic and biological parameters. First, the environmental and biological data were tested for their normal distribution and homogeneity. For data with the normal distribution, parametric analysis of variance (ANOVA) with Tukey's HSD post hoc test was used to compare the significance. In the case of data with clumped distribution, nonparametric ANOVA (Kruskal-Wallis) with Dunn's post hoc test analysed the significance of differences. The tests of normality, parametric and nonparametric ANOVA were carried out in XL stat pro-software package.

Cluster/SIMPROF and NMDS

Cluster/SIMPROF and NMDS were used to segregate the observations of different parameters into clusters based on their similarity/homogeneity. The data or observation in one cluster indicates their similarity or homogeneity whereas, their placement in different clusters shows the dissimilarity or heterogeneity. The data of plankton food web components were initially standardized and log (X+1) transformed to normalize the differences in numerical abundance (Clarke &Warwick, 2001). The Euclidean distance matrix based on group average method was used to understand the spatial grouping of observations during different seasons.

Dominant species index

The dominant species index is used to find out the most common and numerically abundant species in each group of observations or locations. Dominant species of ciliates and heterotrophic dinoflagellates in each location during the spring intermonsoon and southwest monsoon were calculated using the standard equation (Yang *et al.,* 1999; Lee *et al.,* 2009; Lin *et al.,* 2011).

$Yi = (Ni/N) \times fi$

Where Yi is the dominance of species i, Ni is the number of individuals of species i in all locations, N is the number of individuals of all species in all locations, and fi is the frequency of locations at which species i occurs. The species with Yi value ≥0.02 were considered as dominant species.

Redundancy analysis

The interrelationships between the plankton components and their environmental variables were analyzed by redundancy analysis (RDA) models (CANOCO 4.5). Initially, the data was analyzed using detrended correspondence analysis (DCA) to select the appropriate ordination technique. The result of DCA showed axis gradient length <2, suggesting that linear multivariate RDA was suitable for the present case (Birks, 1998; Leps and Smilauer, 2003) with species correlation scaling as ordination scores. The biological variables were log transformed prior to the analysis. Partial RDA was also carried out to find out the environmental parameters contributing more to the explained variation in the biological components. The ordination significance was tested with Monte Carlo permutation tests (499 unrestricted permutations) ($p<0.05$). The results of the RDA are presented in the form of triplots in which the time series samples are displayed by points and environmental variables by arrows. Arrows for species abundance and environmental variables indicate the direction in which the corresponding parameters increase (Leps & Smilauer, 2003).

3.3. Results

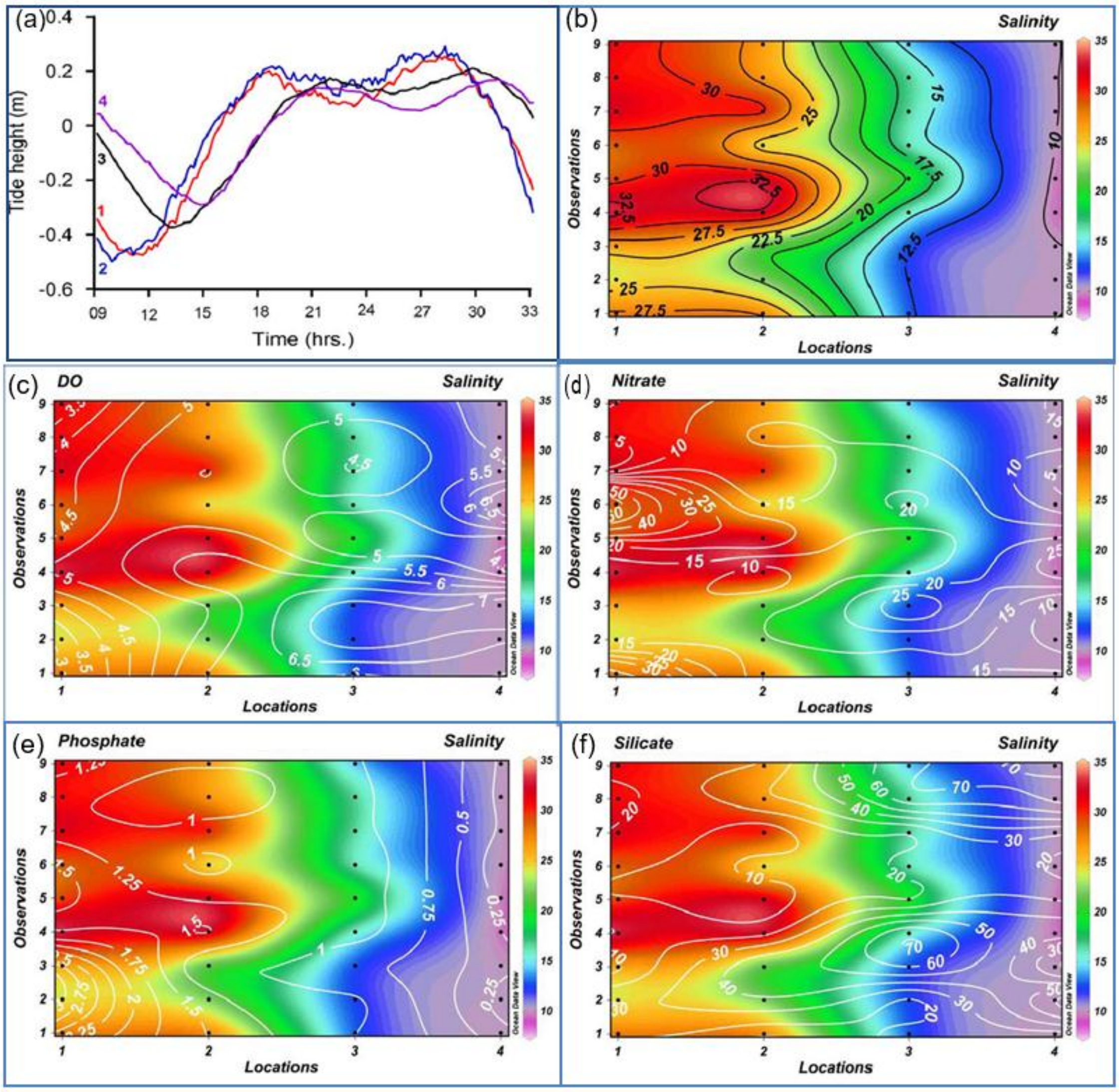
3.3.1. Hydrography- Spring Intermonsoon

The changes in tidal phase and salinity distribution in the Cochin backwater (L1–L4) during the spring intermonsoon period have been presented in Fig: 3.2. The average tidal height in the inlet region was 0.7 m, which decreased toward the upstream (0.5 m). The tidal rhythm was distinct in salinity distribution, more prominently downstream; euhaline waters dominated in the downstream sites and mesohaline waters upstream (Fig: 3.2a). The highest and lowest salinity values were recorded at L1 downstream (av. 29.15 ± 2.78) and L4 upstream (av. 9.94 ± 0.02), respectively (Table: 3.1). In all locations, the highest/lowest salinity coincided with the highest/lowest tidal amplitude. The tidal phase in the upstream sites showed a time lag from that in the downstream sites, and so was the salt intrusion. Salinity showed minor tidal variation in all the sampling locations, but significant spatial variation was observed between the upstream and the downstream (Table: 3.1 & Fig: 3.2b). The dissolved oxygen concentration was generally high in the entire study area with higher values in the mesohaline upstream region as compared to the downstream. The dissolved oxygen was the highest at L4 in the upstream region (av. 5.96 ± 0.15 mg l^{-1}) and the lowest at L1 downstream (av. 3.87 ± 0.18 mg l^{-1}). The tidal variation of dissolved oxygen was minor in all the study locations (Table: 3. 1 & Fig: 3. 2c). Nitrate (NO_3) concentration was remarkably high in the entire study area and showed minor tidal variations except in L1, in the downstream region (Table: 3.1 & Fig: 3. 2d). The distribution of PO_4 showed an increasing trend towards the downstream whereas the trend exhibited by SiO_4 concentration was vice versa (Table: 3.1 & Fig: 3.2 e). While the tidal variation in PO_4 was significant only in the downstream locations, SiO_4 variation was significant at L2 and L3 (Table: 3. 1 & Fig: 3. 2 f). The spatial difference in PO_4 and SiO_4 was significant between the upstream and the downstream (Table: 3.1). Overall trend in the distribution of physicochemical parameters showed significant spatial variations between the downstream and the upstream (Fig: 3.2 a & b.).

Table: 3.1. Spatial distribution of environmental parameters related to tide (ANOVA) during spring intermonsoon. Mean and coefficient of variations (in parentheses) are presented (*P<0.05, significant tidal variation)

Parameters	Spring Intermoonsoon			
	L1	L2	L3	L4
Salinity	29.15 (0.10)	26.90 (0.15)	15.21 (0.16)	9.94 (0.02)
DO (mg l^{-1})	3.87 (0.15)	5.61 (0.07)	5.58 (0.19)	5.96 (0.15)
NO_3 (µM)	16.93 (0.68) *	14.21 (0.35)	16.44 (0.35)	13.42 (0.53)
PO_4 (µM)	1.60 (0.59) *	1.44 (0.66) *	1.05 (0.26)	0.23 (0.32)
SiO_4 (µM)	17.70 (0.39)	20.90 (0.73) *	40.80 (0.59) *	40.99 (0.50)

Fig: 3.2. Distribution of physicochemical variables in the Cochin backwaters during spring intermonsoon (a) The variation in tidal height during the observation; (b) the salinity variation with respect to the tidal phase. The salinity distribution is set as the background in subsequent panels with white contour lines representing (c) dissolved oxygen (DO), (d) nitrate (NO_3), (e) phosphate (PO_4), and (f) silicate (SiO_4).



3.3.2. Hydrography – Southwest Monsoon

The Cochin backwater was heavily influenced by freshwater, which caused low tidal amplitude in the upstream region (Fig: 3. 3a). The tidal height was noticeably low in the downstream regions (0.5 m), which decreased further toward the upstream (0.2 m). The large freshwater influx led to a drastic drop in salinity and an increase in the duration of low tide. The average surface salinity was significantly low in the entire stretch of the study area (0.10 to 8.66 ppt). Relatively high saline/mesohaline conditions (av. 8.62 – 8.66 ppt) were found downstream while extremely low saline conditions (av. 0.1 – 2.11 ppt) were encountered upstream (Table: 3. 2). Due to high advection of freshwater from the upstream, there was a phase lag in tidal propagation and the salinity intrusion in this area was also very weak (Fig: 3. 3b). Even though the tidal variation in salinity was between oligohaline to mesohaline ranges, these variations were large in all the locations except L4 (Table: 3. 2 & Fig: 3. 3b). Similarly, the spatial variation in salinity was significant between all the locations except L1 and L2 in the downstream and L3 and L4 in the upstream area (Table: 3.2 & Fig: 3.3b). The dissolved oxygen concentration was generally high in the entire study area with the highest at L4 and the lowest at downstream (Table: 3. 2 & Fig: 3. 3c). The tidal variation of dissolved oxygen during the study period was infinitesimal in all the study locations (Table: 3. 2 & Fig: 3. 3d). The NO_3 concentration was generally high in the study area. The highest and lowest values of NO_3 were found in L1 and L3, respectively (Table: 3. 2). The tidal fluctuation of NO_3 was small in all locations, whereas spatial variation in its distribution was significant (Table: 3. 2 & Fig: 3. 3d). The distribution of PO_4 and SiO_4 also showed a clear spatial trend; the former increased downstream and the latter upstream (Fig: 3.3e & 3.3e). The tidal variation of PO_4 and SiO_4 in the study area was small in all locations (Table: 3. 2). The overall trend in distribution of all physicochemical parameters except salinity showed low tidal variations. On the other hand, there was a more prominent spatial variation in hydrographic parameters between the downstream and the upstream (Table: 3. 2).

Table: 3.2. Spatial distribution of environmental parameters at various stations according to tide (ANOVA) during southwest monsoon. Mean and coefficient of variations (in parentheses) are presented (*P<0.05, significant tidal variation)

Parameters	Southwest Monsoon			
	L1	L2	L3	L4
Salinity	8.62 (0.60) *	8.66 (0.70) *	2.11 (0.91)*	0.10 (0.30)
DO (mg l^{-1})	4.23 (0.30)	5.83 (0.06)	5.99 (0.06)	6.36 (0.06
NO_3 (µM)	31.30 (0.08)	16.81 (0.25)	8.74 (0.23)	18.77 (0.51)
PO_4 (µM)	1.40 (0.40)	1.11 (0.25)	0.60 (0.24)	0.20 (0.80)
SiO_4 (µM)	42.79 (0.07)	92.62 (0.12)	105.67 (0.08)	108.66 (0.27)

Fig. 3.3: Distribution of physicochemical variables in the Cochin backwaters during southwest monsoon. (a) The variation in tidal height during the observation; (b) the salinity variation with respect to the tidal phase. The salinity distribution is set as the background in subsequent panels with white contour lines representing (c) dissolved oxygen (DO), (d) nitrate (NO_3), (e) phosphate (PO_4), and (f) silicate (SiO_4)

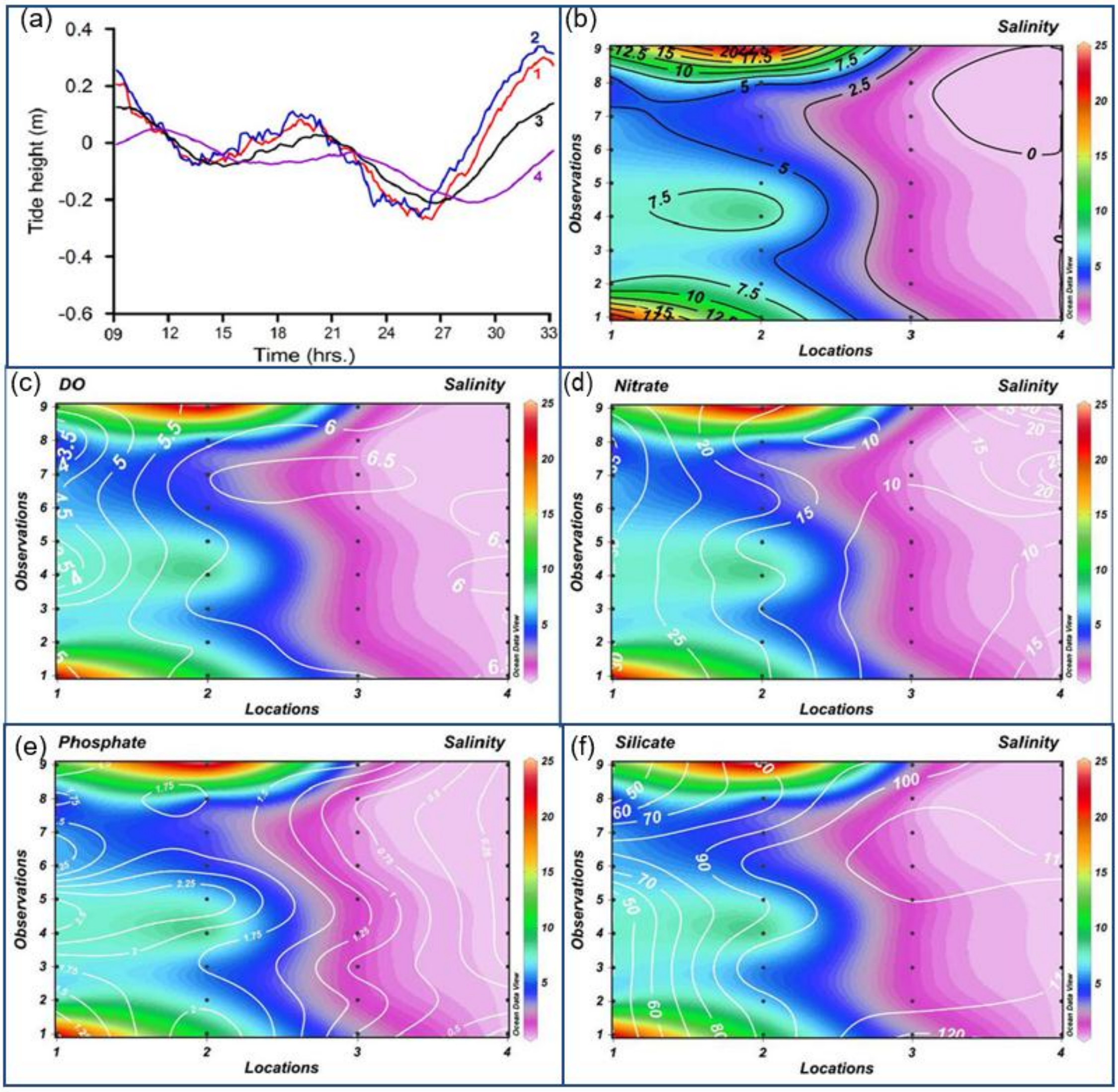
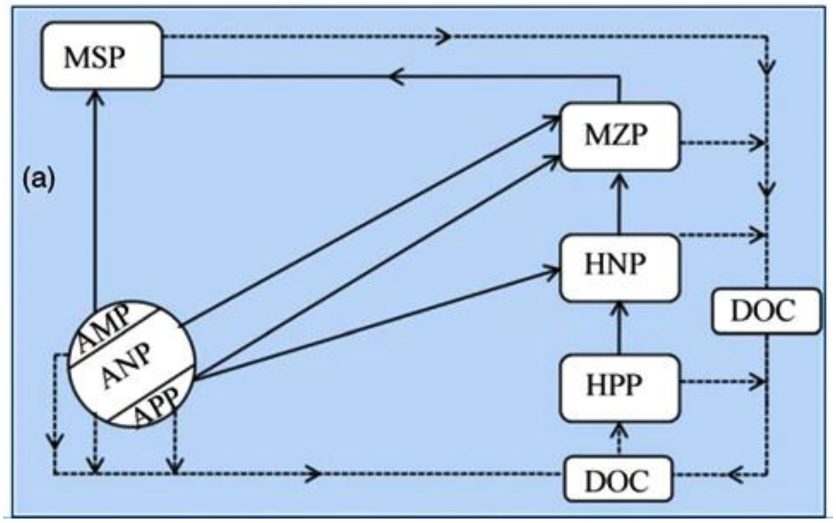
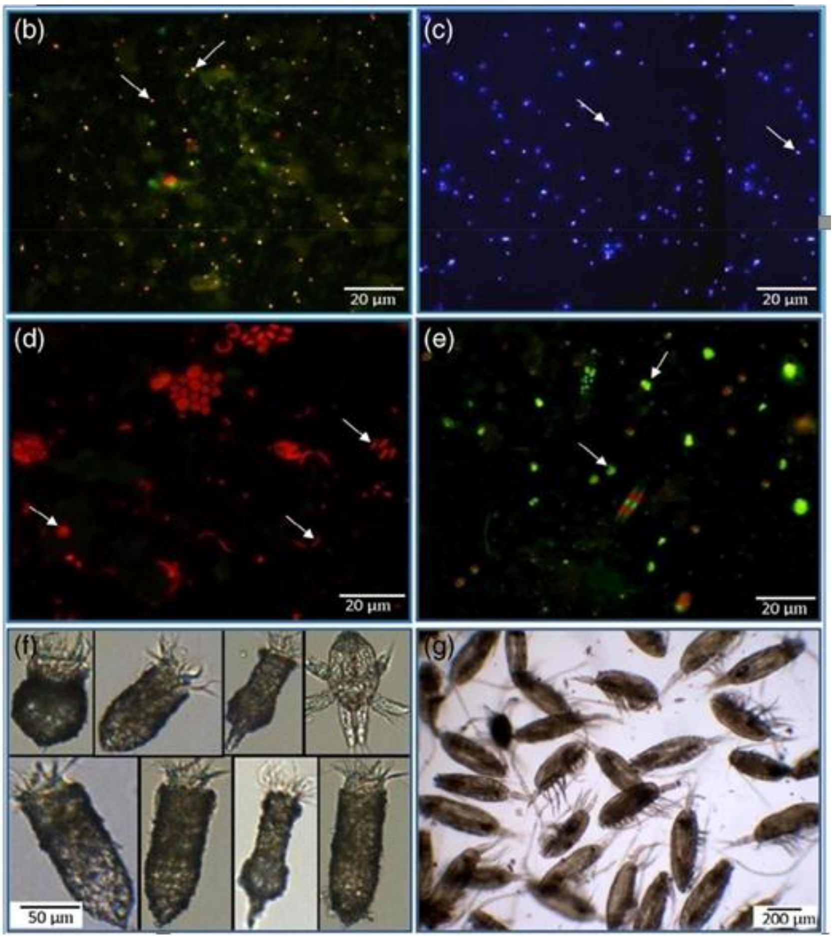


Fig: 3.4. (a) Schematic diagram of the plankton food web in the Cochin backwaters. The subsequent panels represent the photomicrographs of (b) APP -autotrophic picoplankton (c), HPP- heterotrophic picoplankton (d), ANP- autotrophic nanoplankton (e), HNP - heterotrophic nanoplankton (f), MZP - microzooplankton, and (g) MSP- mesozooplankton/ copepods. The abbreviations AMP represent autotrophic Microplankton and DOC represents dissolved organic carbon.





3.3.3. Biological parameters

The Plankton Food web

A schematic picture of a typical plankton food web in an estuarine system is presented in Fig: 3. 4a. The subsequent panel presents the photomicrographs of the plankton components quantified during the present study (Fig: 3. 4b – g). The distribution of various plankton components in relation to the salinity ingress and egress associated with tidal action during spring intermonsoon and southwest monsoon has also been presented in Fig: 3.5 and Fig: 3.6. Detailed information on the abundance and distribution of each plankton components in the temporal and spatial environmental settings in the study area is presented in the following sections.

Picoplankton

The tidal and spatial variation of autotrophic picoplankton and heterotrophic picoplankton during spring intermonsoon is presented in Table: 3.3 & Table: 3.4. Similarly, the abundance of autotrophic and heterotrophic picoplankton in relation to changes in salinity during the spring intermonsoon is presented in Fig: 5a & b. The abundance of autotrophic picoplankton was higher upstream as compared to the downstream. The autotrophic picoplankton abundance (Table: 3. 3) and biomass (Table: 3. 4) were the highest at L4 (av. 3.46×10^7 l^{-1} and av. 8.65 mg C m^{-3}) and the lowest at L1 (av. 1.80×10^7 l^{-1} and av. 4.5 mg C m^{-3}). In all study locations, autotrophic picoplankton showed only low tidal variation (Table: 3. 3) whereas, their spatial variation was significant between the downstream and the upstream locations (Table: 3. 3). The abundance (Table: 3. 3) and biomass (Table: 3. 4) of heterotrophic picoplankton showed relatively high values in the downstream sites. The heterotrophic picoplankton abundance (Table: 3. 3) and biomass (Table: 3. 4) were the highest at L1 (av. 2.20×10^9 l^{-1} and av. 24.2 mg C m^{-3}) and the lowest at L4 (av. 1.53×10^9 l^{-1} and av. 16.8 mg C m^{-3}). The tidal variation in the abundance of heterotrophic picoplankton was significant only in the downstream locations (Table: 3.3). The spatial variation of heterotrophic picoplankton was significant between the downstream and the upstream sampling sites (Table: 3.3).

During the southwest monsoon, the abundance and biomass of autotrophic picoplankton were higher downstream as compared to the upstream (Table: 3. 3). The abundance of autotrophic picoplankton and heterotrophic picoplankton in relation to changes in salinity during the southwest monsoon is presented in Fig: 6a & b. The abundance (Table: 3.3) and biomass (Table: 3.4) of autotrophic picoplankton were the highest at L2 (av.1.52 × 10^7 l^{-1} and av. 0.25 mg C m^{-3}) and the lowest at L4 (av. 0.2 x 10^7 l^{-1} and av. 0.1 mg C m^{-3}). The heterotrophic picoplankton abundance (Table: 3. 3) and biomass (Table: 3. 4) during the southwest monsoon was noticeably higher downstream as compared to upstream. The highest heterotrophic picoplankton abundance and biomass were found at L2 (av. 1.26 × 10^9 $l^{-1}$and av. 13.9 mg C m^{-3}) and the lowest at L4 (av. 0.80 × 10^9 l^{-1} and av. 7.92 mg C m^{-3}). The tidal variation in autotrophic picoplankton and heterotrophic picoplankton was found to be minor in all locations during the southwest monsoon, whereas, their spatial variation was significant between the upstream and the downstream locations (Table: 3.3 & Table: 3.4).

Table: 3.3. Seasonal and spatial distribution of biological parameters (ANOVA). Mean and coefficient of variations (in parentheses) are presented (*P<0.05, significant tidal variation)[APP -autotrophic picoplankton, HPP- heterotrophic picoplankton, ANP- autotrophic nanoplankton, HNP - heterotrophic nanoplankton, MZP - microzooplankton]

Parameters	**Spring Intermonsoon**				**Southwest Monsoon**			
Numerical abundance (No. L^{-1})	L1	L2	L3	L4	L1	L2	L3	L4
APP (×10^7)	1.80 (0.59)*	2.46 (0.34)	2.73 (0.48)	3.46 (0.28)	1.21 (0.24)	1.52 (0.47)	0.40 (0.28)	0.20 (0.14)
HPP (x10^9)	2.20 (0.64)*	2.14 (0.61)*	1.75 (0.44)	1.53 (0.39)	1.24 (0.76)*	1.26 (0.61)*	0.86 (0.42)	0.80 (0.31)
ANP(x10^7)	0.76 (0.33)	2.40 (0.66)*	3.02 (0.63)*	2.8 (0.50)	0.73 (0.30)	1.69 (0.31)	1.52 (0.57)	1.36 (0.40)
HNP(x10^6)	1.64 (0.46)	1.26 (1.03)*	2.60 (0.26)	2.20 (0.10)	1.10 (0.43)	1.25 (0.50)	0.43 (0.67)*	0.55 (0.60)*
MZP(X10^4)	1.11 (0.29)	1.93 (0.38)	3.11 (0.25)	2.62 (0.27)	1.98 (0.28)	1.64 (0.11)	1.19 (0.42)	0.48 (0.50)

Table: 3.4. Seasonal and spatial distribution of biomass (ANOVA). Mean and coefficient of variations (in parentheses) are presented (*P<0.05, significant tidal variation)[APP -autotrophic picoplankton, HPP- heterotrophic picoplankton, ANP- autotrophic nanoplankton, HNP - heterotrophic nanoplankton, MZP – microzooplankton, MSP- mesozooplankton]

Parameters	Spring Intermonsoon				Southwest Monsoon			
Biomass (mg Cm^{-3})	L1	L2	L3	L4	L1	L2	L3	L4
APP	4.50 (0.59)*	6.15 (0.34)	6.83 (0.48)	8.65 (0.28)	2.21 (0.24)	0.25 (0.47)	0.15 (0.28)	0.10 (0.14)
HPP	24.20 (0.64)*	23.54 (0.5)*	19.25 (0.44)	16.83 (0.39)	13.64 (0.76)*	13.86 (0.61)*	9.46 (0.42)	7.92 (0.31)
ANP	162.49 (0.33)	513.12 (0.66)*	645.68 (0.63)*	564.49 (0.50)	156.07 (0.30)	324.98 (0.31)	318.56 (0.31)	269.39 (0.4)
HNP	10.12 (0.46)	7.77 (1.03)*	16.04 (0.20)	13.57 (0.10)	6.79 (0.43)	7.09 (0.50)	2.65 (0.67)*	3.39 (0.60)*
MZP	121.41 (0.29)	211.1 (0.38)	340.17 (0.25)	286.57 (0.27)	216.57 (0.28)	179.38 (0.11)	130.16 (0.42)	52.5 (0.50)
MSP	4.90 (1.12)*	2.12 (1.18)*	8.02 (0.96)*	11.73 (1.25)*	0.48 (0.49)	0.34 (0.36)	0.24 (0.96)*	0.33 (1.07)*

Fig: 3.5. Spatial distribution of functional components in the plankton food web during spring intermonsoon. The salinity distributions set as the background in all panels with white circles representing the distribution of (a) APP autotrophic picoplankton ($\times 10^7$ no.l^{-1}) (b) HPP heterotrophic picoplankton ($\times 10^9$ no. l^{-1}).

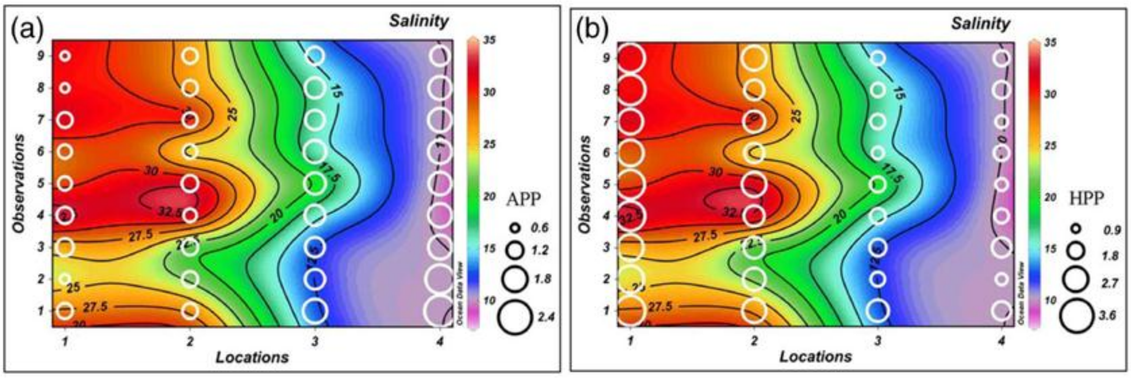
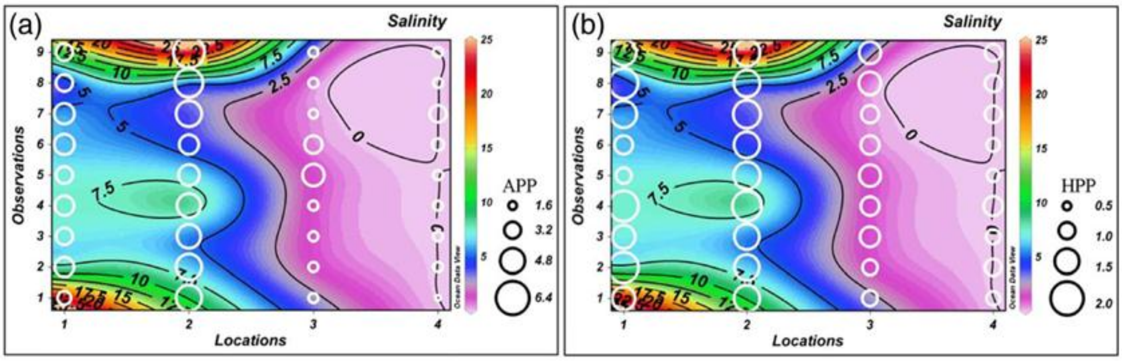


Fig: 3.6. Spatial distribution of functional components in the plankton food web during southwest monsoon. The salinity distributions set as the background in all panels with white circles representing the distribution of (a) APP autotrophic picoplankton ($\times 10^7$ no. l^{-1}) (b) HPP heterotrophic picoplankton ($\times 10^9$ no. l^{-1}).



Nanoplankton

During the spring intermonsoon, the abundance and biomass of autotrophic nanoplankton showed an increasing trend towards the upstream (Table: 3.3). The abundance of autotrophic nanoplankton and heterotrophic nanoplankton in relation to the changes in salinity during the spring intermonsoon is presented in Fig: 3.7a & 7b. The autotrophic nanoplankton abundance (Table: 3.3) and biomass (Table: 3.4) were the highest in L3 (av. 3.02 × 10^7 l^{-1} and av. 645.7 mg C m^{-3}) while the lowest was observed in L1 (av. 0.76 × 10^7 l^{-1} and av. 162.5 mg C m^{-3}). During the period, the tidal variation of autotrophic nanoplankton was found significant at L2 and L3 (Table: 3.3 & 3.4). The abundance and biomass of heterotrophic nanoplankton were significantly higher in the mesohaline upstream as compared to the downstream sites (Fig: 3.7 b). Their abundance (Table: 3.3) and biomass (Table: 3.4) were the highest in L3 (av. 2.6 × 10^6 l^{-1} and av. 16.4 mg C m^{-3}) and the lowest in L2 (av. 1.26 × 10^6 l^{-1} and av. 7.8 mg C m^{-3}) (Table: 3.3).

During southwest monsoon, the autotrophic nanoplankton distribution was almost irregular when presented in the distribution graph (Fig: 3.8a & Table: 3.3). During the study period, autotrophic nanoplankton showed low tidal variation in all locations (Table: 3.3), but their spatial variation was significant between L1 and the upstream sites (Table: 3.3). The spatial difference in heterotrophic nanoplankton during the southwest monsoon showed noticeably higher values downstream as compared to upstream (Fig: 3.8b). Their abundance (Table: 3.3) and biomass (Table: 3.4) was the highest in L2 (av. 1.25 × 10^6 l^{-1} and av. 7.1 mg C m^{-3}) and the lowest in L3 (av. 0.43 × 10^6 l^{-1} and av. 2.7 mg C m^{-3}). The heterotrophic nanoplankton distribution also showed significant spatial difference between the upstream and downstream regions whereas their tidal variation was significant only upstream (Table 3.3). The abundance of autotrophic and heterotrophic nanoplankton showed prominent seasonal variations upstream, but only minor variations downstream (Table: 3.3).

Fig: 3.7. Spatial distribution of functional components in the plankton food web during the spring intermonsoon. The salinity distribution is set as the background in all panels with white circles representing the distribution of (a) ANP -autotrophic nanoplankton (×10^7 no. l^{-1}), and (b) HNP -heterotrophic nanoplankton (×10^6 no. l^{-1}).

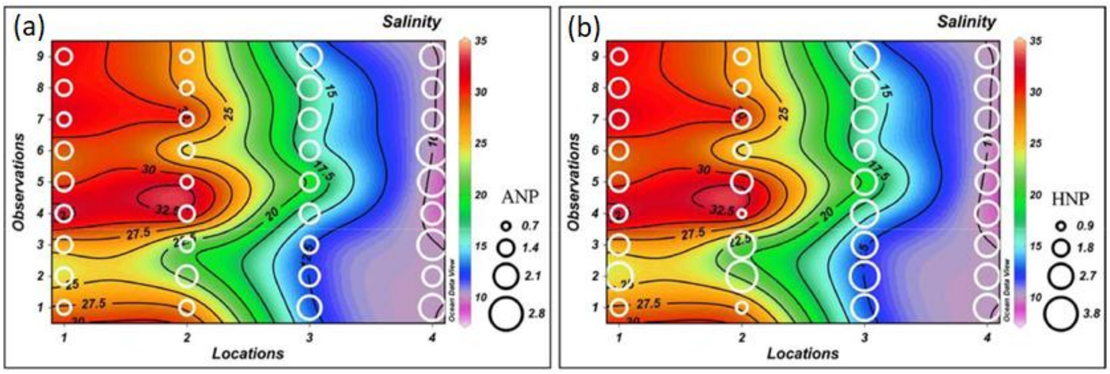
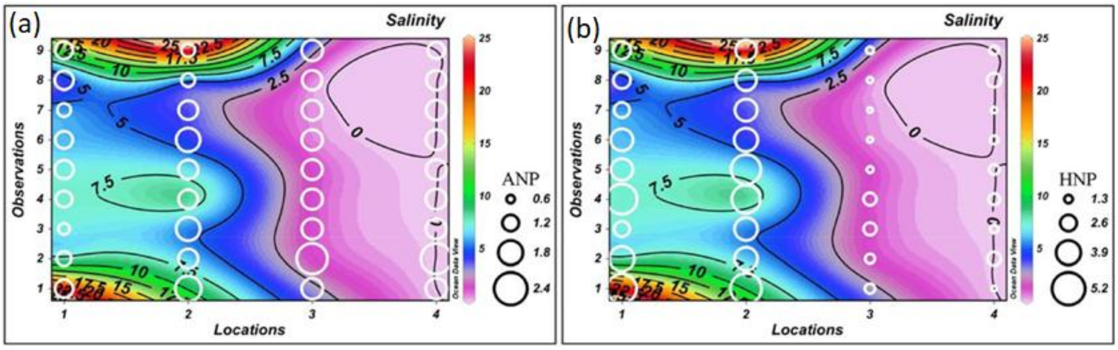


Fig: 3.8. Spatial distribution of functional components in the plankton food web during southwest monsoon. The salinity distribution is set as the background in all panels with white circles representing the distribution of (a) ANP autotrophic nanoplankton (×10^7 no. l^{-1}), and (b) HNP heterotrophic nanoplankton (×10^6 no. l^{-1}).



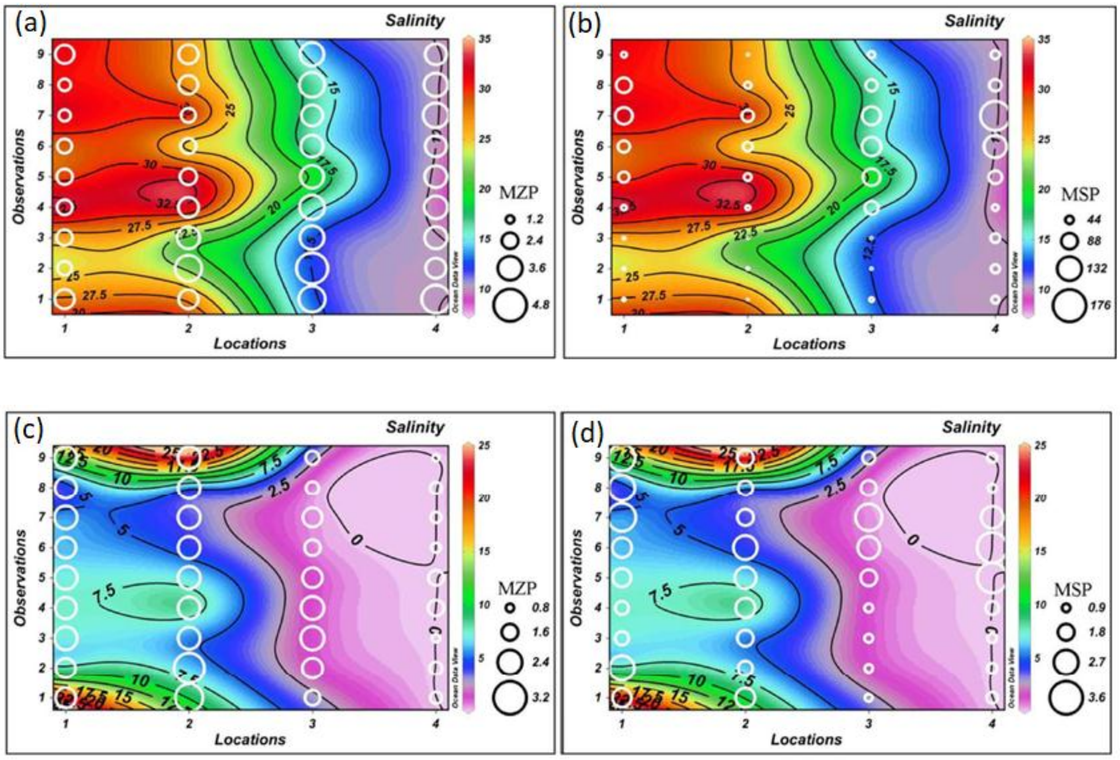
Microzooplankton and Mesozooplankton

During the spring intermonsoon, microzooplankton abundance and biomass was noticeably higher upstream than downstream (Fig: 3.9 a). The highest and lowest abundance and biomass were recorded in L3 (av. 3.11×10^4 l^{-1} and av. 340 mg C m^{-3}, respectively) and L1 (av.1.11×10^4 l^{-1} and av.121 mg C m^{-3}, respectively). The tidal variation in microzooplankton abundance and biomass was minor in all locations (Table: 3.3 & 3.4) whereas, their spatial variation was significant between the upstream and the downstream locations (Table: 3.3 & 3.4). During the southwest monsoon, the abundance and biomass of microzooplankton community was noticeably low in upstream than downstream (Fig: 3.9c). The microzooplankton showed highest abundance and biomass at L1 (av. 1.98×10^4 l^{-1} and av. 216 mg C m^{-3}) while the lowest was observed at L4 (av. 0.48×10^4 l^{-1} and av. 52.50 mg C m^{-3}). The tidal variation in microzooplankton abundance was minor in the entire study area (Table: 3.3), whereas, the spatial variation was significant between the upstream and downstream sites (Table: 3.3 & 3.4). The seasonal variation in abundance of microzooplankton was large in the upstream location but, insignificant in the downstream (Table: 3.3 & 3.4).

High mesozooplankton biomass was found throughout the study area during the spring intermonsoon with an increasing trend toward the upstream (Table: 3.4; Fig: 3.9b). The highest mesozooplankton biomass was recorded at L4 (av. 11.7 ± 1.3 mg C m^{-3}), followed by L3 (av. 8.02 ± 0.96 mg C m^{-3}) in the upstream region. The mesozooplankton biomass over 24-h time series sampling showed significant tidal variations in all the locations (Table: 3.4). On the other hand, the spatial variation in mesozooplankton biomass distribution was significant only between the upstream and the downstream sites (Table: 3.4). During the southwest monsoon, the mesozooplankton biomass is significantly lower than that of the spring intermonsoon.

Relatively high mesozooplankton biomass was found in the downstream region during the southwest monsoon as compared to upstream (Fig. 9d); the highest was observed in L1 (av. 0.48 ± 0.5 mg C m^{-3}) and the lowest in L3 (av. 0.24 ± 0.96 mg C m^{-3}) (Table: 3. 4). The variation in mesozooplankton biomass over 24-h time series sampling showed large fluctuations in the upstream sites while it was small in the case of downstream locations (Table: 3.4). The spatial variation in mesozooplankton biomass was found to be significant only between L1 and the upstream locations (L3 and L4) (Table: 3.4). Large seasonal variation in mesozooplankton biomass was evident in the upstream locations as compared to downstream (Table: 3.4).

Fig: 3.9. Spatial distribution of Micro and Meso zooplankton. The salinity distribution is set as the background in all panels with white circles representing the distribution of (a, c) MZP microzooplankton (×10^4 no. l^{-1}) and (b, d) MSP mesozooplankton biomass (ml 100 m^{-3}). a&b represents distribution during spring intermonsoon period while c & d represents distribution during southwest monsoon period.

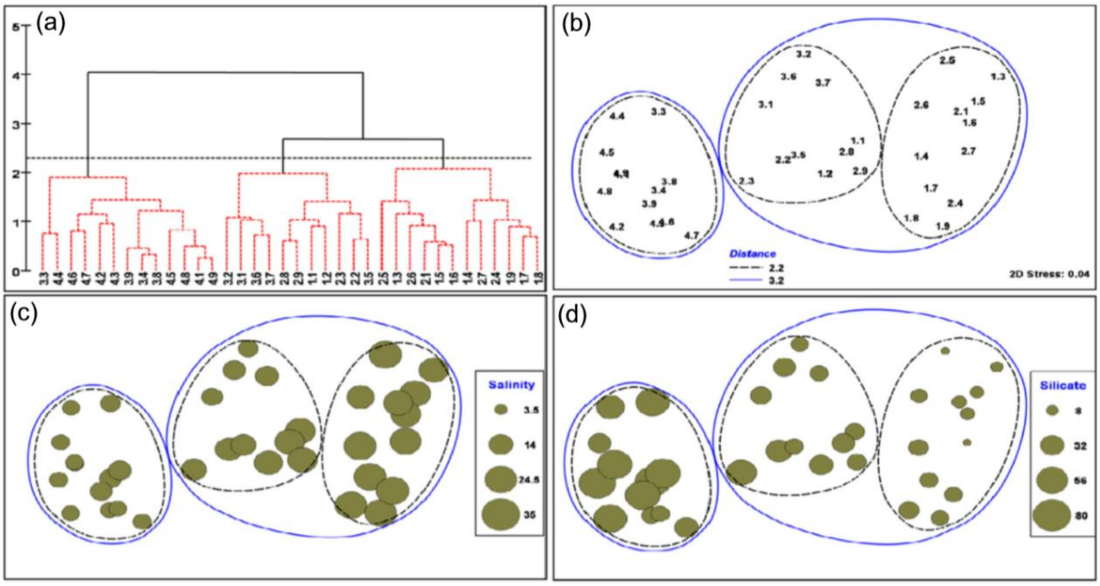


Segregation of environmental and plankton variables

The result of NMDS/SIMPROF analyses of hydrographic parameters during the spring intermonsoon is presented in Fig: 3. 10. Based on the spatial distribution of major physicochemical parameters (salinity, nitrate, phosphate, silicate, and dissolved oxygen) during the spring intermonsoon, three minor clusters and two major clusters were identified (Fig. 3. 10a & 3.10b). The minor clusters 1, 2, and 3 sequentially represented the mesohaline, mesohaline-high saline (polyhaline), and high saline (euhaline) waters in various locations during the time series observations. In subsequent panels (Fig: 3.10c–i), the quantitative data of salinity, silicate, and plankton food web components are superimposed on spatially clustered time series observations. The quantitative difference in parameters between the mesohaline upstream and euhaline downstream during the spring intermonsoon are presented in Fig.3.10. It is clear that there was a noticeable increase in the abundance of autotrophic picoplankton, autotrophic nanoplankton, heterotrophic nanoplankton, microzooplankton, and mesozooplankton in the upstream mesohaline regions (L3 and L4) as compared to the downstream euhaline region (L1 and L2).

The spatial distribution of hydrographic parameters measured during the southwest monsoon segregated using NMDS/SIMPROF is depicted in Fig: 3.11. Two major clusters of observations were segregated for the southwest monsoon based on the distribution of physicochemical parameters (Fig. 3.11a, b). The clusters 1 and 2 represented the mesohaline and oligohaline waters, respectively, in various sampling locations during the time series measurements. In the subsequent panels (Fig: 3.11 c – i), the quantitative data of salinity, silicate and plankton food web components are superimposed on spatially clustered time series observations. It was possible in these figures to distinguish the oligohaline upstream and mesohaline downstream regions during the southwest monsoon. The abundance of autotrophic picoplankton, heterotrophic picoplankton, heterotrophic nanoplankton, microzooplankton and mesozooplankton was noticeably high in the downstream mesohaline regions as compared to the upstream oligohaline region.

Fig: 3.10. (a) Cluster and (b) NMDS plots presenting the segregation of locations/observations based on the distribution of physicochemical parameters during the spring intermonsoon. The subsequent panels show physicochemical NMDS plots overlaid with the bubbles of (c) salinity, (d) silicate, (e) APP (f) ANP (g) HPP (h) HNP (i) MZP (j) MSP for visualizing their distribution based on spatially assembled observations.]



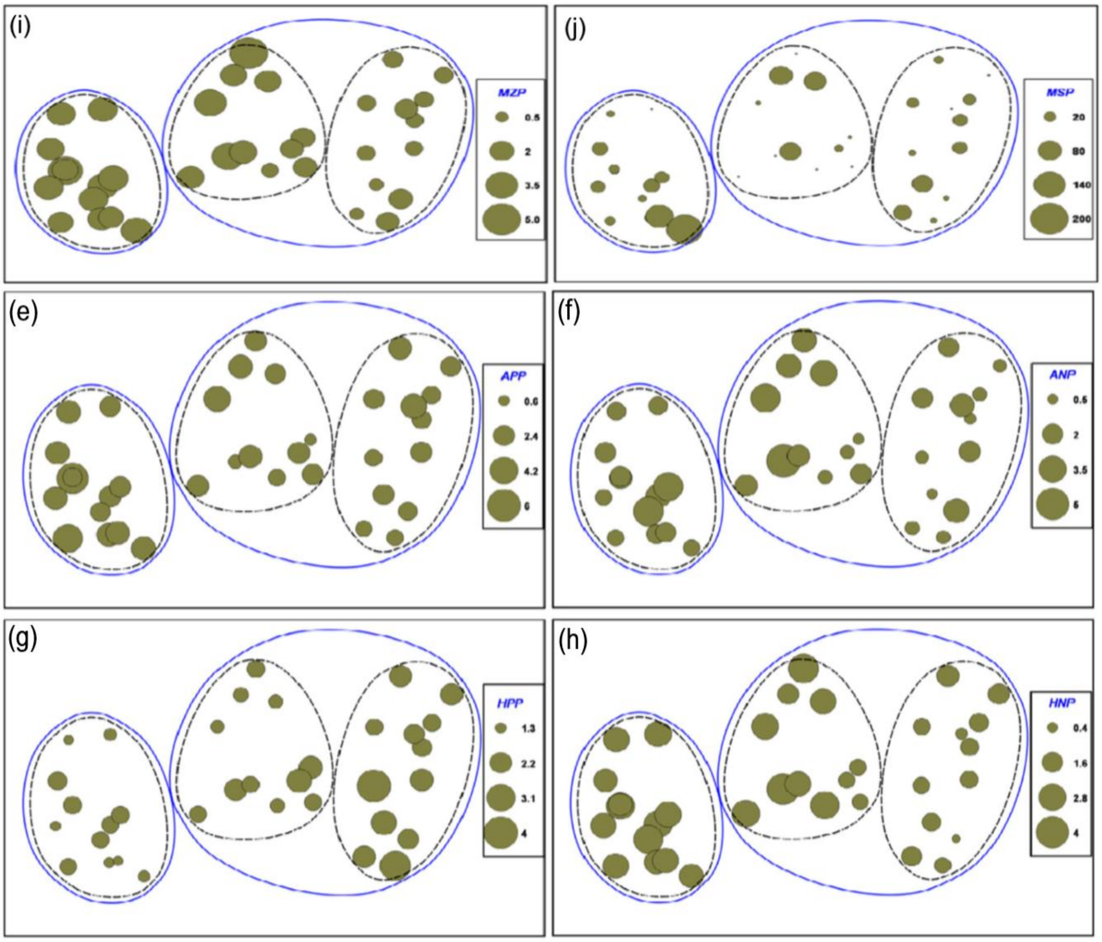
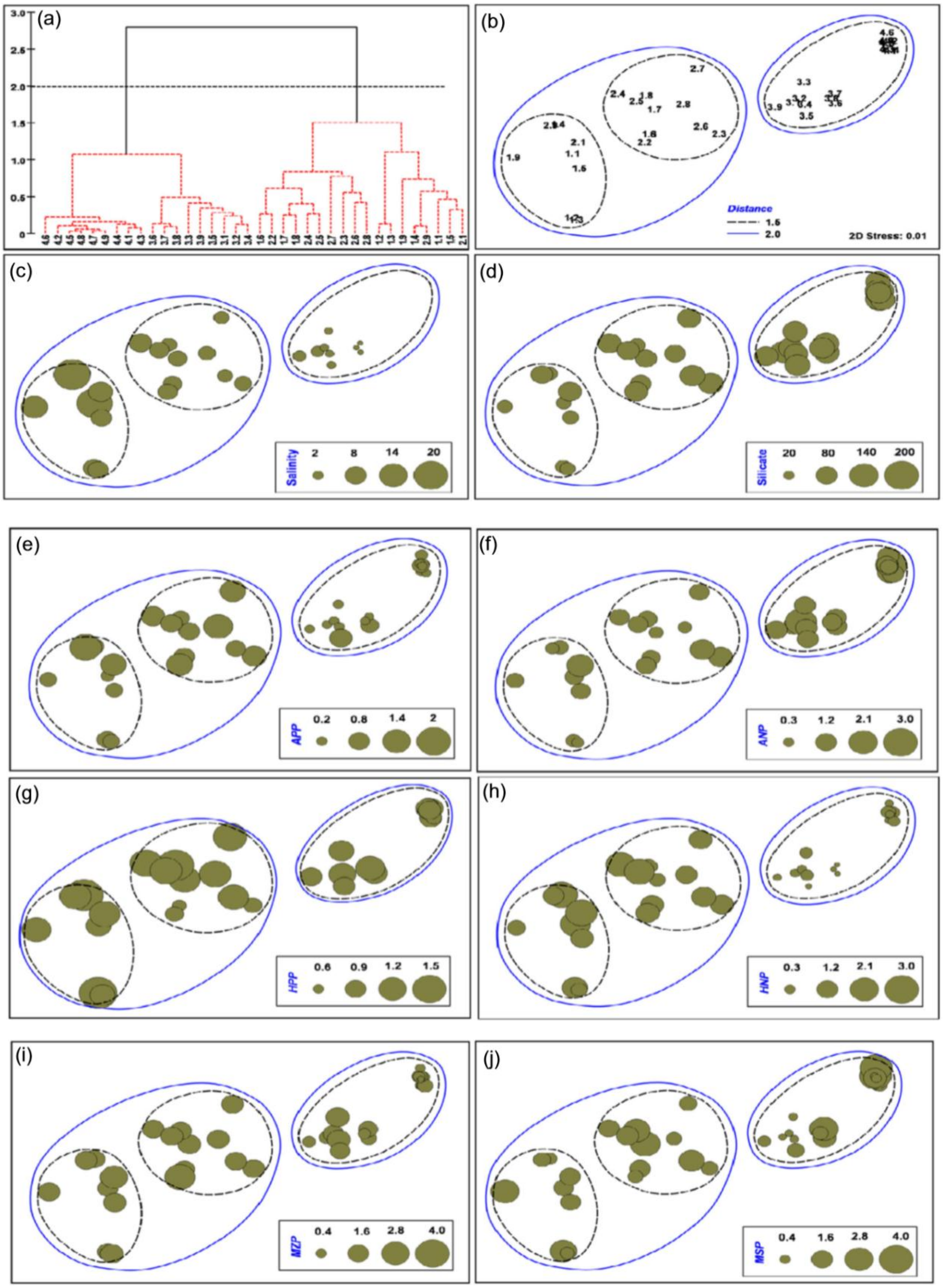


Fig: 3.11. (a) Cluster and (b) NMDS plots presenting the segregation of locations/observations based on the distribution of physicochemical parameters during the southwest monsoon. The subsequent panels show physicochemical NMDS plots overlaid with the bubbles of (c) salinity (d) silicate, (e) APP (f) ANP (g) HPP (h) HNP (i) MZP (j) MSP for visualizing their distribution based on spatially assembled observations.

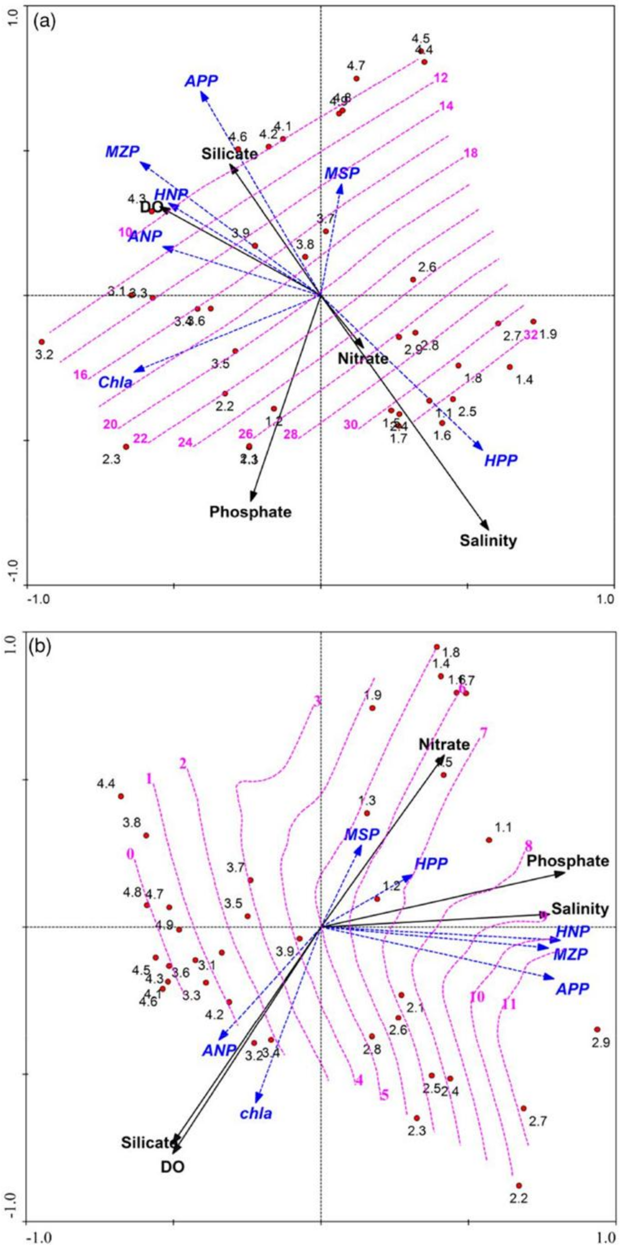


3.3.4. Interrelationships of environmental parameters and plankton components

Redundancy analysis (RDA) clearly demarcated the spatial difference and dynamics in environmental parameters during the sampling periods and also presented how they influence the food web components (Fig: 3.12). The RDA full model in which salinity, silicate, phosphate, dissolved oxygen, and nitrate were considered as environmental variables showed that they together explained 52.1 and 57.9% of the variance in plankton components during the spring intermonsoon and the southwest monsoon, respectively. The RDA partial model, with salinity as the foremost variable and silicate and dissolved oxygen as co-variables, showed that the major variable alone could explain 32% of the variance in biological parameters during both seasons. Monte Carlo test showed that all the ordinations attempted in the RDA analyses are significant (F=4.915, P=0. 006) in spring intermonsoon and in southwest monsoon (F=5.215, P=0. 008). The prevalence of high salinity in the downstream sites was evident in the triplot. During the spring intermonsoon, the downstream was polyhaline (18–30 ppt) or euhaline (>30) whereas the upstream was mesohaline (5–18 ppt). During southwest monsoon, the upstream was limnohaline (<0.5) and oligohaline (0.5–5 ppt) and the downstream mesohaline (5–18 ppt). An inverse relationship between dissolved oxygen and silicate with salinity was evident as they increased with a decrease in salinity during both seasons. Though the overall pattern during both seasons showed an increasing trend in salinity toward downstream, the salinity values during the spring intermonsoon were significantly higher than those observed during the southwest monsoon. During both seasons, the upstream region was characterized by higher silicate and dissolved oxygen associated with the river influx whereas the downstream locations had higher phosphate concentration associated with saline waters intrusion. It is clear in RDA that changes in the salinity gradients make a noticeable difference in the distribution of most of the plankton functional components. During the spring intermonsoon, autotrophic picoplankton, microzooplankton, heterotrophic nanoplankton, and autotrophic nanoplankton increased toward the upstream sites (Fig. 3.12a). On the other hand, during the southwest monsoon, autotrophic picoplankton, heterotrophic nanoplankton, microzooplankton, and mesozooplankton were noticeably high downstream (Fig. 3.12b). Eventhough the autotrophic nanoplankton density distribution showed an irregular fluctuation, RDA confirmed their high density orientation towards the upstream during southwest monsoon.

Fig: 3.12. RDA triplot showing the distribution and interrelationships of environmental and biological parameters during (a) spring intermonsoon and (b) southwest monsoon. The overlaid attribution contours (pink dotted line and values) represent the spatial distribution of salinity and its relationship with other environmental and biological components. The sampling locations (1–4) and the time series observations in each of these locations are displayed by small red filled circles.

For example, points 1.1–1.9 represent the nine time series observations carried out at location 1. Different plankton functional components and environmental parameters are displayed by arrows; the blue dotted arrows indicate the former, and the black arrows indicate the latter.



3.4. Discussion

3.4.1. Temporal and spatial variations in hydrography

Being a monsoonal estuary, the Cochin backwater is characterized by large seasonal salinity fluctuation caused by the alternating dry (spring intermonsoon) and rainy (southwest monsoon) periods (Madhupratap, 1987; Qasim 2003). The semidiurnal mixed tides play a dominant role in spatial distribution of salinity in the Cochin backwater during the spring intermonsoon whereas large freshwater influx from the upstream dominates over tidal forcing during the southwest monsoon (Qasim & Gopinathan, 1969; Srinivas *et al.,* 2003). The maximum tidal height in the Cochin backwater observed during the present study was 0.7 m during the spring intermonsoon period, which indicates the low tidal amplitude/microtidal behavior of the system. The time lag in the tidal phase upstream is a general feature of the Cochin backwater due to its vastness, about 50-km stretch from the Kochi inlet to the L4 site upstream (Shivaprasad *et al.,* 2013). During the spring intermonsoon, the river influx into the Cochin backwater becomes the seasonal lowest, which favours active salinity incursion into the system through the inlets (Qasim, 2003; Jyothibabu *et al.,* 2006); this, in turn causes the highest seasonal salinity observed in the Cochin backwater during the spring intermonsoon. The high nutrient concentration observed throughout the Cochin backwater is a typical feature of the system irrespective of seasons (Qasim, 2003; Jyothibabu *et al.*, 2006). The seven rivers that empty into the study area are responsible for the high concentration of silicate whereas several non-point sources also contribute to the elevated nitrate levels (Sankaranarayanan & Qasim, 1969; Saraladevi *et al.,* 1983; Jyothibabu *et al.,* 2006). The phosphate concentration in the Cochin backwater was the seasonal highest during the spring intermonsoon due to high salinity during the period, which aids the desorption of phosphate from the suspended particles (Reddy & Sankaranarayanan, 1972; Martin *et al.,* 2008). During spring intermonsoon, the distribution of physicochemical parameters in most of the study locations showed relatively minor tidal variations, whereas the spatial difference between the locations in the downstream and the upstream was large which point towards a clearcut difference in the ecology of these regions (Fig: 3. 2 & Table: 3. 1). During the southwest monsoon, due to heavy rainfall, freshwater occupied a major part of the Cochin backwater (Madhupratap, 1987; Jyothibabu *et al.,* 2006). This seasonal physiographic feature of the study region was clear in the present study also. Large seasonal variation in salinity was evident in all the study locations (Fig: 3.3 & Table: 3. 2). The enormous freshwater influx during the southwest monsoon caused low tidal amplitude in the Cochin backwater. Due to increased freshwater influx and the resulting low salinity, the concentration of dissolved oxygen in the entire study area was the seasonal highest during the southwest monsoon. The NO_3 concentration was high during the southwest monsoon, contributed both by the river influx and non-point sources (Qasim, 2003;

Jyothibabu *et al.*, 2006). The SiO_4 concentration was the seasonal highest during the southwest monsoon assisted by the increased river influx during the period. This caused large seasonal fluctuation in the availability of silicate in the Cochin backwater (Table: 3.2). The overall trend in distribution of physicochemical parameters showed low tidal variations of all parameters except the salinity. On the other hand, the spatial variations in most of the hydrographic parameters between the downstream (L1 and L2) and the upstream (L3 and L4) sites were significant (Table: 3.1 & Table: 3.2). Most of the hydrographic parameters during both seasons showed minor tidal variations as compared to their spatial and seasonal variations. Low tidal variations of the physicochemical parameters in most of the study locations can be attributed to the low tidal amplitude in the system. The study showed that, during the spring intermonsoon, the downstream region was polyhaline (18–30 ppt) and euhaline (>30 ppt), whereas, the upstream area was mesohaline (5–18 ppt). During the southwest monsoon, the upstream was limnohaline (<0.5 ppt) and oligohaline (0.5–5 ppt) and the downstream mesohaline (5–18 ppt). These spatial shifts in salinity regimes during the two seasonal sampling caused changes in the distribution of biological components. The autotrophic picoplankton, heterotrophic nanoplankton, microzooplankton, and mesozooplankton showed a clear seasonal shift from the upstream during the spring intermonsoon to the downstream during the southwest monsoon. This indicates the spatial shift in the abundance of planktonic grazers in the Cochin backwater during the two seasons. Conversely, irrespective of seasons, the autotrophic nanoplankton was higher in the upstream.

3.4.2. Ecology and dynamics of the plankton food web

The present study exhibited that both autotrophic and heterotrophic forms of picoplankton and nanoplankton are abundant in monsoonal estuaries. The trophic interaction in a plankton food web becomes effective when both prey and consumers become abundant and coexists in time and space (Landry & Fagerness, 1988; Garrison *et al.*, 2000; Calbet and Landry, 2004; Landry *et al.*, 2008). While considering the spatial distribution of plankton components in the Cochin backwater during the spring intermonsoon, the upstream mesohaline regions seem to have a more efficient plankton food web as compared to the downstream due to close coupling between plankton consumers and their potential prey (Fig: 3.9 & Fig: 11a). The hydrography of the Cochin backwater changes drastically during the southwest monsoon due to enormous fresh water influx from rivers that feed the upstream region (Madhupratap, 1987). The present study also emphasizes the drop-in consumer abundance in the upstream locations during the southwest monsoon, which makes the spatial distribution of predator and prey discrete. For example, autotrophic nanoplankton density was higher in upstream in both season but during southwest monsoon the predator population, mesozooplankton was largely concentrated towards the downstream which lead to a weak predator prey interaction which inturn results in a weak linear food chain. It is proven that the major size fraction of primary producers in the linear food chain of Cochin backwater belongs to autotrophic nanoplankton (Kumaran & Rao, 1975; Gopinathan, 1975; Menon *et al.,* 2000; Qasim, 2003; Madhu *et al.,* 2007; Madhu *et al.,* 2010). Therefore, the major reason for the presence of unconsumed carbon in Cochin backwater during southwest monsoon was found to be due to the spatial mismatch in the prey and predator population which was particularly prominent in linear food chain.

But in the case of microbial food web, the abundance of all the plankton components – prey and predator organisms (APP, HPP, HNP & MZP) – showed a clear spatial displacement from upstream to downstream along with the shifting mesohaline region as the season changes from spring intermonsoon to southwest monsoon (Fig 3.12). Thus, it can be assumed that there is a spatial shift in the active microbial food web region from upstream to downstream during southwest monsoon. In spite of the spatial shift, the orientation of both predator and prey organisms in the same ecological region (downstream) showed the presence of an efficient microbial food web in southwest monsoon also. It is noticeable that in the existing studies, the low abundance of prey and predator organisms in southwest monsoon led to the conclusion that reduction in number reduces the efficiency of the food web which results in its weakening. But efficiency of a food web is a combination of different factors like abundance, rate of resource utilization and rate of conversion of utilized resource into biomass. To find out the change in efficiency of the food web of Cochin backwater it is essential to consider how all these factors changes during both seasons. Unfortunately, the available studies which address the growth and grazing rate of lower size fraction was conducted only during spring intermonsoon season due to the assumption that efficiency of microbial food web decreases during southwest monsoon. (Jyothibabu *et al.,* 2006; Madhu *et al.,* 2007; Jyothibabu *et al.,* 2015). In the present observation the close coupling between the predator and prey organisms in the downstream mesohaline region during southwest monsoon indicated an active microbial food web region in monsoon as well. The other factors like grazing rate and carbon transfer from lower trophic level to the higher trophic level of microbial food web is addressed in the following chapters.

Badylak *et al.* (2007) indicated that autotrophic picoplankton is the numerically abundant primary producer in Tampa Bay Estuary even though they were not dominated in case of biovolume. Sincy in 2005 identified that Cochin backwater is rich in unicellular cyanobacterial genera. Present observation also shows that autotrophic picoplankton is numerically abundant in Cochin backwater. Sherr and Sherr (1994) showed that heterotrophic nanoplankton is the dominant grazer of both heterotrophic and autotrophic picoplankton in the marine environment. In the present observation, the spatial distribution of autotrophic picoplankton and its grazers suggest the efficient utilization of autotrophic picoplankton crop in the backwater irrespective of the season even though the active consumption zone differs (Fig: 9 – 11). Therefore, even when the linear food chain weakens due to the spatial disparity in predator and prey population, microbial food web is able to pump carbon to the higher trophic levels particularly in the mesohaline patches of the estuary during southwest monsoon.

3.5. Conclusion

In agreement with previous studies there was a general reduction in the numerical abundance of all planktonic components during southwest monsoon. Temporal variation of the parameters within the tidal cycle was insignificant. Spatial difference and segregation in plankton food web components except autotrophic nanoplankton were very clear in the Cochin backwater during both sampling periods. There was a seasonal spatial shift in the mesohaline environment and all the plankton components showed an affinity to mesohaline environment. This indicates a clear spatial shift in the region of active plankton food web (region shows close coupling between plankton consumers and their potential prey) in the Cochin backwater between the seasons which can have applications in designing the seasonal food web models for monsoonal estuaries.

According to the present study the major reason for the presence of unconsumed carbon in Cochin backwater during monsoon could be explained based on the spatial mismatch in the prey and predator population which was particularly prominent in linear food chain. The higher the autotrophic nanoplankton density (the most abundant primary producer population of Cochin backwater) in upstream despite the orientation of its predator population (MSP) towards the downstream lead to a weak linear food chain in monsoon. There was a spatial shift in the active microbial food web region from upstream to downstream during southwest monsoon as well. Dissimilar to the results of previous works (Jyothibabu *et al.,* 2006; Jyothibabu *et al.,* 2015), in spite of the spatial shift the orientation of both predator and prey organisms in the same ecological region (downstream) showed the presence of an efficient microbial food web in southwest monsoon also. The spatial distribution of autotrophic picoplankton and its grazers (heterotrophic nanoplankton and microzooplankton) suggest the efficient utilization of autotrophic picoplankton crop in the backwater irrespective of the season (even though the active consumption zone differs). The more detailed predator prey interaction with special reference to autotrophic picoplankton is addressed in the following chapter.

Chapter IV

Autotrophic picoplankton as a food web component of Cochin Backwater

4.1. Introduction

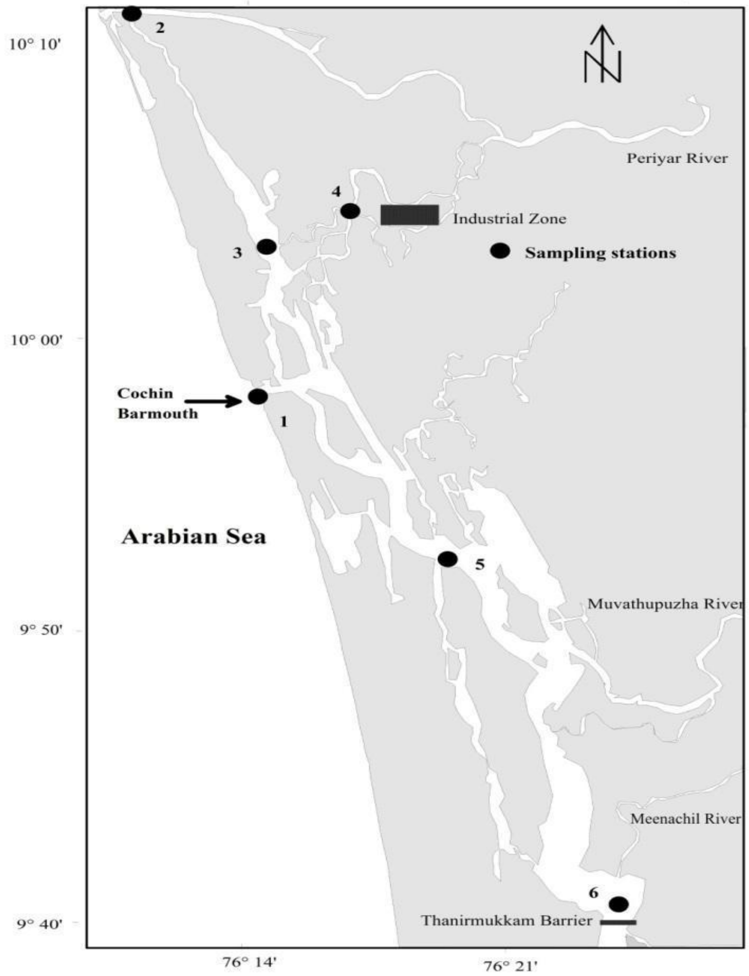
Even though autotrophic picoplankton is not considered to be a major carbon contributor in nutrient rich aquatic ecosystems, it is well established that voracious grazing of autotrophic picoplankton by protozoans and metazoans is likely to occur in estuaries and nearshore waters (Menon *et al.,* 1971; Perkins *et al.,* 1981; Silver & Alldredge 1981; Caron *et al.,* 1985; Gast, 1985; Glover, 1985; Fahnenstiel *et al.,* 1986; Stockner & Antia, 1986; Stockner, 1988; Landry & Kirchman, 2002; Menon *et al.,* 2000; Callieri and Stockner, 2002). According to the available literature the high heterotrophic picoplankton abundance and production in the Cochin backwater is the major carbon source to support an efficient microbial food web in the system (Thottathil *et al.,* 2008). But it is also proven that Cochin estuary harbors plenty of autotrophic picoplankton and they act as a major food source for lower size predators (Menon *et al.,* 2000; Qasim, 2003; Sincy, 2005; Jyothibabu *et al.,* 2006; Sooria *et al.,* 2015). Therefore, the present chapter runs into two minor objectives:

- To study the seasonal dynamics of autotrophic picoplankton community
- To Study the interrelationship between autotrophic picoplankton and its grazers (Heterotrophic nanoplankton and microzooplankton) in comparison with that of heterotrophic picoplankton.

4.2. Study area

As it is mentioned in previous chapter, the balance between freshwater and tidal intrusion determines the ecological characteristics of Cochin backwater. The northern arm of the estuary receives freshwater from rivers named Periyar and Chalakkudy whereas the southern limb from five rivers (Muvattupuzha, Pamba, Manimala, Meenachil, and Achancoil). Thus, the annual freshwater influx is around $22{,}000 \times 10^6$ m^3 (Revichandran *et al.,* 2012). There are two barmouths for the estuary through which the sea water enters. The Azheekode barmouth situated at the northern end is with 250 m width and is shallower than Cochin barmouth (450 m width) (Fig: 4.1).

Fig: 4.1. Study area (Cochin Backwater) showing 6 sampling locations (Stn. 1- Fort Kochi, Stn. 2- Azheekode, Stn. 3- Nedungadu, Stn. 4- Varappuzha, Stn. 5- Arookutty and Stn. 6- Thanneermukkam)



4.3. Sampling strategy and methods

Six sampling locations were selected along the salinity gradient of Cochin backwater. Stn.1 and Stn.2 represented Cochin and Azheekode barmouth respectively. Stn. 3 and Stn. 4 were characterized by low saline waters which are located near the industrial belt. Stn. 5 represented the middle part of the southern arm of the estuary which receives water from Muvattupuzha River and Stn. 6 was the low saline southern upstream.

Three hourly time series sampling was conducted in the above mentioned six locations in the Cochin backwater during the spring intermonsoon (March 2009) and southwest monsoon (September 2009) seasons. During the seasonal sampling, field measurements began at 0900 hours and ended at 0900 hours of the next day (24 h). Water samples for salinity, nutrients, Dissolved oxygen (DO), Autotrophic picoplankton (APP), Heterotrophic picoplankton (HPP) heterotrophic nanoplankton (HNP) and Microzooplankton (MZP) were collected and processed according to the methods described in Chapter 3 (section: 3.2.4).

4.4. Resluts

4. 4. 1. Physico- chemical parameters

The distribution of salinity during the sampling period is represented using surfer plot (Fig: 4.2). During spring intermonsoon, salinity was generally high towards the barmouth region and low towards the upstream during both seasons. Maximum salinity at surface was observed at stn. 2 (avg. 29.15 ± 2.78 ppt) and minimum at stn. 4 (avg.1.27 ± 0.26 ppt) which was the upstream of northern arm of the estuary (Fig: 4.2a). At bottom, salinity maxima (avg. 31.88 ± 1.97) was observed at Fortkochi (Stn.1) and minima (avg. 9.99 ± 0.212) was at Thanneermukkam (Stn. 6) which is the southern upstream of the estuary (Fig: 4.2b). During southwest monsoon, maximum surface salinity was at Stn. 1 (avg. 8.66 ± 6.08) and minimum at Stn. 4 (avg.0.00) (Fig.4.2c). While at bottom salinity varied from avg. 0.01 ± 0.04 (Stn. 4) to avg. 33.39 ± 1.26 (Stn. 1) (Fig: 4.2d).

Surface values of dissolved oxygen concentration were low in spring intermonsoon (avg. 3.87 ± 0.22 to avg. 5.96 ± 0.11 mg l^{-1}) than southwest monsoon (Fig: 4.3a). In bottom waters the maximum value was noticed at Stn. 4 (avg. 4.39 ± 1.15 mg l^{-1}) and minimum at Stn. 1 (avg. 2.31 ± 1.13 mg l^{-1}) (Fig:4. 3b). During southwest monsoon highest surface value was found at Stn. 4 (avg. 6.36 ± 0.88 mg l^{-1}) and lowest at Stn. 2 (avg. 4.23 ± 0.72 mg l^{-1}) (Fig: 4.3c). DO values of bottom waters showed maxima at Stn. 6 (avg. 5.27 ± 0.49 mg l^{-1}) and minima at Stn.4 (avg. 2.92 ± 1.26 mg l^{-1}) (Fig:4. 3d).

Fig: 4.2. Distribution of salinity (a) Salinity distribution at surface during spring intermonsoon (b) Salinity distribution at bottom during spring intermonsoon (c) Salinity distribution at surface during southwest monsoon (d) Salinity distribution at bottom during southwest monsoon

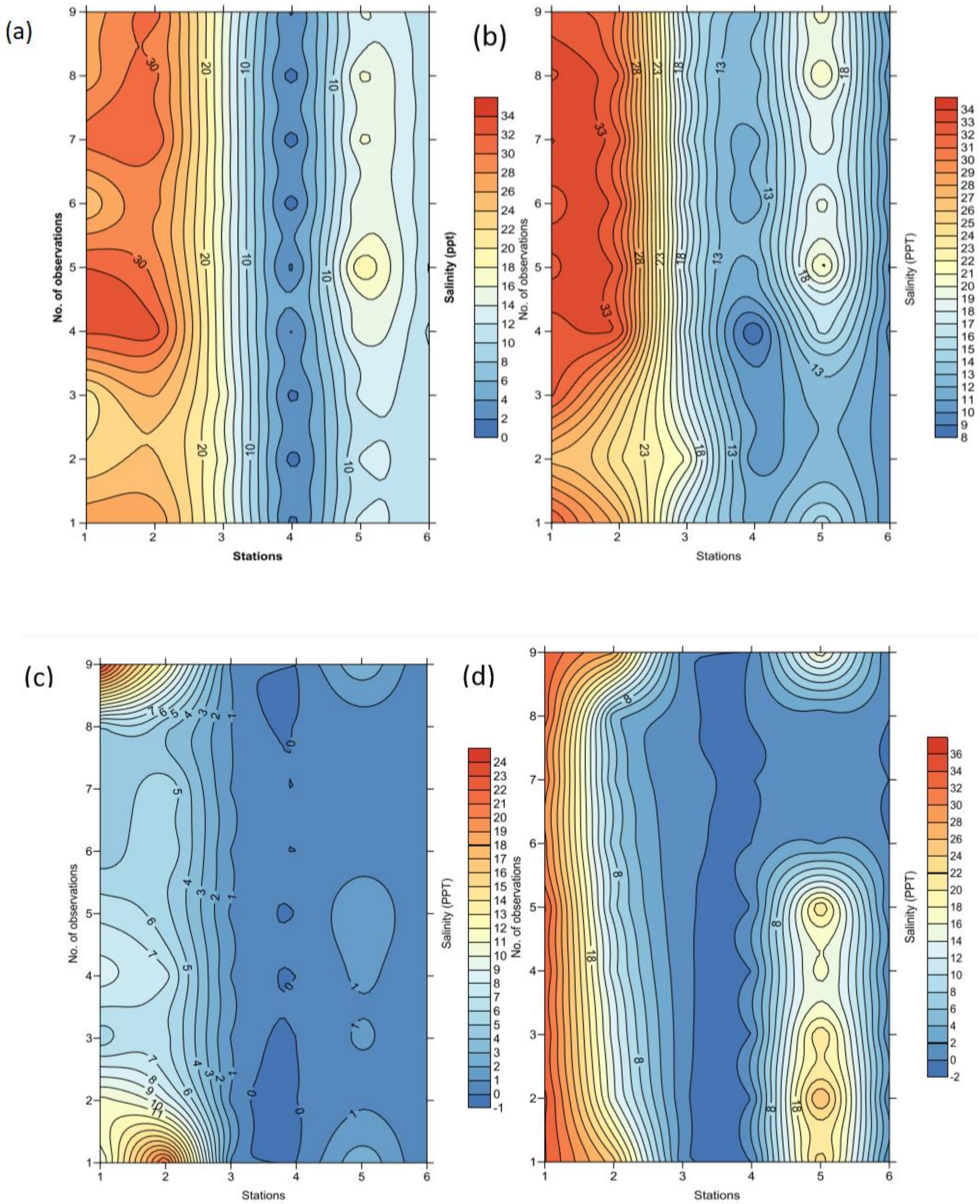
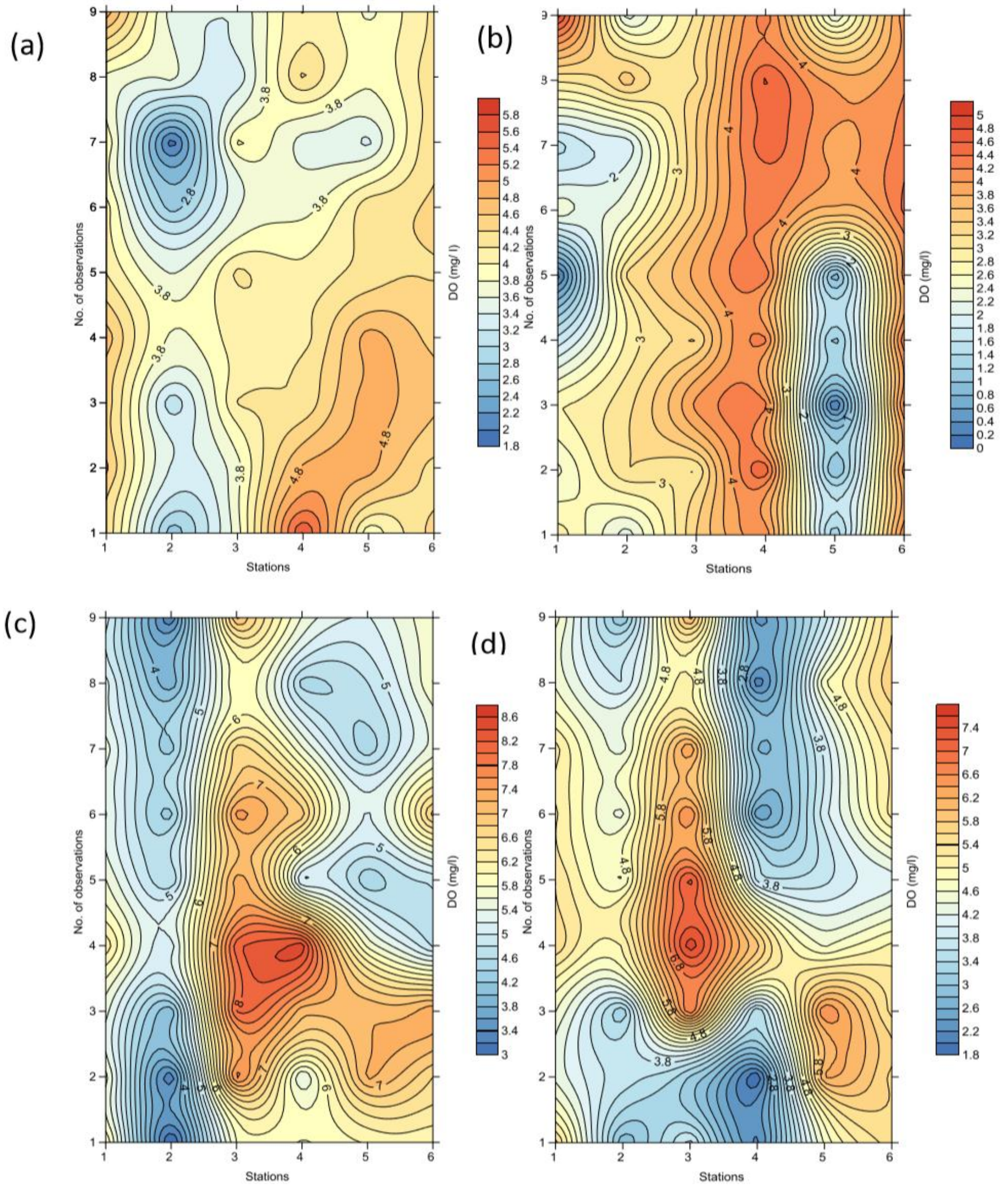


Fig: 4.3. Distribution of Dissolved Oxygen (a) DO distribution at surface during spring intermonsoon (b) DO distribution at bottom during spring intermonsoon (c) DO distribution at surface during southwest monsoon(d) DO distribution at bottom during southwest monsoon.



Nutrients were generally high throughout the study area. At surface, nitrate showed highest value at Stn. 4 (avg. 22.5 ± 5.79 µM) and minimum at Stn. 3 (avg. 5.7 ± 1.60 µM) during spring intermonsoon (Fig: 4.4a). The highest value at bottom was also observed at Stn. 4 (avg. 18.74 ± 5.40 µM) and minimum at Stn. 3 (avg. 6.5 ± 2.05 µM) (Fig: 4.4b). During southwest monsoon also, the maximum surface value for nitrate was observed at Stn. 4 (avg. 34.31 ± 10.02 µM) and minimum at Stn. 6 (avg. 0.61 ± 0.18

μM) (Fig: 4. 4c). Whereas, at bottom, the maximum was observed at Stn. 4 (avg. 30.74 ± 7.39 μM) and minimum at Stn. 3 (avg. 9.31 ± 5.70 μM) (Fig. 4.4d). In the case of phosphate, maximum surface value was observed at Stn. 2 (avg.1.60 ± 0.94 μM) and minimum at Stn. 6 (avg. 0.23 ± 0.09 μM) (Fig: 4.5a) during spring intermonsoon period. At bottom also, same trend was observed (Fig: 4.5b). Whereas, in southwest monsoon highest concentration in surface was observed at Stn. 3 (avg.3.05 ± 1.02 μM) and minimum at Stn. 6 (avg. 0.20 ± 0.12 μM) (Fig: 4.5c). At the same time the bottom value was extremely high at Stn. 2 (avg. 8.76 ± 5.58 μM) and minimum at Stn. 6 (avg. 0.21 ± 0.09 μM) (Fig: 4.5d). Silicate concentration was generally high throughout the study area with the highest values in southwest monsoon. During spring intermonsoon period the surface maxima was detected at northern upstream (Stn. 4) and minimum at Stn. 2 (avg. 45.62 ± 22.49 and 17.70 ± 0.84 μM respectively) while the bottom values showed a maximum at Stn. 3 (avg. 40.74 ± 17.56 μM) and minimum at Stn. 1 (avg. 5.63 ± 3.08 μM) (Fig: 4.6a & 6b). In southwest monsoon, the maximum surface value for silicate was observed at Stn. 3 (av. 125.21 ± 13.85 μM) and minimum at Stn. 1 (av. 90.99 ± 29.68 μM) (Fig: 6c). Bottom value for silicate concentration also showed a similar trend with maximum at Stn. 3 and minimum at Stn. 1 (Fig: 6d).

Fig: 4.4. Distribution of Nitrate (µM) *(a) Distribution of nitrate at surface during spring intermonsoon (b) Distribution of nitrate at bottom during spring intermonsoon (c) Distribution of nitrate at surface during southwest monsoon (d) Distribution of nitrate at bottom during southwest monsoon.*

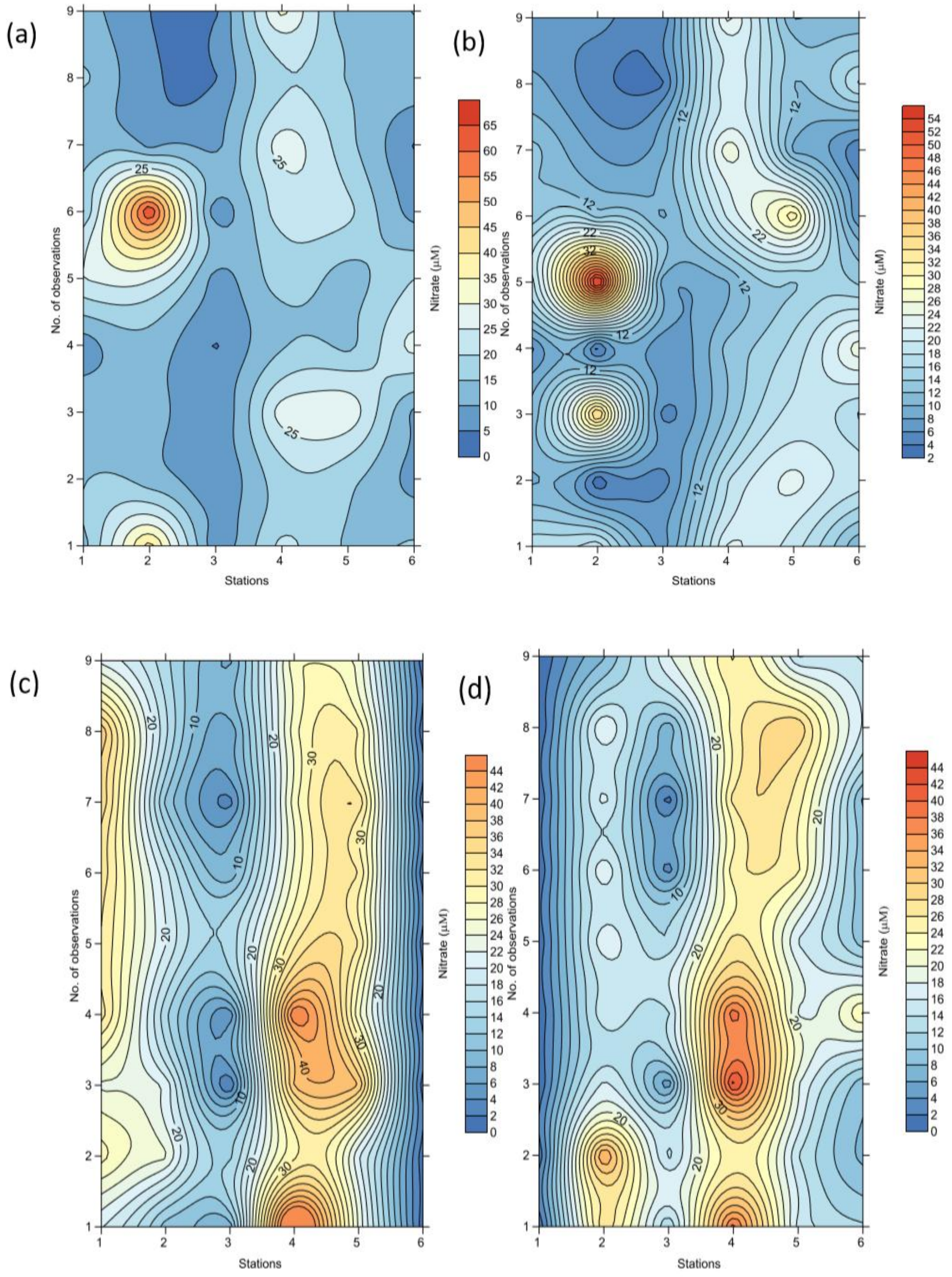


Fig: 4.5. Distribution of Phosphate (μM) *(a) Distribution of phosphate at surface during spring intermonsoon (b) Distribution of phosphate at bottom during spring intermonsoon (c) Distribution of phosphate at surface southwest monsoon (d) Distribution of phosphate at bottom during southwest monsoon.*

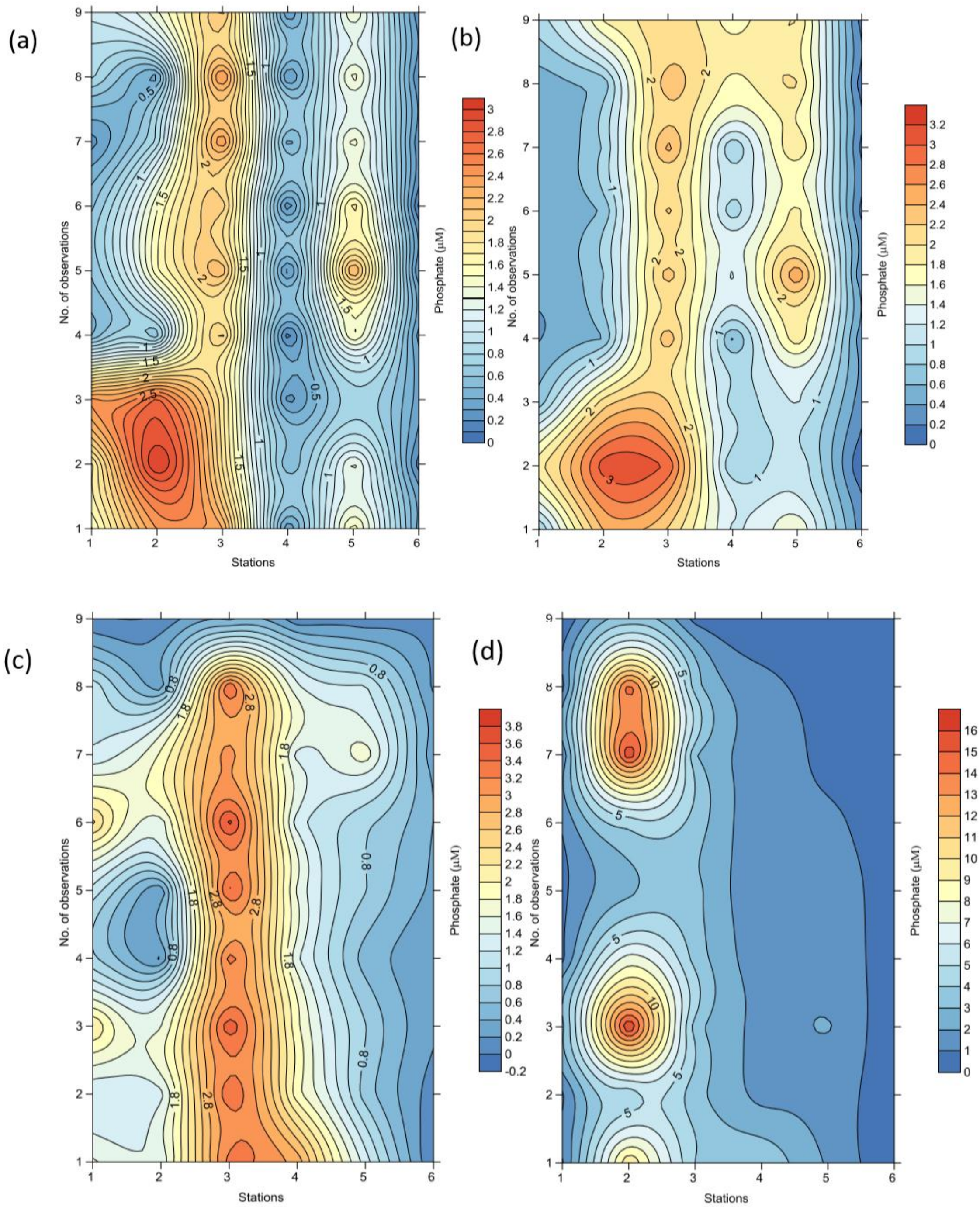
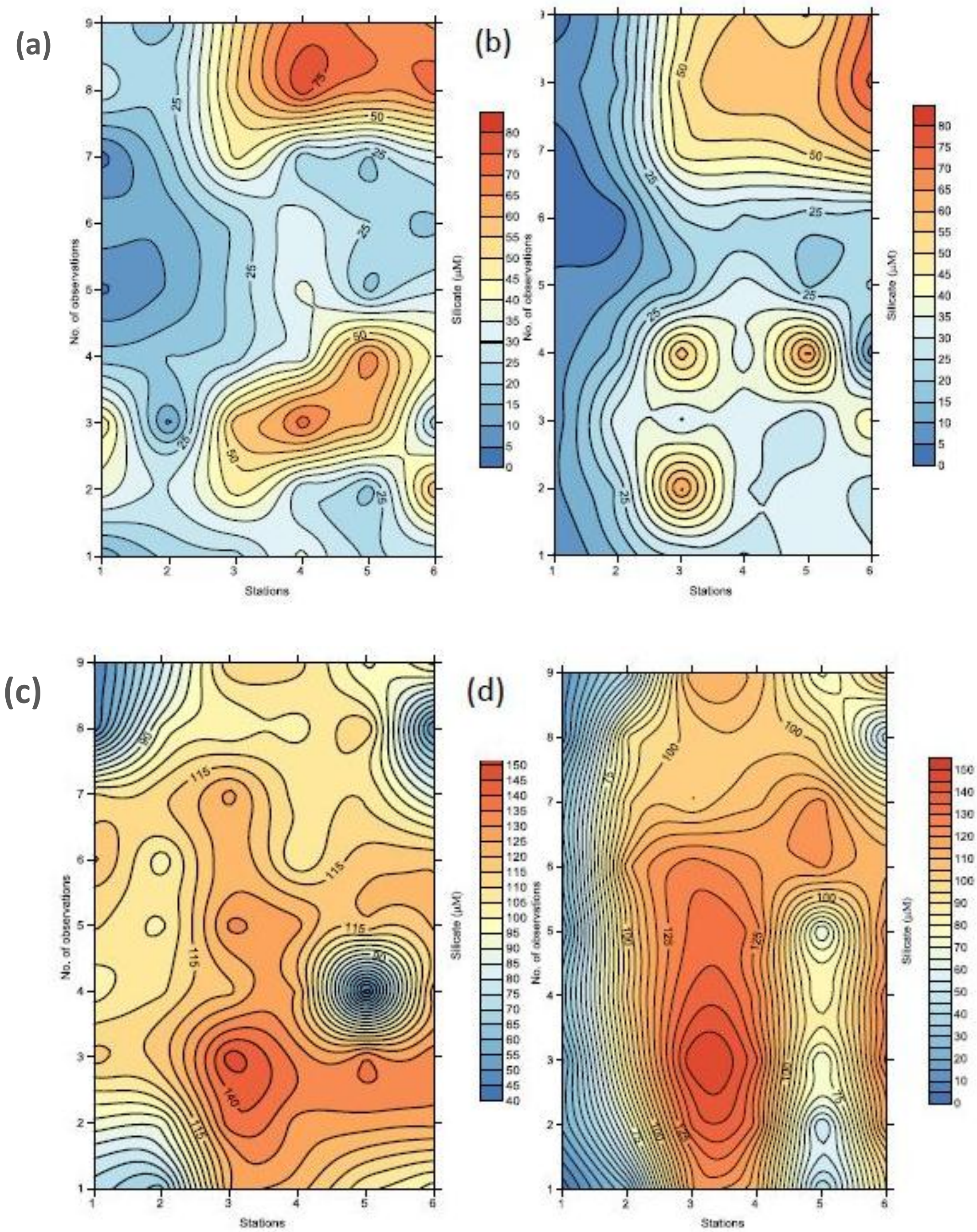


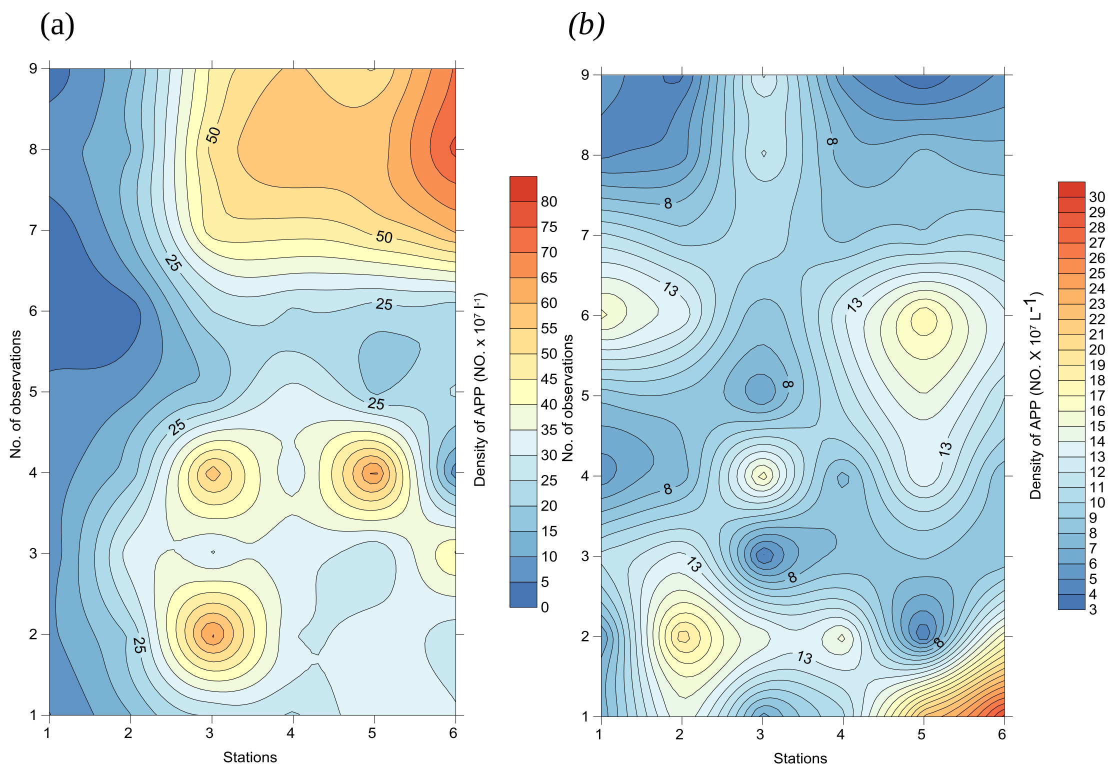
Fig.4.6. Distribution of Silicate (µM) (a) Distribution of silicate at surface during spring intermonsoon (b) Distribution of silicate at bottom during spring intermonsoon (c Distribution of silicate at surface during southwest monsoon (d) Distribution of silicate at bottom during southwest monsoon.

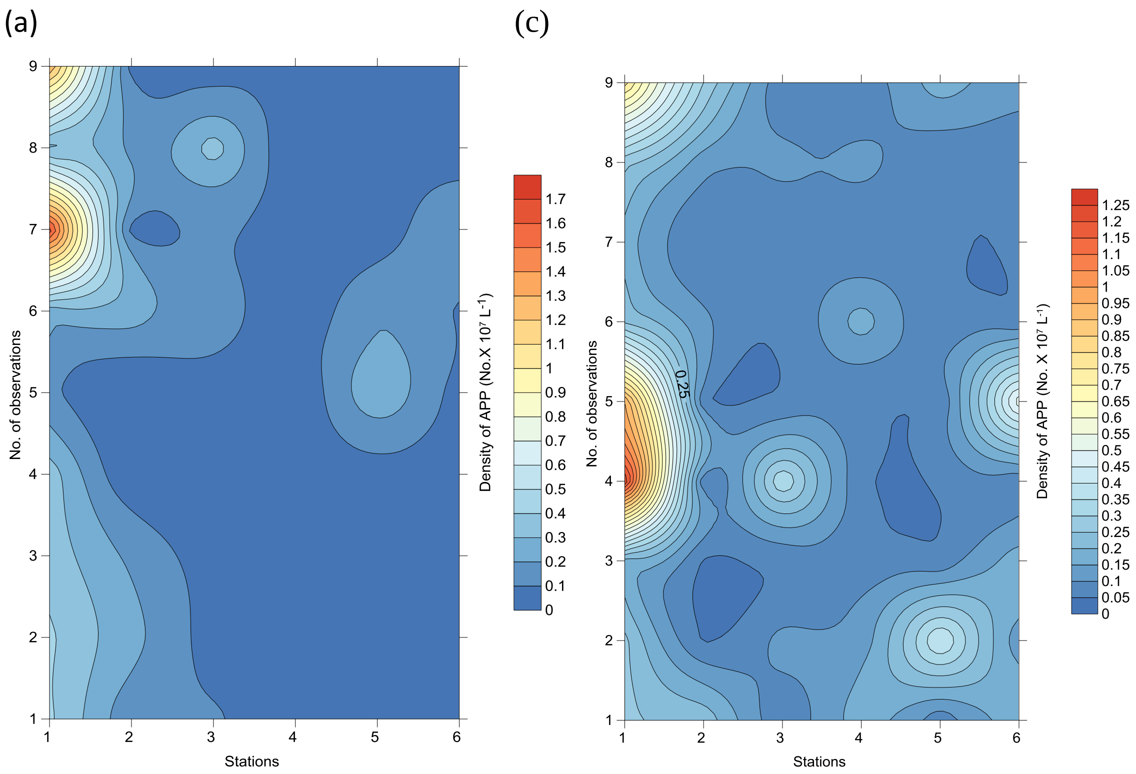


4.4.2. Distribution of autotrophic picoplankton, heterotrophic picoplankton and its predators (Heterotrophic nanoplankton and Microzooplankton)

During spring intermonsoon, average numerical density of autotrophic picoplankton increased from downstream to upstream with a maximum at Stn. 5 (avg.10.96 ± 2.33 x $10^7 l^{-1}$) and minimum at Stn. 1 (avg. 5.43 ± 1.89 x 10^7 l^{-1}) at surface. Bottom waters also showed same trend with a maximum at Stn. 6 (avg. 12.1 ± 7.30 x 10^7 l^{-1}) and minimum at Stn. 1 (avg. 8.48 ± 3.81 x 10^7 l^{-1}) (Fig: 4.7a & 7b). Whereas in southwest monsoon, average numerical density of autotrophic picoplankton increased from upstream to downstream with a maximum at Stn. 1 (avg. 0.57 ± 0.50 x 10^7 l^{-1}) and minimum at Stn. 4 (avg. 0.02 ± 0.02 x 10^7 l^{-1}). Bottom waters also showed same trend with a maximum at Stn. 1 (avg. 0.48 ± 0.40 x 10^7 l^{-1}) and minimum at Stn. 4 (avg. 0.10 ± 0.05 x 10^7 l^{-1}) (Fig: 4.7c & 7d).

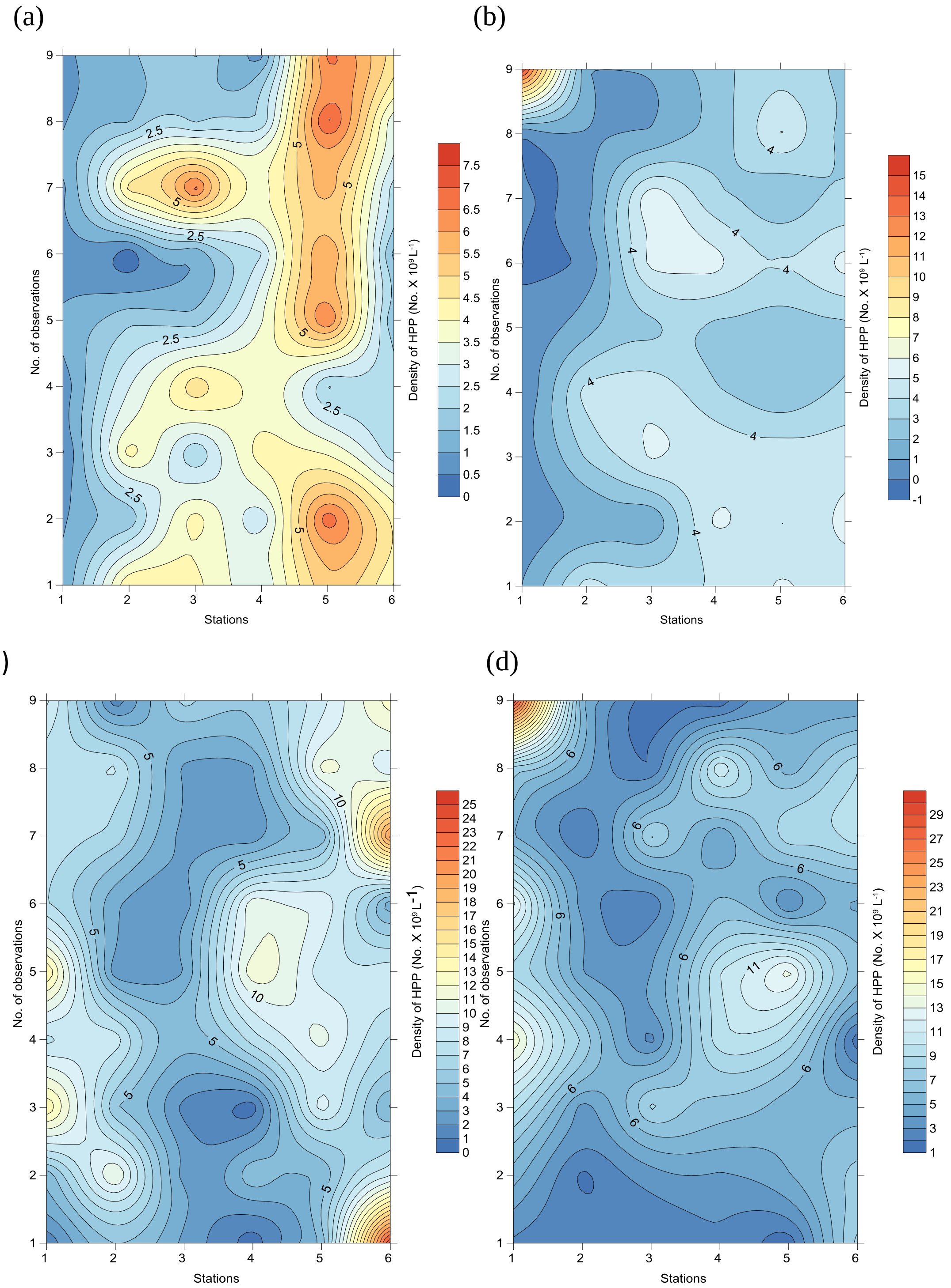
Fig: 4.7. Density distribution of APP during both seasons (a) Density distribution of APP at surface during spring intermonsoon (b Density distribution of APP at bottom during spring intermonsoon (c) Density distribution of APP at surface during southwest monsoon (d) Density distribution of APP at bottom during southwest monsoon





Heterotrophic picoplankton (HPP) showed highest surface density in Stn. 5(avg. 2.92 ± 1.07 x 10^9 l^{-1}) and the lowest at Stn. 1 (avg. 0.87 ± 0.21 x 10^9 l^{-1}) during spring intermonsoon. Whereas, at bottom, the maximum density was observed at Stn. 6 (avg. 3.84 ±1.18 x 10^9 l^{-1}) and the minimum at Stn. 1 (avg. 1.85 ± 0.48 x 10^9 l^{-1}) (Fig: 4.8a & 8b x 10^9 l^{-1}). In southwest monsoon, the maximum surface density was observed at Stn. 1 (avg. 0.10 ± 0.07 x 10^9 l^{-1}) and minimum at Stn.3 (avg. 0.03 ± 0.02 x 10^9 l^{-1}). At bottom, the highest density was observed at Stn. 1 (avg. 0.10 ± 0.07 x 10^9 l^{-1}) and minimum at Stn. 3 (avg. 0.03 ± 0.01 x 10^9 l^{-1}) (Fig: 4.8c & 8d).

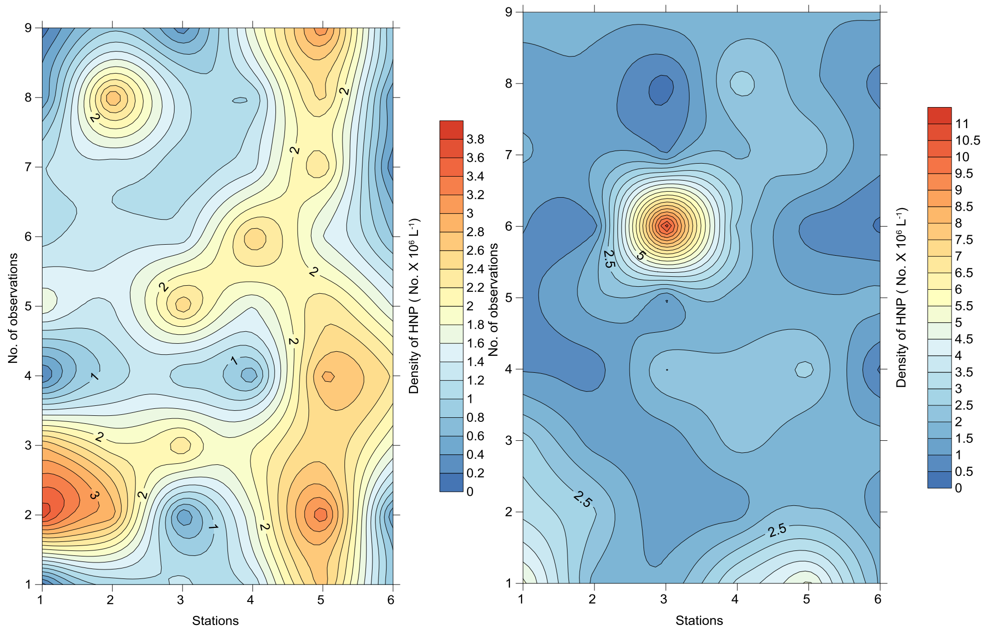
Fig: 4.8. Density distribution of HPP during both seasons (a) Density distribution of HPP at surface during spring intermonsoon (b) Density distribution of HPP at bottom during spring intermonsoon (c) Density distribution of HPP at surface during southwest monsoon (d) Density distribution of HPP at bottom station during southwest monsoon.



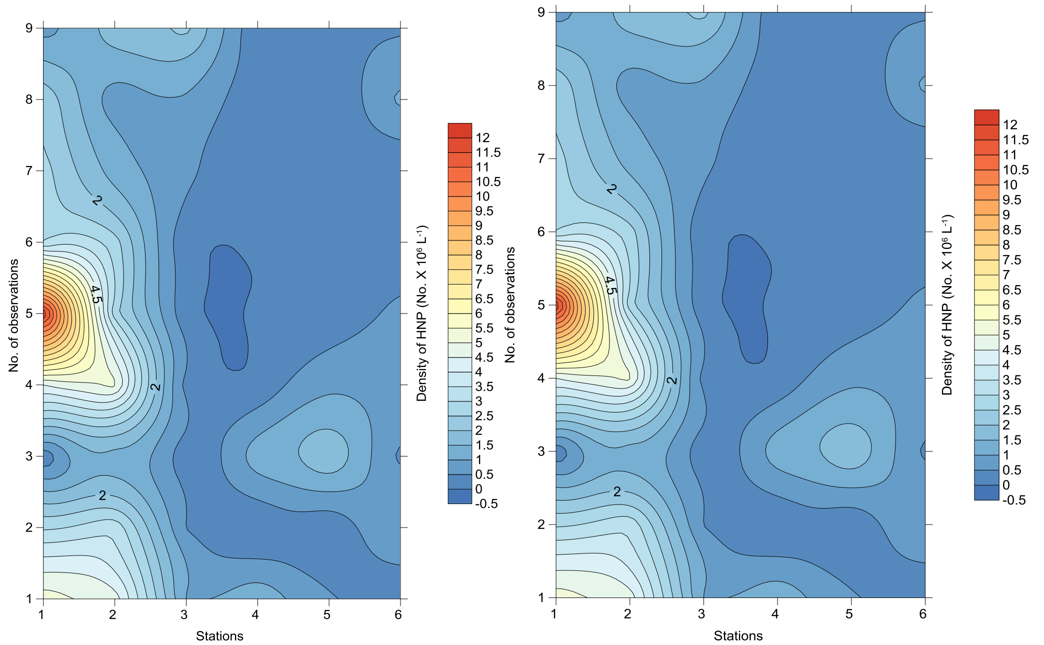
The density distribution of heterotrophic nanoplankton (HNP) showed close coupling with its prey organism (autotrophic picoplankton) during spring intermonsoon period. Similar to autotrophic picoplankton distribution heterotrophic nanoplankton density also increased from downstream to upstream with a maximum at stn.5 (avg. 2.6 ± 0.5 x 10^6 l^{-1}) and minimum at stn.1 (avg. 1.26 ± 1.29 x 10^6 l^{-1}). Bottom waters also followed same trend with a maximum at Stn. 3 (avg. 2.36 ± 7.30 x 10^6 l^{-1}) and minimum at Stn. 2 (avg. 1. 50 ± 0. 58 x 10^6 l^{-1}) (Fig: 4.9a & 9b). In southwest monsoon also, heterotrophic nanoplankton distribution followed the same pattern of autotrophic picoplankton with a maximum surface density at at stn.1 (avg. 3.74 ± 3.49 x 10^6 l^{-1}) and minimum at stn. 4 (avg. 0.36 ± 0.57 x 10^6 l^{-1}). Bottom waters also showed same trend with a maximum at Stn. 1 (avg. 2.36 ± 7.30 x 10^6 l^{-1}) and minimum at Stn. 6 (avg. 0.36 ± 0.30 x 10^6 l^{-1}) (Fig: 4.9c & 9d).

Fig: 4.9. Density distribution of HNP during both seasons (a) Density distribution of HNP at surface during spring intermonsoon (b) Density distribution of HNP at bottom during spring intermonsoon (c) Density distribution of HNP at surface during southwest monsoon (d) Density distribution of HNP at bottom during southwest monsoon

(a) (b)

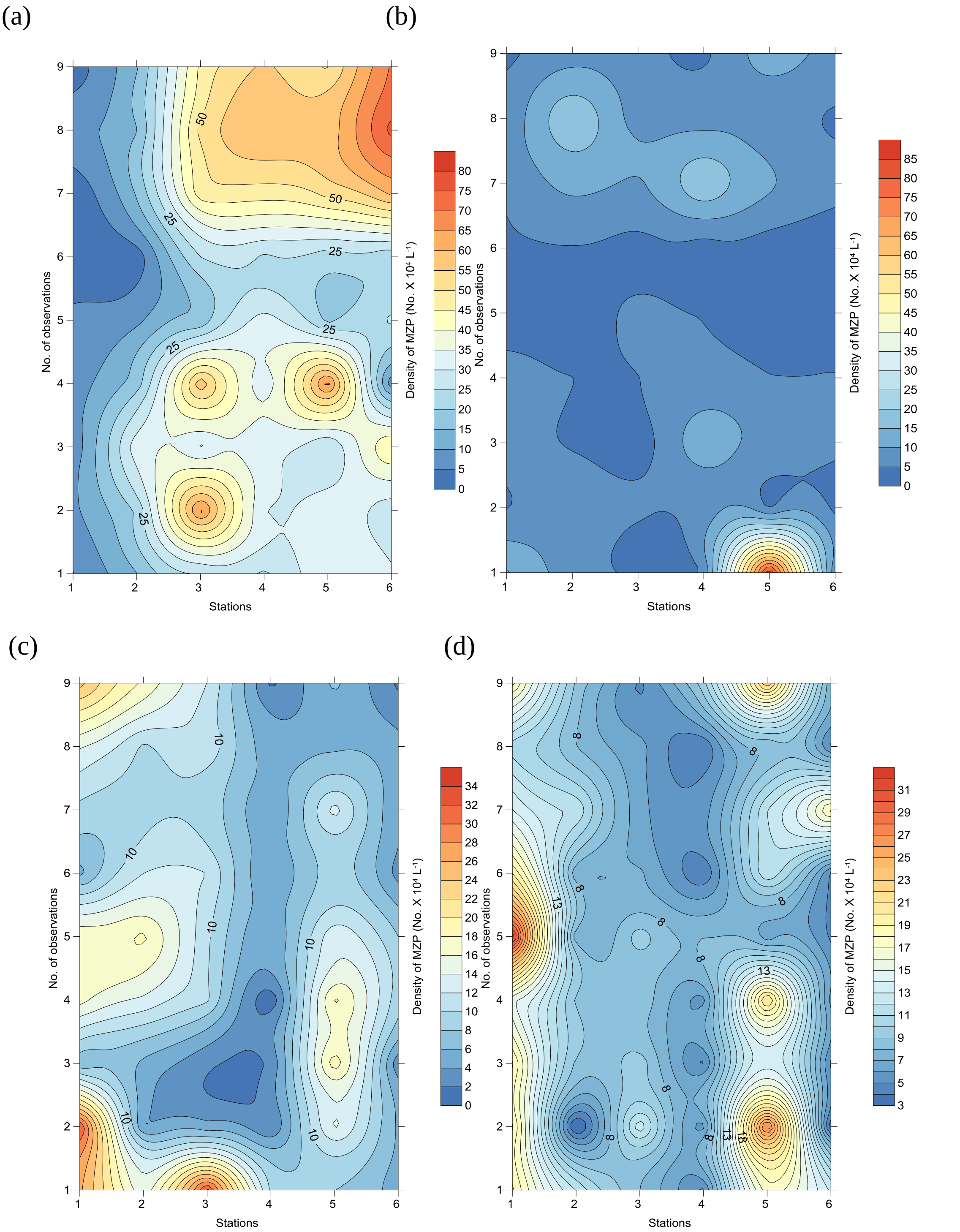


(c) (d)



Another population of predator organism considered in the present study is microzooplankton (MZP). During spring intermonsoon, the average density of microzooplankton also increased from downstream to upstream with a maximum at stn.5 (avg. 23.33 ± 13.84 x 10^4 l^{-1}) and minimum at stn.2 (avg. 9.10 ± 1.74 x 10^4 l^{-1}). At bottom minimum density was observed at Stn.4 (avg. 3.77 ± 3.56 x 10^4 l^{-1}) and maximum at Stn. 5 (avg. 10.98 ± 13.13 x 10^4 l^{-1}) (Fig. 4.10a & 10b). Whereas in southwest monsoon, their density showed a reverse trend with a maximum surface density at stn.1 (avg.17.04 ± 9.34 x 10^4 l^{-1}) and minimum at stn.4 (avg. 3.63 ± 2.65 x 10^4 l^{-1}). Bottom waters also showed a similar trend with maximum at Stn.1 (avg. 18.62 ± 5.94 x 10^4 l^{-1}) and minimum at Stn. 4 (avg. 5.77 ± 1.8 x 10^4 l^{-1}) (Fig: 4.10c & 10d).

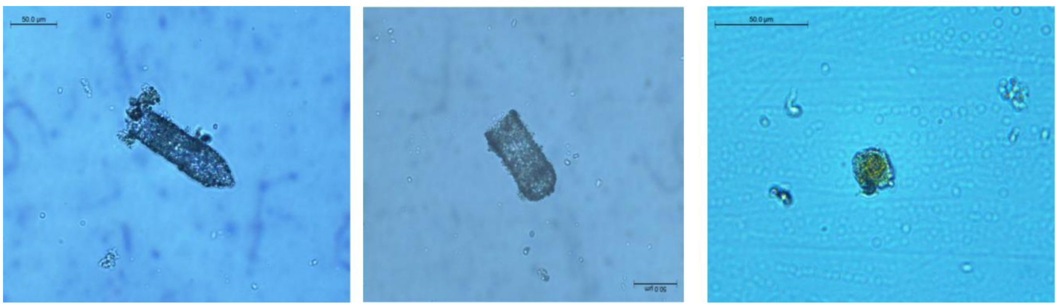
Fig: 4.10. Density distribution of MZP during both seasons (a) Density distribution of MZP at surface during spring intermonsoon (b) Density distribution of MZP at bottom during spring intermonsoon (c) Density distribution of MZP at surface during southwest monsoon (d) Density distribution of MZP at surface during southwest monsoon



The microzooplankton community was mainly composed of ciliates, heterotrophic dinoflagellates, and crustacean nauplii (Table: 4.1). A complete list of various species of microzooplankton and their density distribution with in the period of observation is given in appendix (Table: 1- 24) A total number of 51 species were identified. Out of which 36 species were ciliates and 15 species were dinoflagellates. Others were identified up to group level and they constituted 3 groups – Radiolarians, Rotifers and crustacean nauplii. During spring intermonsoon period, 26 species of ciliates and 14 species of dinoflagellates were identified at surface. Radiolarians, Rotifers and crustacean nauplii contributed rest. Most abundant species were *Tintinnidium incertum* and *Didinium* sp. Least abundant species was *Halteria* sp. At bottom, 16 species were ciliates and 7 were dinoflagellates. Rest of the groups were contributed by Radiolarians, Rotifers and crustacean nauplii. The most abundant was *Tintinnidium incertum* and least abundant was *Pyrophacus* sp. During southwest monsoon, 20 species of ciliates and 8 species of dinoflagellates were identified. Rest of them was contributed by Radiolarians, Rotifers and crustacean nauplii. Most abundant one was *Strombidium* sp. and least abundant ones came under the group Radiolaria. At bottom, 16 species of ciliates and 10 species of dinoflagellates were identified. Rest of the groups were contributed by Radiolarians, Rotifers and crustacean nauplii. Most abundant species was *Tintinnopsis nucula* and the least abundant was *Orthodonella.*

The following panel shows some of the major species encountered in the samples

(a) Tintinnidum sp. *(b) Strombidium* sp. *(c) T. incertum*



(d) *Tintinnopsis beroidea* (e) *T. acuminata* (f) *Didinium* sp.

Table 4.1. Microzooplankton community composition of Cochin Backwater during the study period.

Ciliates	Dinoflagellates	Others
Mesodinium rubrum	*Amphidinium* sp.	*Radiolaria*
Tintinnopsis cylindrica	*Gymnodinium* sp.	
T. nucula	*Prorocentrum gracile*	*Rotifer*
T. minuta	*P. micans*	
T. beroidea	*P. lima*	*Crustacean nauplii*
T. uruguayensis	*Gyrodinium glacialis*	
T. lohmanni		
T. tocantinensis	*G. spirale*	*Unidentified*
Tintinnidium incertum	*Alexandrium insuetum*	
T. primitivum	*A. tropicale*	
T. radix	*A. monilatum*	
T. acuminata	*Protoperidinium depressum*	
Codonella sp.	*P. leonis*	
Codonellopsis pusilla	*P. globulus*	
Stenosemella sp.	*Noctiluca scintillans*	
Dictyocysta seshaiyai	*Pyrophacus* sp.	
Petalotricha sp.		
Polykrikos kofoidi		
Dileptus sp.		
Nassula notata		
Geleia nigriceps		
Orthodonella sp.		
Euplotes sp.		
Laboea strobila		
Strombidium bilobum		
S. conicum		
S. sphericum		
S. capitatum		
Strobilidium minimum		
Lohmaniella spiralis		
L. oviformis		
Didinium sp		
Spaerophrya magna		
Lagynphrya salina		
Holophyra marina		
Halteria gradinella		
H. chlorelligera		

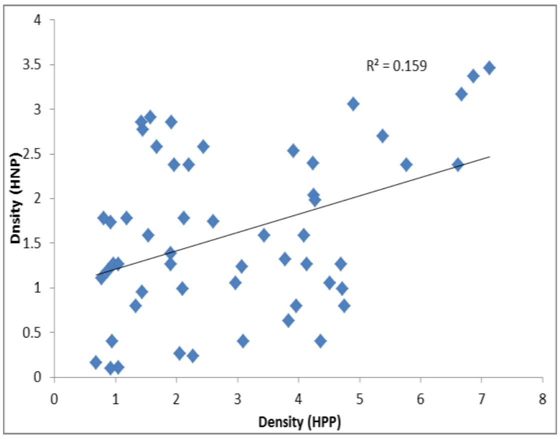
4.4. 3. Predator- Prey Interrelationship

From the results presented in Chapter 3, section 4.2, it is clear that apart from heterotrophic picoplankton, autotrophic picoplankton is also consumed by predator population of microbial food web (heterotrophic nanoplankton and microzooplankton) in Cochin backwater. Consequently, in order to understand the affinity between predator and prey organisms during both seasons, simple correlation method was used. Major predator – prey interactions considered are APP vs HNP, APP vs MZP, HPP vs HNP & HPP vs MZP.

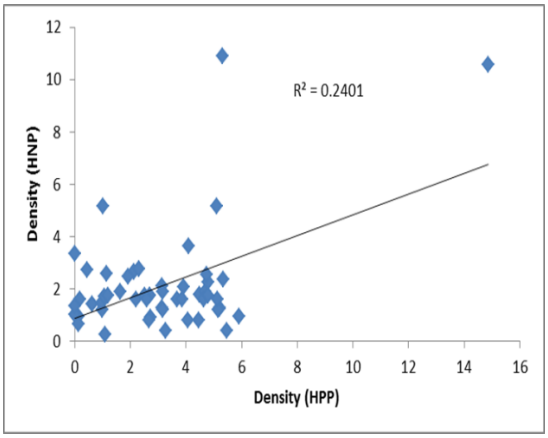
During spring intermonsoon autotrophic picoplankton density did not show any significant relationship with its predator population (heterotrophic nanoplankton and microzooplankton) both at surface and bottom. But heterotrophic picoplankton showed a strong positive relationship with heterotrophic nanoplankton both at surface ($n=54$, $r= 0.4$, $p<0.05$) and bottom ($n=54$, $r= 0.5$, $p<0.05$) (Fig: 4.11a & 11b). The population dynamics of both heterotrophic picoplankton and heterotrophic nanoplankton with in a tidal cycle was found to be tightly coupled during spring intermonsoon period (Fig: 4.11c & 11d). Heterotrophic picoplankton was also significantly correlated with microzooplankton both at surface ($n=54$, $r= 0.4$, $p<0.05$) and bottom ($n=54$, $r= 0.4$, $p<0.05$) (Fig: 4.11e & 11f). The coupling between heterotrophic picoplankton and microzooplankton is well explained in Fig: 4.11g & 11h.

Fig: 4. 11. Relationship between predators and prey during spring intermonsoon period (a) Significant positive correlation between HPP and HNP at surface (b) Significant positive correlation between HPP and HNP at bottom (c) Coupling between HPP and HNP population at surface with in a tidal cycle (d) Coupling between HPP and HNP population at bottom with in a tidal cycle (e) Significant positive correlation between HPP and MZP at surface (f) Significant positive correlation between HPP and MZP at bottom (g) Coupling between HPP and MZP population at surface with in a tidal cycle (h) Coupling between HPP and MZP population at bottom with in a tidal cycle .

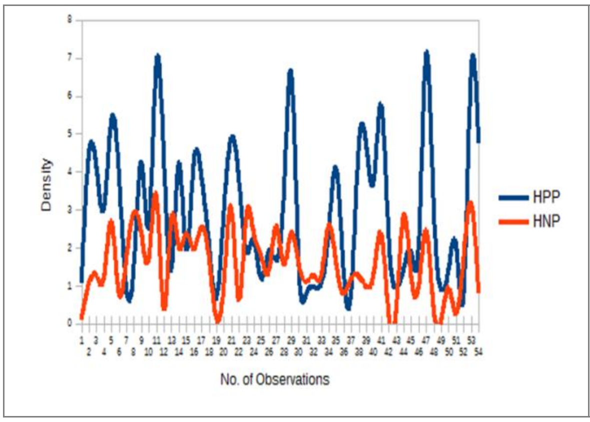
(a)



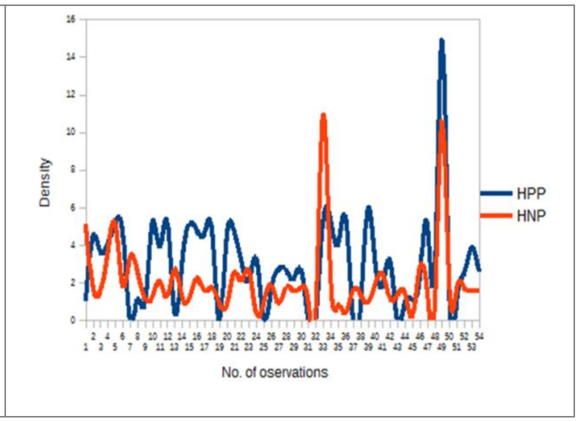
(b)



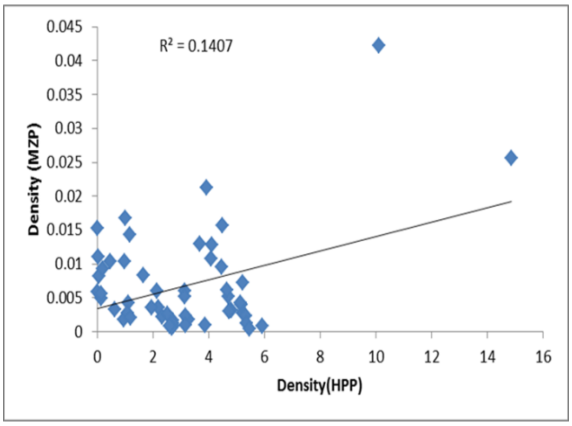
(c)



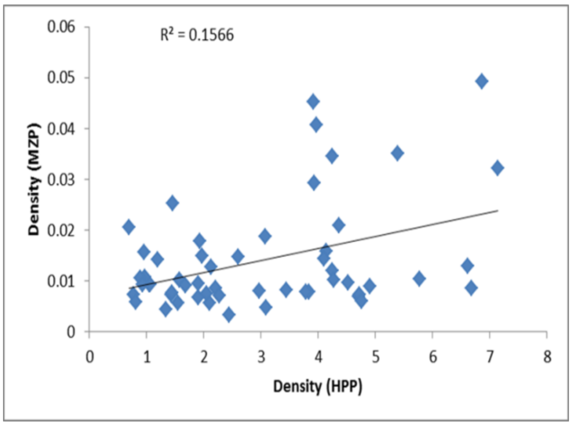
(d)



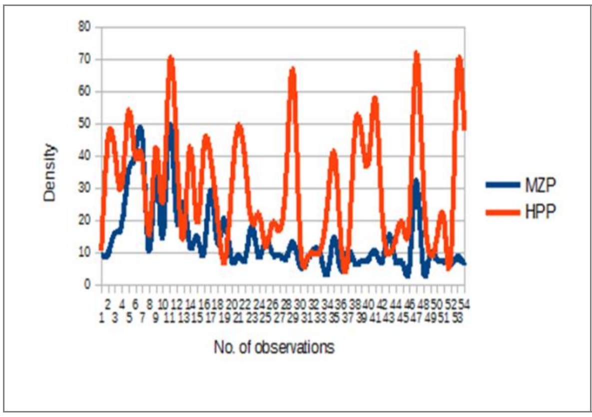
(e)



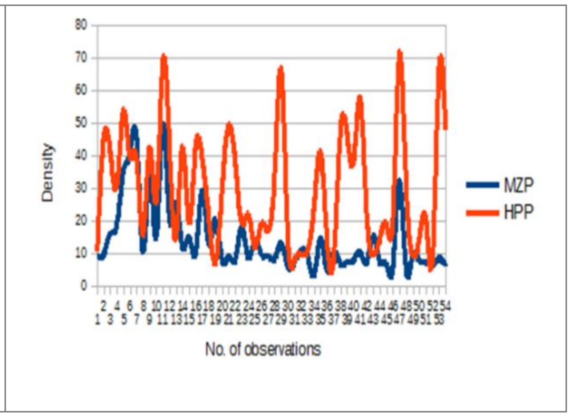
(f)



(g)



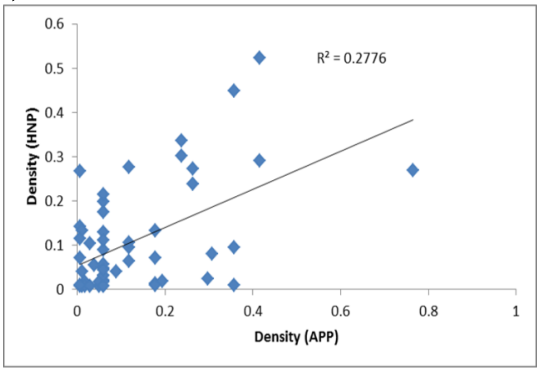
(h)



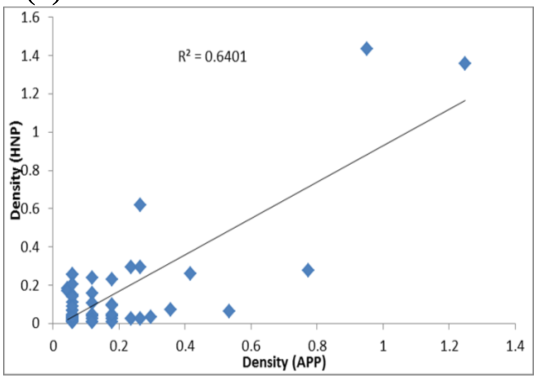
On the other hand, in southwest monsoon, heterotrophic picoplankton (density) did not show any significant relationship with its predator population (HNP and MZP) both at surface and bottom. However autotrophic picoplankton showed a strong positive correlation with heterotrophic nanoplankton at surface (n=54, r=0.51, $p<0.01$) and bottom (n=54, r=0.80, $p<0.01$) (Fig: 4.12a & 12b). The graphical representation of population fluctuation of both predator and prey organism is illustrated in Fig: 4.12c & 12d. Autotrophic picoplankton was also significantly correlated with microzooplankton both at surface (n=54, r=0.37, $p<0.05$) and bottom (n=54, r=0.47, $p<0.05$) during southwest monsoon (Fig. 4.12e & 12f). The variation in both populations with in a tidal cycle is represented in Fig: 4.12g & 12f.

Fig: 4.12. Relationship between predators and prey during southwest monsoon period (a) Significant positive correlation between APP and HNP at surface (b) Significant positive correlation between APP and HNP at bottom (c) Coupling between APP and HNP at surface population with in a tidal cycle (d) Coupling between APP and HNP population at bottom with in a tidal cycle (e) Significant positive correlation between APP and MZP at surface (f) Significant positive correlation between APP and MZP at bottom (g) Coupling between APP and MZP population at surface with in a tidal cycle (h) Coupling between APP and MZP population at bottom with in a tidal cycle .

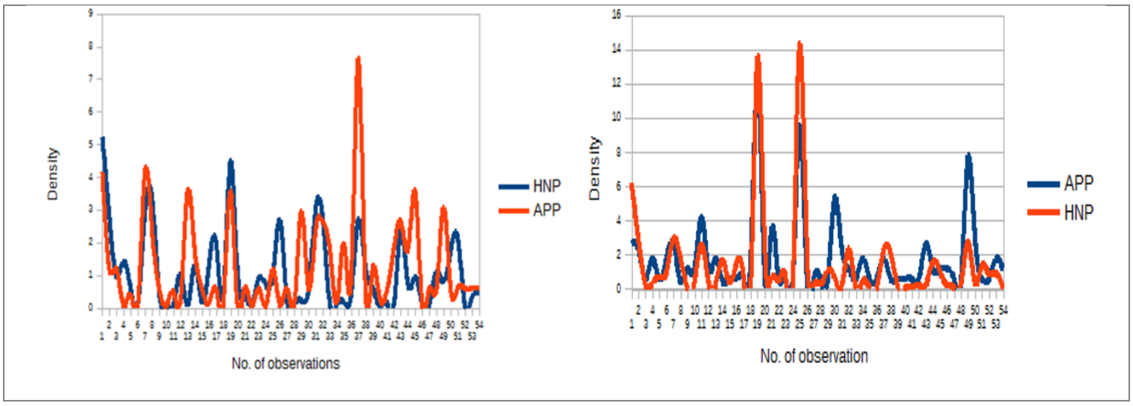
(a)



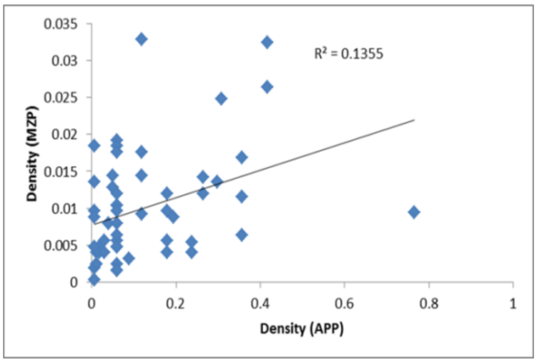
(b)



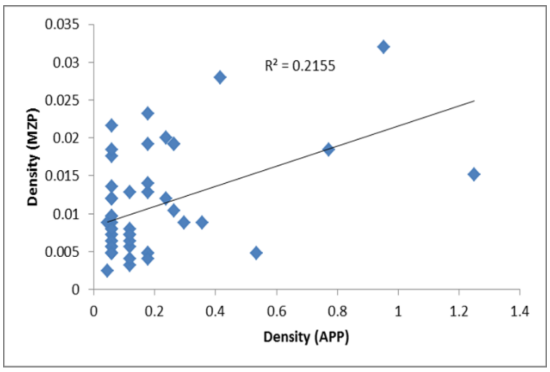
(c) (d)



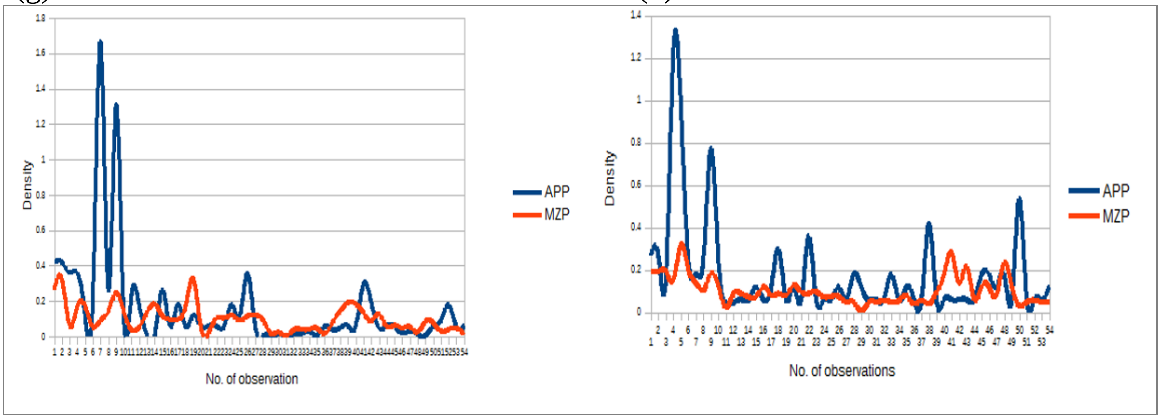
(e)



(f)



(g) (h)



4.5. Discussion

Salinity was high towards the downstream region than at the upstream of the backwater. This salinity gradient is found to be common characteristics of all estuaries. The high nutrient values observed throughout the study area could be attributed to the eutrophic characteristics of the estuary. It can be noted that the nitrate maxima during both seasons was detected in the stations near to industrial belt (Stn.4 & Stn.3). In the case of phosphate, the value was higher during southwest monsoon than the spring intermonsoon period. Phosphate concentration was very high in the bottom samples of barmouth region (Stn.2) which can be explained by the fast and continuous regenerative activity of phosphate into the overlying high saline brackish water (Reddy & Sankaranarayanan, 1972). Distribution of silicate was almost irregular but showed high values towards the northern arm of the estuary which can be due to the high riverine influx.

4.5.1. Inter relationship between environmental parameters and autotrophic picoplankton distribution

Generally autotrophic picoplankton density showed a remarkable increase towards upstream region during spring intermonsoon and towards downstream region during southwest monsoon (which was similar to the observations of chapter.3). The grazers of autotrophic picoplankton also showed same trend, and this can be related to their affinity towards the mesohaline environment (Sooria *et al.*, 2015).

Even though the nutrient parameters showed high values throughout the study period, autotrophic picoplankton did not show any relationship with any of the nutrient parameters. This result again confirms the hypothesis that their population is controlled by 'Top down' control rather than bottom up factors (Johnson *et al.,* 1982; Iturriaga & Mitchell, 1986) especially in eutrophic condition.

4.5.2. Predator – Prey interaction and significance of autotrophic picoplankton in Cochin Backwater

The significant correlation between heterotrophic picoplankton and its predators compared with that of autotrophic picoplankton in spring intermonsoon indicate a dependency of microbial food web on heterotrophic community during the season. Whereas a very strong positive correlation between autotrophic picoplankton and its predators compared with that of heterotrophic picoplankton in southwest monsoon indicate the dependency of microbial food web on the autotrophic community during southwest monsoon. There were many earlier studies in Cochin backwater that confirmed a switching over of backwater system from net autotrophy to net heterotrophy during southwest monsoon (Thottathil *et al.,* 2008; Sarma *et al.,* 2009; Jyothibabu *et al.,* 2015). According to them there was a season enhanced bacterial heterotrophic activity during southwest monsoon due to the increased allochthonous in put by rivers. They also point towards the possibility of other unknown factors which might have an additional effect resulting in heterotrophic switch over. The present result brings out one more factor which leads to heterotrophic switch over of the estuary during southwest monsoon. As the microbial food web in the system is more dependent on autotrophic picoplankton crop during southwest monsoon there is an accumulation of more bacterial biomass which can enhance a high heterotrophic activity along with the allochthonous input. During spring intermonsoon period, as the higher trophic levels of microbial food web mostly depend up on bacterial population (fig: 4.11), lot of phytoplankton biomass (especially that of smaller size range) goes unutilized and thus the total primary production increases considerably than the system respiratory rate. Autotrophic picoplankton are able to photosynthesize at low light intensities as they got the accessory pigments which can operate at low light levels (Callieri *et al.*, 1996; Raven, 1998; Callieri, 2007). This trait is highly advantageous for them particularly during monsoon when the turbidity of water increases considerably. At the same time the predators of microbial food web become more dependent on autotrophic picoplankton during southwest monsoon which results in enormous amount of unconsumed bacterial biomass and thus the system switch over towards net heterotrophy. In this way, even when the system become heterotrophic, autotrophic picoplankton can pump surplus amount of carbon to the food web of Cochin backwater. The above results are well explained in the following chapter with the support of experimental proofs.

4. 6. Conclusion

In the present study, apart from bacteria, autotrophic picoplankton was also found to be a major carbon contributor to the higher trophic level of microbial food web. Their population density was found to be low in southwest monsoon than that in the spring intermonsoon period which could be attributed to their high predation rate during southwest monsoon. The tight coupling between the autotrophic picoplankton and its predator population during southwest monsoon indicate that not only the salinity decrease mentioned in earlier research works (Madhupratap & Haridas, 1975; Madhupratap *et al.*,1987; Jyothibabu *et al.,* 2015; Jyothibabu *et al.,* 2006) but also the high predation rate during southwest monsoon control the autotrophic picoplankton population in Cochin backwater. Thus it is explicit that even though they do not dominate in the system biomass due to the high predation pressure, they contribute much towards the carbon cycling of the system. The disparity between the nutrient parameters and autotrophic picoplankton abundance shows that their population density is not determined by the external nutrient concentration in a eutrophic system.

In spring intermonsoon predators showed strong affinity towards heterotrophic picoplankton. The significant correlation between predators with bacteria or heterotrophic picoplankton during spring intermonsoon period and with autotrophic picoplankton during southwest monsoon season further explain the reason for the switch over of backwater system from net autotrophy to net heterotrophy during southwest monsoon (Thottathil *et al.,* 2008; Sarma *et al.,* 2009; Jyothibabu *et al.,* 2015). All these results point towards the fact that the food web dynamics of tropical monsoonal estuaries are more complicated than ever thought and the existing hypotheses must be reassessed in a new light.

Chapter V

Contribution of autotrophic picoplankton to the microbial food -web in terms of carbon

5. 1. Introduction

The hypothesis that carbon export in the pelagic ecosystem is exclusively depended upon primary production from larger phytoplankton has been challenged by various authors in 1970s and 1980s by introducing the possible existence of a 'microbial loop' (Pomeroy, 1974; Williams, 1981; Azam *et al.*, 1983). Recently, the inverse ecosystem modeling studies reveals that most carbon export in the oligotrophic open ocean is driven by autotrophic picoplankton population (Richardson *et al.,* 2004, 2006; Richardson & Jackson 2007). Size fractionated biomass estimation and grazing experiments were widely used to quantify the carbon export from autotrophic picoplankton in the global ocean (Landry & Hasset, 1982; Platt *et al.,* 1983; Stockner *et al.,* 2000; Garrison *et al.,* 2000; Worden *et al*., 2004; Richardson *et al.,* 2004 & 2006, Brown *et al.* 2008; Landry 2002; Taylor *et al.* 2011) and all these experiments confirms the huge implication of these minute primary producers.

However, in the case of eutrophic coastal waters the contribution of autotrophic picoplankton to the system production and export is still under controversy. While some of the aquatic biologists and ecologists agrees on the dominance of larger phytoplankton cells which contribute exclusively to the carbon export in the eutrophic coastal waters (Raven, 1986; Riegman *et al.*, 1993; Iriarte & Purdie, 1994; Morel *et al.,* 1991, Landry & Kirchman, 2002), others suggest that autotrophic picoplankton are important but an overlooked size fraction of costal ecosystems (Marshall & Nesius, 1996; Phlips *et al.,* 1999; Marshall, 2002). They also prove that autotrophic picoplankton can accomplish high biomass and dominate the total phytoplankton biomass in estuaries during certain conditions (Ray *et al.,* 1989; Buchanan *et al.,* 2005; Badylak & Phlips 2004; Murrell & Lores, 2004; Phlips *et al.,* 1999). But studies related to carbon turnover from this trophic level is absent in Indian coastal waters especially in monsoonal estuaries. Even though there are some previous studies which ascertain the substantial contribution of autotrophic picoplankton community towards the microbial food web of Cochin backwater, no effort was taken to quantify their carbon input to the higher trophic levels (Rajaneesh *et. al.*, 2015; Sooria *et. al*., 2015; Arya *et al.,* 2016). A few studies which address the growth and grazing rate of lower size fraction was conducted only during spring intermonsoon season due to the assumption that efficiency of microbial food web decreases during southwest monsoon (Jyothibabu *et al.,* 2006; Jyothibabu *et. al.,* 2015). This is the first study of its kind which compares both dry and wet period to understand the efficiency of the lowest trophic level clearly. Hence there were 3 objectives for the present Chapter.

- To check the population control of autotrophic picoplankton based on growth rate and grazing rate
- To quantify the standing stock of autotrophic picoplankton and its export to the next trophic level in terms of carbon during both seasons.
- To compare the efficiency of microbial food web during both seasons

5. 2. Materials and Methods

Grazing experiment was conducted during spring intermonsoon and Southwest Monsoon period to estimate the growth rate and grazing rate of autotrophic picoplankton by its predators (heterotrophic nanoplankton and microzooplankton). The method used for the experiment was dilution technique (Landry & Hasset, 1982). 20 litres of water were collected in polythene carboys from the same station (Marine Science Boat Jetty) during both seasons and transported to the laboratory immediately. The water was then gently filtered through a 200µm mesh to eliminate larger predators or mesozooplankton.

Although the screening of experimental samples through 200µm sieve may disturb large and fragile microzooplankton, this process is widely used in microzooplankton grazing experiments for discarding the mesozooplankton (Froneman & McQuaid, 1997; Putland, 2000; Stelfox - Widdicombe *et al.,* 2004). Prey and predator- free water was obtained by gently filtering half of the water collected through a 0.2µm polycarbonate filter. The prey and predator- free water was then combined with unfiltered brackish water to generate concentrations of 100, 50, and 25 percentage of the ambient concentration. For each dilution, triplicate bottles were incubated to minimize the error (total volume in each bottle was 2 litres). Incubation was carried out in ambient light placing the bottles in the flow through system kept at the station itself. Before incubation was begun, a water sample was taken from each bottle of the dilution series to provide a measure of the initial chlorophyll *a* concentration of autotrophic picoplankton. For this the 250 ml of each dilution series was first filtered through 3µm glass fiber filter paper to eliminate larger cells and then through 0.2 µm (Whatman) to collect autotrophic picoplankton. The corresponding bottles were sampled again (250ml) at the end of the incubation period (24 hr) for measuring the final autotrophic picoplankton chlorophyll *a* concentration and the measurements were carried out in a fluorometre (10- AU, Turner design) according to the protocol of UNESCO (1994). Changes in the chlorophyll *a* concentration over 24hr incubation were used to calculate the apparent phytoplankton growth rate, in each of the dilutions based on the following theoretical considerations

1. Growth of individual phytoplankton is not directly affected by the presence or absence of other phytoplankton
2. Probability of a phytoplankton cell being consumed is a direct function of the rate of encounter of consumers with prey cells
3. Change in phytoplankton community ‘P’, over some time ‘t’ can be represented by the exponential equation

$P_t = P_0 e^{(k-g)} t$……………………………. (1)

Where ‘k’ = Instantaneous coefficient of phytoplankton growth

‘g’ = coefficient of microzooplankton grazing

$1/t \ln (p_t/p_0) = k - (d.f.) g$………………………… (2)

Where P_t is the final chlorophyll concentration got after incubation, P_0 is the initial chlorophyll concentration and d.f is the dilution factor.

The proportion of initial chlorophyll *a* standing stock (P_i) turned over, as % d^{-1}, by the predators (ie. Clearance rate) was calculated according to the formula

$P_i = 1 - e^{-g} * 100$………………………………….. (3)

Initial and final concentration of Dissolved Organic Carbon (DOC) and Total Organic Carbon Concentration (TOC) was measured following high temperature catalytic oxidation using a TOC analyzer (Shimadzu TOC-VCPH). Particulate Organic Carbon (POC) was calculated by subtracting DOC value from corresponding TOC value of the samples (UNESCO, 1994). Autotrophic picoplankton density was also estimated according to the standard protocol (Porter & Feig, 1980). To quantify the standing stock in terms of carbon, a subsample of 10 ml was taken initially from the unfiltered water, prefiltered though 3µm pore sized glass fiber filter and then on to 0.2µm nuclepore filter paper. Cells were categorized under 3 groups based on their fluorescence using EFM (Callieri & Stockner, 2002). Biovolume was converted into carbon using corresponding factors (Garrison, 2000).

5. 3. Results

During spring intermonsoon the salinity of the collected water was measured to be 33 ppt. DOC and POC showed very high values (362µm and 402µm respectively) (table: 5.1). The apparent growth rate (1/t ln (p_t/p_0)) calculated from the initial and final size fractionated chlorophyll *a* sample was plotted against the fraction of unfiltered estuarine water and the results were analysed for both seasons. The linear regression model obtained during spring intermonsoon period is given in Fig: 5.1a. From the linear regression model the growth rate 'k' (d^{-1}), Grazing rate 'g' (d^{-1}) and the clearance rate of autotrophic picoplankton (% d^{-1}) was calculated. Growth rate (k) was found to be 0.47 ± 0.02 d^{-1} and grazing rate was 0.44 ± 0.1 d^{-1} during spring intermonsoon. Clearance rate was about 37% (Table: 5.1). Three groups of autotrophic picoplankton were identified in the collected samples named *Synechococcus*, *Prochlorococcus* and picoeukaryotes (Table: 5.1). Density of *Synechococcus* was estimated to be 0. 33 x 10^7No l^{-1} and that of *Prochlorococcus* was 0.08 x 10^7 No l^{-1}. Picoeukaryote density was around 0.14 x 10^7 No l^{-1}. The total standing stock in terms of carbon (mg C m^{-3}) was calculated to be 1.62 mg Cm^{-3} (Table: 5.1).

The linear regression model for the southwest monsoon season is given in Fig: 5.1b. Growth rate and grazing rate of autotrophic picoplankton were recorded higher than that of spring intermonsoon (0.95 and 1.08 respectively) (Table: 5.1). Clearance rate was also very high in southwest monsoon than that of spring intermonsoon period (Table 5.1). During southwest monsoon the salinity in the sampling station was considerably low (7ppt). DOC and POC values were lower than that of spring intermonsoon. At the same time the density of autotrophic picoplankton was lower than spring intermonsoon with the complete absence of *Prochlorococcus* cells. Even though the density was low, the standing stock in terms of carbon ($mgCm^{-3}$) was considerably higher than that of spring intermonsoon (Table: 5.1).

Fig: 5.1. The linear regression model obtained from the dilution experiment. Instantaneous APP growth rate k and grazing rate g is obtained from the y intercept and the negative slope calculated from the linear equation. (a) The regression model obtained during spring intermonsoon (b) The regression model obtained during southwest monsoon.

(a) *(b)*

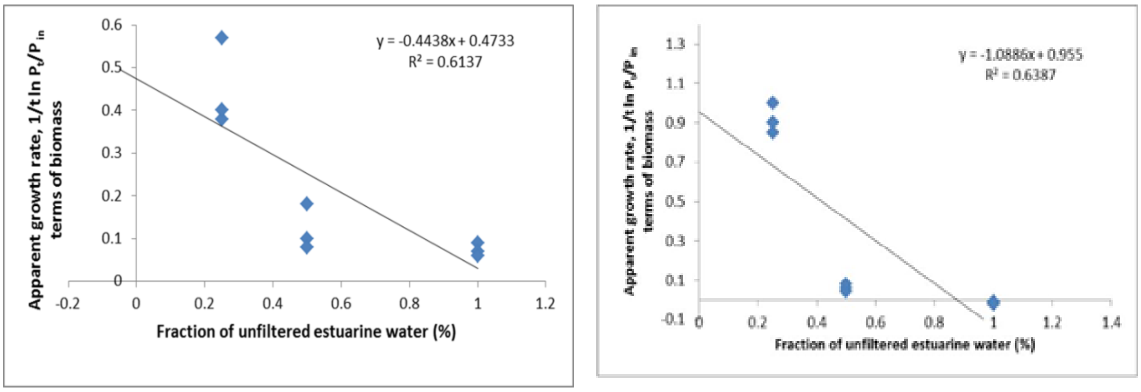


Table: 5.1. Comparison between the carbon budgets of autotrophic picoplankton community during both seasons

	Spring Intermonsoon	**Southwest monsoon**
Saliniy (ppt)	33	7
DOC (µM)	362	258
POC (µM)	406	325
Growth rate ‘k' (d-1)	0.47	0.95
Grazing rate ‘g' (d-1)	0.44	1.08
Clearance rate	37%	59%
Density (No.x 107/l)		
Synechococcus	0.33	0.14
Prochlorococcus	0.08	0
Picoeukaryotes	0.14	0.29
Total	0.55	0.43
Standing stock (mgCm-3)		
Synechococcus	0.3	0.14
Prochlorococcus	0.02	0
Picoeukaryotes	1.3	2.9
Total	1.62	3.04

5.4. Discussion

As the sampling station was in the downstream region of the estuary, a euhaline condition (33 ppt) was observed during spring intermonsoon period. Whereas, in southwest monsoon, the hydrography of the location changed from euhaline to mesohaline (7ppt) condition. According to the salinity change, the total density of autotrophic picoplankton also showed a decreasing trend which can be related to the high clearance rate. Along with the density decrease in southwest monsoon, autotrophic picoplankton community also experienced a shift in structure with an increase in the density of picoeukaryote population and a complete absence *Prochlorococcus* cells (Table: 5.1). In southwest monsoon, picoeukaryotes contributed highest to the population. This result was similar to the earlier observation (Arya *et al.,* 2016). *Prochlorococcus* is an organism with very low amount of carbon / cell due to the low cell specific fixation rate (Whitton & Potts, 2012). Therefore, even though they were present in spring intermonsoon, they did not contribute much to the community carbon biomass. But the decline in total density during southwest monsoon was compensated by the increase in picoeukaryotes resulted in a rapid increase in the carbon contribution of autotrophic picoplankton community during southwest monsoon.

Growth rate and grazing rate of autotrophic picoplankton were less in spring intermonsoon than in southwest monsoon. It can be related to the euhaline condition prevalent at the sampling station during spring intermonsoon (Sooria *et al.*, 2015). This result also substantiates the findings of Chapter. 3. It should be noted that growth and grazing rate of autotrophic picoplankton is almost equal during spring Intermonsoon period (0.47 and 0.44 respectively) which point towards the existence of the autotrophic picoplankton population in a static equilibrium. Lower clearance rate of autotrophic picoplankton cells (37%) during spring intermonsoon indicate lower consumption rate. This result along with the results explained in chapter IV (The significant correlation with the bacterial population and predator population) again suggests the dependency of microbial food web of Cochin backwater on bacterial population during spring intermonsoon period. However, in monsoon the growth and grazing rate was very high (0.95 and 1.08 respectively) which could be due to the change in salinity towards the mesohaline range (Sooria *et al.,* 2015). In southwest monsoon grazing rate was considerably high compared to growth rate and the clearance rate was also higher than spring intermonsoon (59 %). This result indicates high consumption of autotrophic picoplankton crop by the predators in the microbial food web of Cochin backwater during southwest monsoon (present result also support the finding of Chapter V, ie. the dependency of microbial food web on autotrophic picoplankton during southwest monsoon).

5.5. Conclusion

Growth rate and grazing rate of autotrophic picoplankton were less in spring intermonsoon than in southwest monsoon. It can be related to the euhaline condition prevalent at the sampling station during spring intermonsoon. The biomass contribution of autotrophic picoplankton in terms of carbon was also low in spring intermonsoon due to the presence of the group *Prochlorococcus* (contains only very low amount of carbon/ cell) where as carbon contribution was high in southwest monsoon due to the high abundance of picoeukaryotes and absence of *Prochlorococcus*. Clearance rate was also low in spring intermonsoon (37%) compared to that of southwest monsoon (59%) which can also be associated with the euhaline condition and the dependency of predators on bacterial population during spring intermonsoon. Thus, it is clear that in spite of the seasonal variation, the efficient microbial food web always exists in the mesohaline region irrespective of the seasons, even if there is a shift in the affinity of predators to the type of prey (heterotrophic or autotrophic). More over the high consumption of autotrophic picoplankton during southwest monsoon indicate the sustenance of food web by autotrophic picoplankton during this season even if mesozooplankton considerably reduces in density which impairs the effective utilization of larger phytoplankton. Thus, it can be assumed that autotrophic picoplankton population in a monsoonal estuary have got a significant role in buffering the effect of general weakening of classic foodchain during southwest monsoon by acting as an alternate carbon source for the higher trophic levels.

Chapter VI

Relative biomass as an index of competitive exclusion in microalgae – A skeptical inquiry

6. 1. Introduction

All naturalists in their scientific expedition address a quite common, yet complex question why diversity occurs in nature and how it is maintained. The Competitive exclusion principle by Gause (1934) was one of the statements which tried to address the problem to a certain extent. The principle states that "complete competitors cannot coexist”. ie. Two species competing for the same resources cannot coexist at constant population values. When one species has even the slightest advantage over another, the one with the advantage will dominate in the long term. Even though there were controversies, it was admired by a majority for one or two decades (Rand, 1952; Ud vardy, 1959; Hardin 1960). But all agreed to the ambiguity of this principle as stated by Hardin in his historical review- *“The competitive exclusion principle is one element in a system of ecological thought. We cannot test it directly by itself. What the whole ecological system is we do not yet know”* (Hardin, 1960). Later Hutchinson (1961) could prove the “empirical falsification” of the principle by pointing out paradoxical effect of plankton which thrives in a system where no equilibrium is achieved. Paradox of the plankton describes the situation in which a limited range of resources supports an unexpectedly wide range of plankton species. But, this is an era where we are more aware of the vastness of the microbial diversity of aquatic systems. The task becomes more complex as Hutchinson’s ‘assemblage of order of magnitude of tens of species’ has now been replaced by ‘order of magnitude of tens of species of different size classes’. At the same time, we observe entirely different planktonic communities in the coastal and open oceanic systems. Thus, again the question pops up: “competition or coexistence?”.

With a few exceptions (Barber, 2007; Vallina *et al.*, 2014; Mutshinda *et. al.*, 2016), accumulating evidences from size scaling studies of microalgae suggests that in aquatic environments producers with efficient nutrient intake ability increase in biomass until they competitively exclude the inferior ones (Chisholm, 1992 b; Li, 2002; Irigoien *et al.*, 2004; Tubay *et. al.*, 2013; Marañón, 2015; Acavedo- Trejos *et al.*, 2015). Despite the fact that selective predation strategies and top-down control of smaller taxa is well accepted, there is a common belief that diatoms or the large size fraction of microalgae dominates in eutrophic conditions whereas oligotrophic systems are dominated by autotrophic picoplankton or lower size fraction (Chisholm *et al.*, 1988; Landry *et al.*, 1996; Stockner *et al.*, 2000; Marañón *et al.*, 2001; Marañón *et al.*, 2013; Marañón *et al.*, 2015; Acavedo-Trejos *et al.*, 2015). Thus, the current outlook on the marine phytoplankton diversity can be simplified into the following sentences:

1. Smaller cells outcompete larger cells in oligotrophic waters.

2. Larger cells outcompete the smaller ones in eutrophic waters.

However, when we carefully examine those studies, we can deduct a common fact that the inference of all those studies are comprehended from a general methodology- either the relative contribution of biomass of a particular size class or the species-specific pigment contribution. Consequently, repeatedly observed higher relative biomass of diatoms in eutrophic environments and that of autotrophic picoplankton in oligotrophic environments has been suggested as the competitive success of higher and lower size strata in corresponding nutrient gradients. Therefore, the present chapter addresses the main issue 'whether the concept of size constrains of micro algae is a result of competitive exclusion or the outcome of our methodological artefact'. The rationale for the inquiry can be summarized as follows.

1. There are examples of ecosystems, especially estuaries where lower size fraction is numerically abundant even though their biomass contribution is far less than that of larger cells (Marshall & Nesius, 1996; Phlips *et al.*, 1999; Menon *et al.*, 2000; Marshall, 2002; Badylak *et al.*, 2007). If they are less competitive in eutrophic waters, why do they exist in large numbers?

2. In systems where high competition occurs, it is likely that the superior competitors exclude the inferior ones. But in eutrophic systems the small cells never get eliminated, instead they even dominate when there is a reduction in predation pressure (Ray *et al.*, 1989; Badylak & Phlips, 2004; Buchanan *et al.*, 2005).

3. If small cells are less competitive in nutrient-rich waters, their absolute biomass should also be low in such systems. But it is notable that the absolute biomass of autotrophic picoplankton increases with increase in trophic status (Bell & Kalff, 2001).

4. In oceanic systems also, it is observed that cell counts of autotrophic picoplankton increases proportionally to larger cells in response to nutrient enrichment (Barber & Hiscock, 2006; Barber, 2007).

These observations point towards the common fact that the smaller cells also respond to the increase in nutrient status. Hence a re-evaluation of conventional approaches we have adopted to explain the interaction between different algal size fractions is inevitable. Accordingly, this chapter has two major objectives.

1. To compare an oceanic ecosystem and a eutrophic coastal ecosystem both in terms of absolute and relative contribution of biomass of smallest size fraction (APP) of phytoplankton

2. To compare both systems based on the numerical density of autotrophic picoplankton and nutrient status.

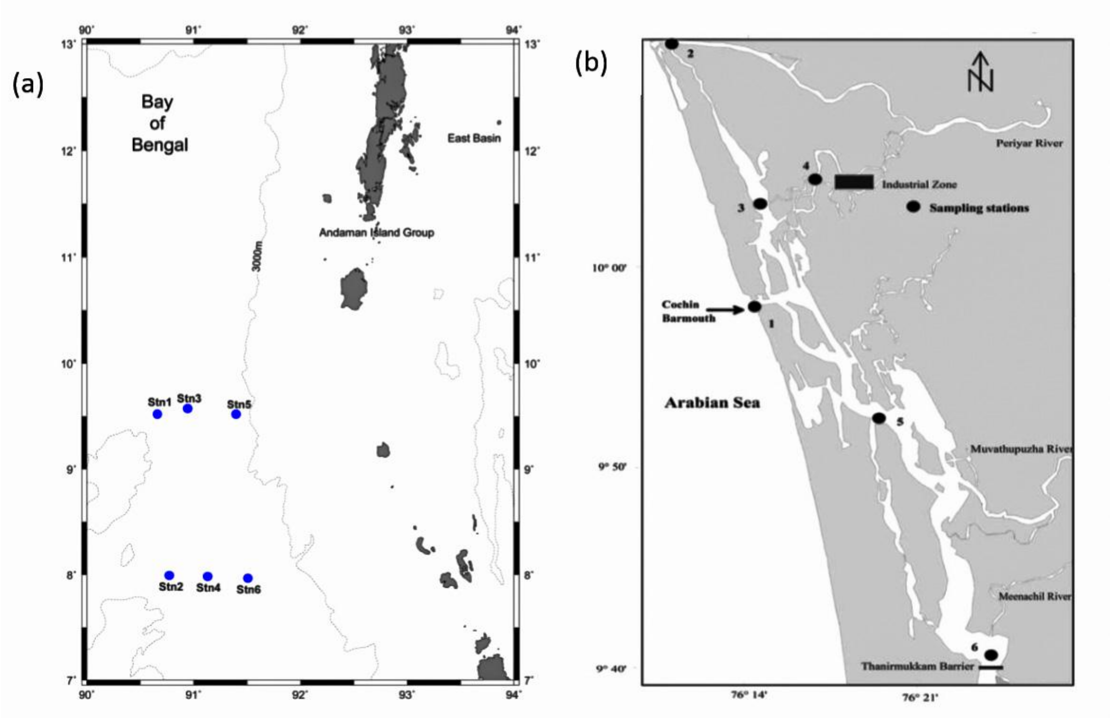
6.2. Study area

Oceanic samples were collected from Andaman Sea (study area. a). Sampling was done from 6 stations located in two transect (Fig: 6.1a & Table.1). Total depth of the stations varied from 3210m to 3708m. Cochin backwater was selected as eutrophic coastal ecosystem (study area. b). Samples were also collected from 6 locations of the Cochin backwater (Fig: 6.1b)

Table: 6.1. Details of the sampling locations in the Andaman Sea

Stn. No	Date	Time UTC	Depth (m)	Lat	Long
1	14.04.2016	0:55	3060	9°31.218'	90°39.522'
2	16.04.2016	2:18	3210	07°59'15.884"	90°46'01.5888"
3	18.04.2016	8:30	3488	09°31'20.5938"	90°56'31.1356"
4	20.04.2016	15:54	3465	07°59'00.2219"	91°07'05.2428"
5	22.04.2016	16:59	3626	09°31'01.4400"	91°17'41.2000"
6	24.04.2016	16:00	3708	07°58'59.7564"	91°28'14.6424"

Fig: 6.1. The study area (a) shows 6 sampling locations in the Andaman Sea (b) shows 6 sampling locations in Cochin Backwater (Stn. 1- Fort Kochi, Stn. 2- Azheekode, Stn. 3- Nedungadu, Stn. 4- Varappuzha, Stn. 5- Arookutty and Stn. 6- Thanneermukkam)



6.3. Methodology

Oceanic samples were collected onboard ORV Sagar Kanya as a part of cruise conducted by NCAOR (SK 329) during spring intermonsoon (April 2016). Salinity profile observation was done using Conductivity-Temperature-Depth (CTD) system (Sea Bird, Model SBE-911 plus, accuracy of conductivity 0.0003 S/m, temperature 0.001 C and pressure 0.015%). Water samples were collected from 3 depths (5m, 50m and 100m) using Niskin samplers fitted to the CTD system. Samples were analyzed for inorganic nutrients, total chlorophyll and fractionated chlorophyll according to standard protocols (Grasshoff *et al.* 1983 & UNESCO 1994). Autotrophic picoplankton density and microzooplankton density were also analyzed.

Water samples (10 ml) preserved in glutaraldehyde were processed for estimating autotrophic picoplankton (Porter and Feig 1980). For microzooplankton 10 litres of water sample was collected from each depth by triggering the Niskin samplers in corresponding depths during upcast. Although Joint Global Ocean Flux Studies

(JGOFS) protocols (UNESCO, 1994) suggest 250 ml - 2 litres volume as standard for microzooplankton, in the present study more quantity (10 ltr) were processed to get reliable representation of microzooplankton community as the Bay of Bengal was reported as an oligotrophic system. Water samples were siphoned directly from sampler by regulating the flow and allowed to gently pass through a 20µm Nitex screen for retaining all the organisms ≥20 µm size. Then the screen was backwashed in to 200ml bottle using distilled water. The final volume of sample was made up to 100ml and then preserved with 3% acid lugol's solution. The subsamples were taken from this sample and allowed to settle under gravity in a settling chamber for 48 h. The settled samples were observed under a light microscope fitted with image analyzer. The microzooplankton community was broadly grouped into ciliates, heterotrophic dinoflagellates, and crustacean larvae. Ciliates and heterotrophic dinoflagellates were identified up to the species level based on available literature (Kofoid & Canmpbell, 1939; Subrahmanyan, 1971; Maeda 1986; Krishnamurty *et al.*, 1995). From Cochin backwater, samples were collected from 2 depths (surface and bottom) during the same season and processed following the methodology mentioned in chapter 3.

6.4. Results

Andaman Sea

Minimum average salinity was observed at surface (avg. 32.52 ± 1.37ppt) and maximum at 100m (avg. 34.66 ± 0.30ppt). Nitrate (NO_3) maximum was observed at 100m (avg.12.56 ± 1. 69µM) and minimum at surface (avg. 1.12 ± 0.35µM). Phosphate (PO_4) and Silicate (SiO_4) also showed same trend with maximum at 100m (avg.1.33 ± 0.23, avg. 13.32 ± 2. 61µM respectively) and minimum at surface (avg. 0.21 ± 0.06, avg. 4.19 ± 0.90 µM respectively). Nitrite (NO_2) showed maximum values at 50m (avg.0.09 ± 0.02µM) and minimum at surface (avg.0.06 ± 0.01µM) (Table: 6.2). A subsurface chlorophyll maxima (50m) was observed in the study area (avg. 2.27 ± 1.7 mg m^{-3}) (Fig: 6.2). Biomass of autotrophic picoplankton (fractionated chlorophyll) was also maximum at 50m (avg.0.66 ± 0.3 mg m^{-3}) (Fig: 6.3). Their density also showed a maximum at 50m (avg.3.5 ± 0.58 x 10^7 L^{-1}) and a minimum at surface (avg. 0.89 ± 0.72 x $10^7 L^{-1}$) (Fig: 6.4 & Fig: 6.5). At the same time the percentage contribution of autotrophic picoplankton biomass to the total chlorophyll biomass was very high (27 to 88%) in all the stations (Fig: 6.6). Microzooplankton also showed same trend with maximum abundance at 50m (avg.5.01 ± 0.24 x 10^3 m^{-3}) and a minimum at surface (avg. 4.1 ± 0.43 x $10^3 m^{-3}$) (Fig: 6.7 & Fig: 6.8).

Table: 6.2. Distribution of chemical parameters in study area.1(Andaman Sea)

Stations	Depth	Salinity	NO_3	PO_4	SiO_4
Stn. 1	5	31.2	0.98	0.18	3.32
	50	32.8	1.61	0.45	4.23
	100	34.8	12.57	0.2	13.21
Stn. 2	5	32.1	1.34	0.18	3.55
	50	31.8	1.66	0.97	4.34
	100	34.6	14.75	0.32	11.44
Stn. 3	5	32.5	1.12	0.53	3.87
	50	33.8	1.43	1.49	4.01
	100	34.5	11.57	0.27	14.34
Stn. 4	5	30.45	1.54	0.36	5.02
	50	30.7	0.65	1.57	4.84
	100	35	13.07		16.31
Stn. 5	5	29.9	0.5	0.18	5.6
	50	33.1	5.19	0.51	11.16
	100	34.1	13.57	1.39	15.37
Stn. 6	5	31.2	1.24	0.15	3.79
	50	31.2	1.01	0.29	3.67
	100	34.6	9.87	1.11	9.25

Fig: 6.2. Distribution of total phytoplankton biomass (total chlorophyll a) in the Andaman Sea.

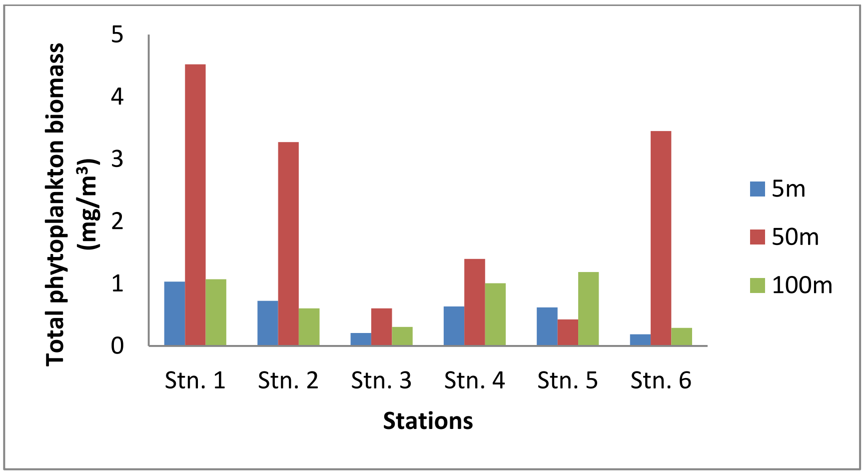


Fig: 6.3. Distribution of autotrophic picoplankton biomass (fractionated chlorophyll a) at various sampling locations in the Andaman Sea.

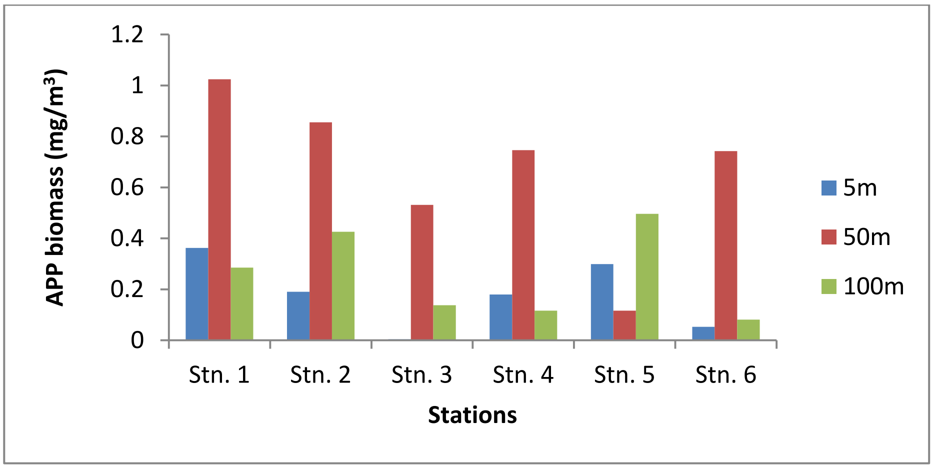


Fig: 6.4. Density distribution of autotrophic picoplankton at various sampling locations in the Andaman Sea.

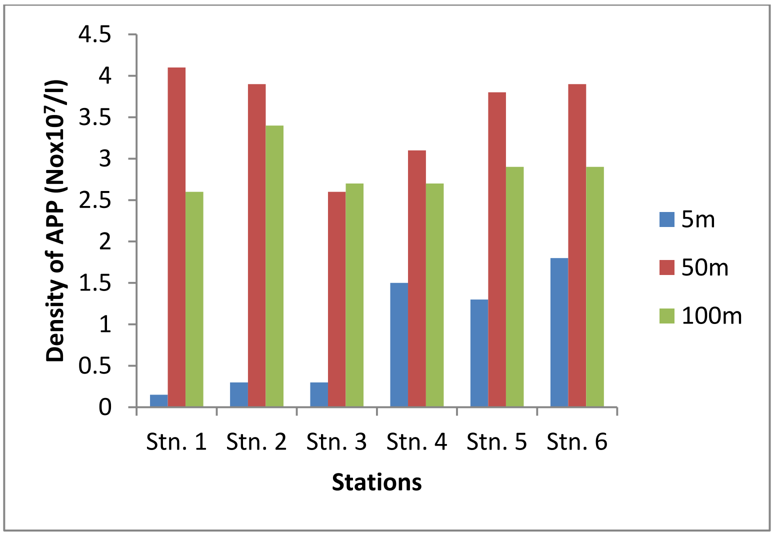


Fig. 6.5. Photographs of the slides showing density variation of APP at different depth. Panel (a) represents 5m with lowest density. Panel (b) represents 50m with highest density and panel (c) represents 100m with intermediate density.

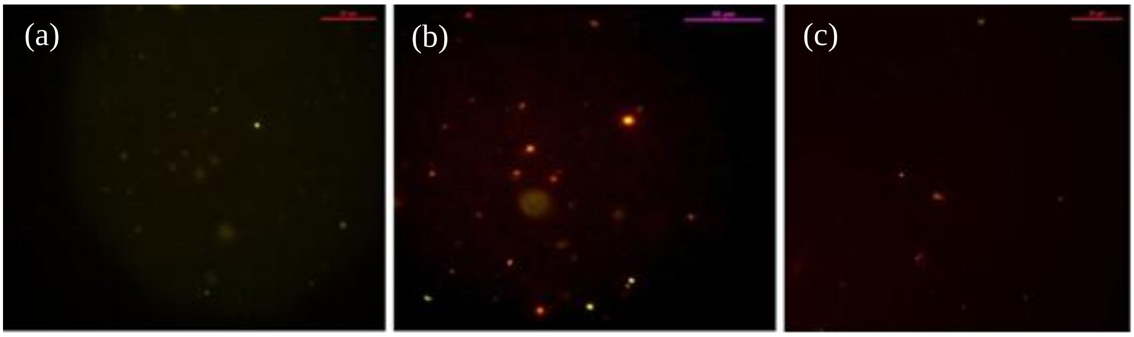


Fig: 6. 6. Percentage contribution of the APP biomass to the total phytoplankton biomass at various locations in the Andaman Sea.

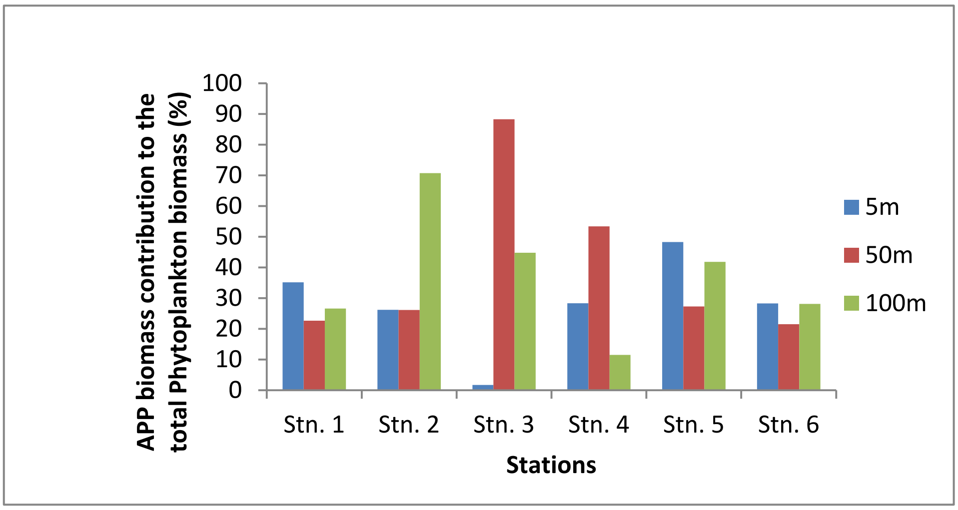


Fig.6.7. Density distribution of microzooplankton at various sampling locations in the Andaman Sea

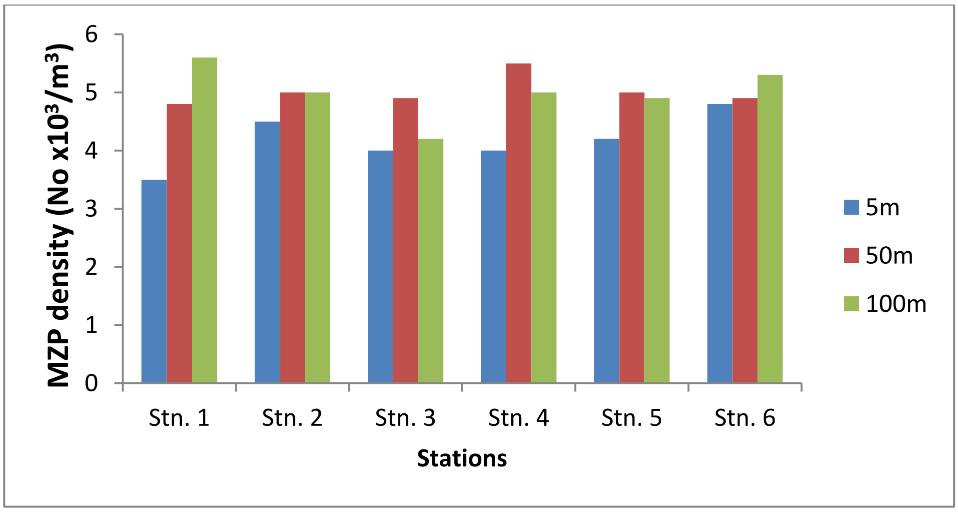
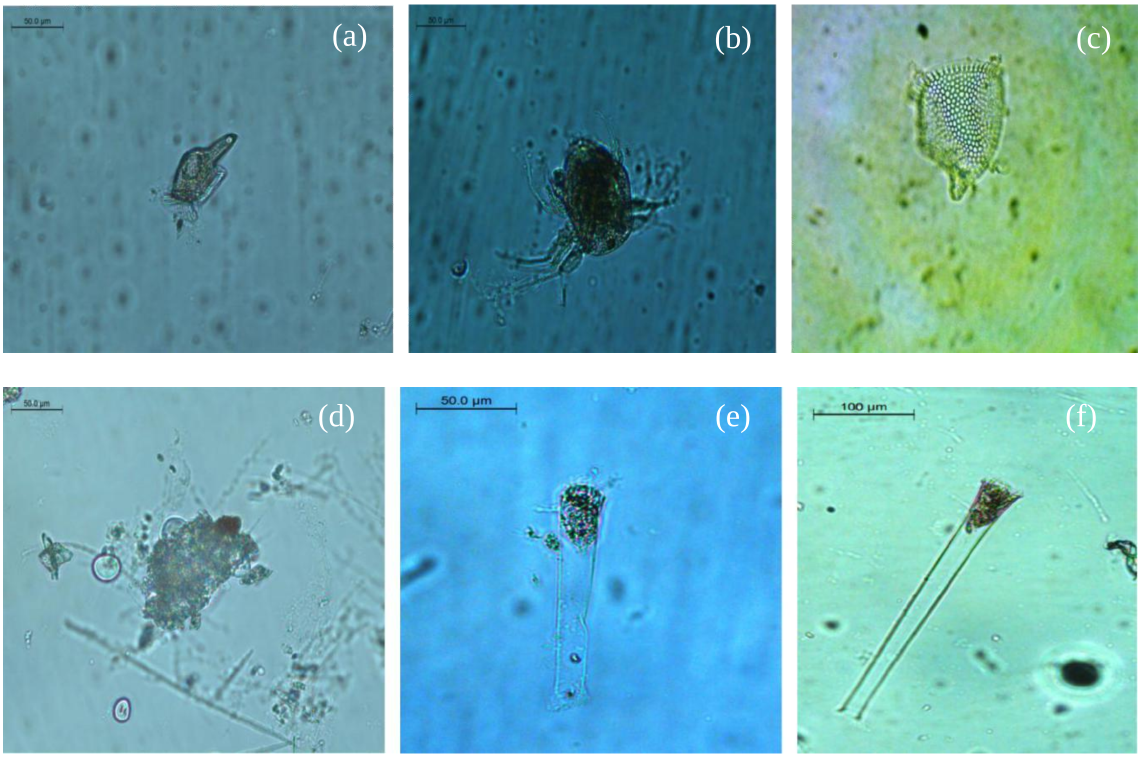


Fig. 6.8. Some of the major microzooplankton encountered in the oceanic sample **(a)*Dinophysis caudate* (b) Nauplius larva (c) *Dinophysis* sp. (d) *Tintinnopsis sp.* (e) *Leprotintinnus* sp. (f) *Eutintinnus* sp.**



6.5. Cochin Backwater

Minimum salinity was observed at surface (avg.16.75 ±10.76 ppt) and maximum at bottom (av.20.76 ± 9.86 ppt). Nitrate maximum was observed at surface (avg.13.29 ± 6.3µM) and minima at bottom (avg. 11.53 ± 7.43 µM). Phosphate was maximum at bottom (avg. 1.21± 0.93 µM) and minimum at surface (avg. 0.92± 0.89 µM). On the other hand, silicate showed a maximum at surface (avg. 53.9 ± 23.72µM) and minimum at bottom (avg. 44.76 ± 26.52 µM) (Table: 6. 3). Total chlorophyll *a* was higher at bottom (avg. 22.90 ± 20.1mg m^{-3}) and lower at surface (avg. 21.4 ± 18.9 mg m^{-3}) (Fig: 6.9). Fractionated chlorophyll *a* (APP fraction) also showed same trend with a high value at bottom (avg. 0.90 ± 0. 61 mg m^{-3}) and low at surface (av. 0.7 ± 0.17 mg m^{-3}) (Fig: 6.10). Autotrophic picoplankton density was also high at bottom (avg. 10.44 ± 1.28 x 10^7L^{-1}) compared to surface (avg. 9. 66 ± 2.11 x 10^7L^{-1}) (Fig: 6.11). At the same time, the percentage contribution of biomass of autotrophic picoplankton was very low in the system (1 to 5%) (Fig: 6.12). Microzooplankton density was also high at bottom (avg. 24.78 ± 14.64 x 10^7m^{-3}) than surface (avg. 21.57 ± 13.27 x10 m^{-3}) (Fig: 6.13).

Table: 6. 3. Distribution of chemical parameters in study area. 2 (Cochin backwater)

Surface	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn.5	Stn. 6	avg.	STDEV
Salinity	26.6	30.56	15.66	1.06	16.57	10.1	16.76	10.76
NO_3	16.25	6.24	4.605	19.37	14.5	18.47	13.23	6.31
PO_4	0.827	0.351	2.458	0.261	1.456	0.184	0.92	0.890
SiO_4	29.105	21.30	54.71	78.63	66.77	72.875	53.9	23.72
Bottom	**Stn. 1**	**Stn. 2**	**Stn. 3**	**Stn. 4**	**Stn.5**	**Stn. 6**	**avg.**	**STDEV**
Salinity	32.89	32.12	15.88	12.25	21.33	10.1	20.7	9.863
NO_3	8.725	4.565	3.61	21.95	11.855	18.47	11.53	7.43
PO_4	0.48	0.653	2.343	1.713	2.034	0.056	1.21	0.94
SiO_4	10.16	14.43	51.64	58.82	57.032	76.492	44.77	26.52

Fig: 6.9. Distribution of total phytoplankton biomass (total chlorophyll a) at various locations in Cochin Backwater.

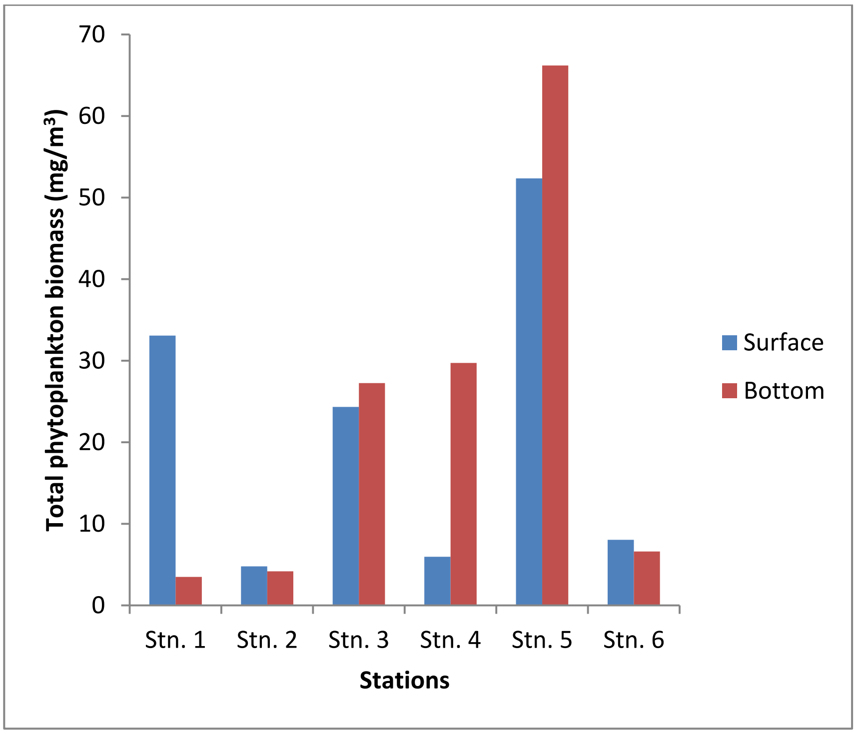


Fig: 6.10. Distribution of autotrophic picoplankton biomass (fractionated chlorophyll a) at various sampling locations in Cochin Backwater.

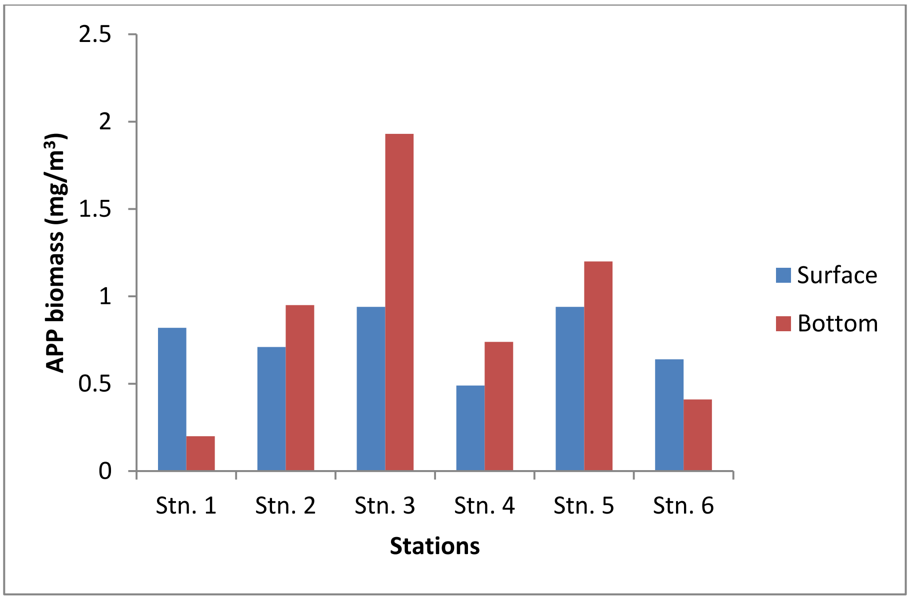


Fig: 6.11. Density distribution of autotrophic picoplankton at various sampling locations in Cochin Backwater.

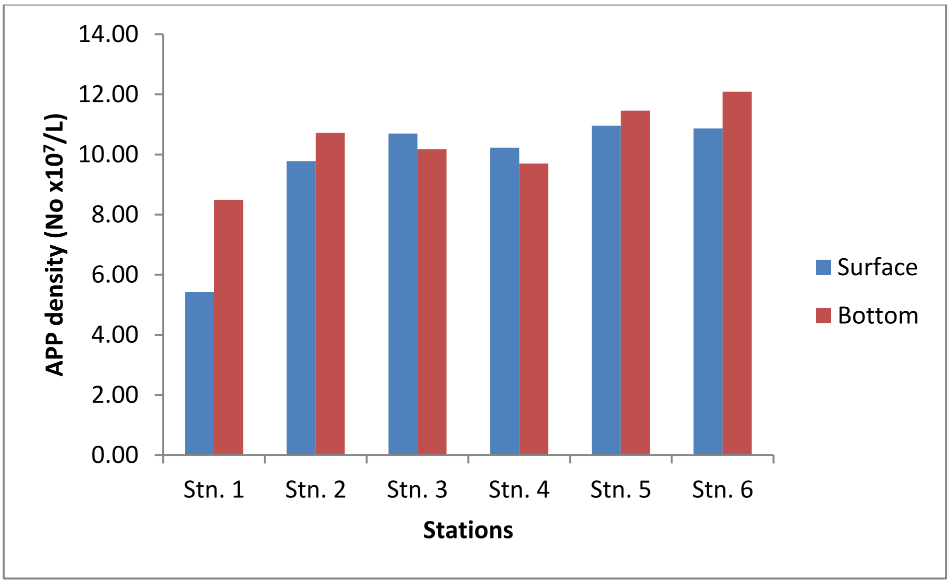


Fig: 6.12. Percentage contribution of the autotrophic picoplankton biomass to the total phytoplankton biomass at various locations in Cochin Backwater.

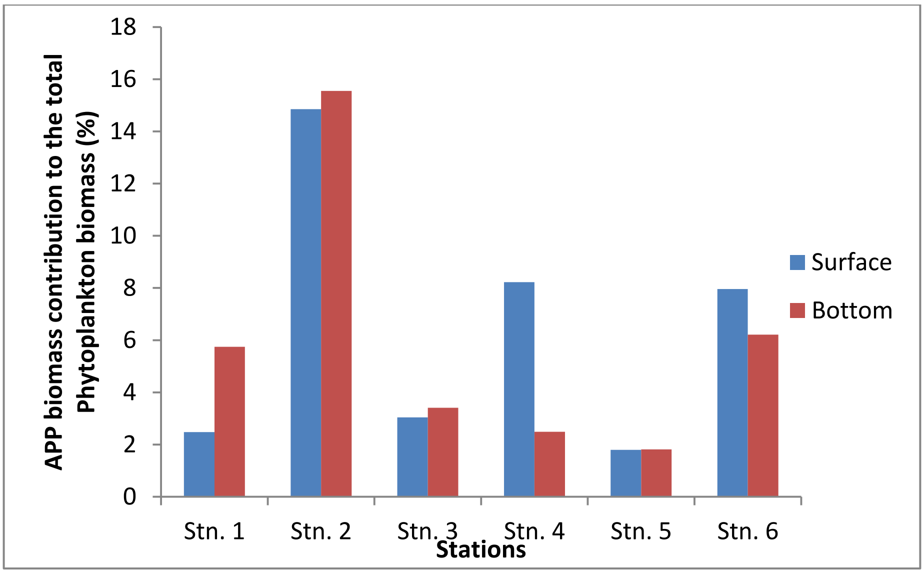
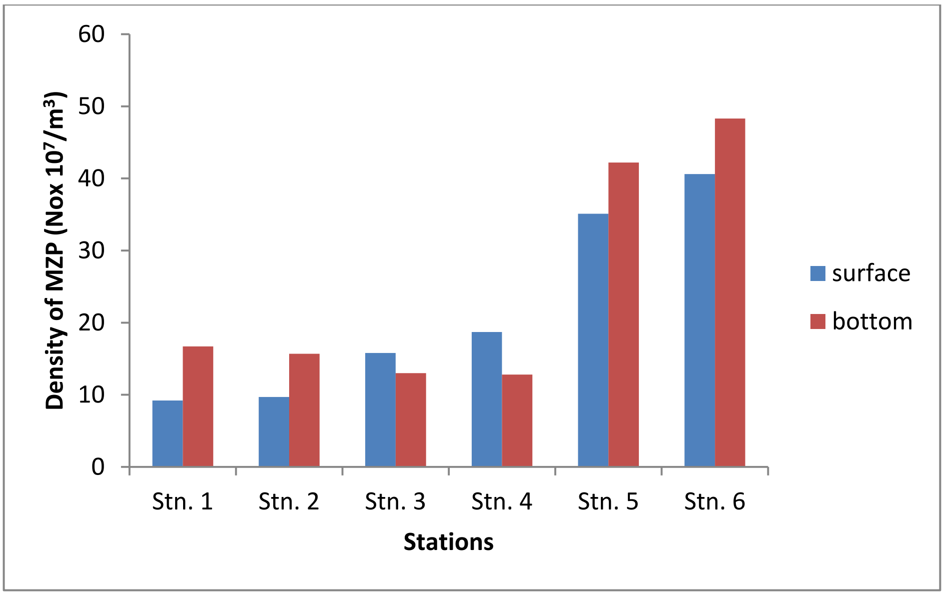


Fig: 6.13. Density distribution of microzooplankton at various sampling locations in Cochin Backwater.



6.6. Discussion

Numerical density of autotrophic picoplankton was very high in Cochin backwater than in Andaman Sea. Total chlorophyll also showed same trend with higher concentration in Cochin backwater and lower concentration in oceanic waters. Likewise, fractionated chlorophyll (absolute biomass of autotrophic picoplankton) was also high in Cochin backwater compared to Andaman Sea. The microzooplankton density (grazer density) was also very high in Cochin backwater than in Andaman Sea. All these results show that eutrophic waters harbor highest numerical density and absolute biomass of autotrophic picoplankton and their grazers.

At the same time, the percentage contribution of the autotrophic picoplankton biomass to the total chlorophyll biomass was very high in ocean (27 to 88%) compared to backwater (1 to 5%). But it should be noted that there is a fivefold increase in the grazer population (microzooplankton density) in Cochin backwater. Therefore, it can be proposed that the lower biomass contribution of autotrophic picoplankton in eutrophic water could be a result of intense grazing pressure rather than the weak competency of these cells in nutrient rich systems. In Andaman Sea, both density and chlorophyll maxima was found to be coupled with nitrite maxima at 50 m. At the same time in Cochin backwaters these parameters was not related to nitrite or nitrate. This confirms that nutrient parameter does not affect the distribution of autotrophic picoplankton in eutrophic waters instead grazing pressure drives the population dynamics. Moreover, it is proven that compared with larger cells smaller cells would be slower in converting nutrients into biomass and as a result they achieve lower maximum growth rate (Maranon *et al.*, 2013). Thus, it should be expected that in eutrophic systems, the percentage biomass contribution of smaller cells can never reach that of larger cells due to the intense grazing pressure and lower maximum growth rate even if they contribute considerably to the food chain. Thus, there are certain limitations in considering the biomass contribution as an index of competitive success in microalgae. A skeptical analysis of above view point is given below.

Do the widely assumed biomass constraints of smaller cells really matter in eutrophic environment?

Hutchinson suggested that non-equilibrium conditions brought about by the highly varying environment lead to the coexistence of phytoplankton by reducing the chance of competitive exclusion, whereas, some others proposed that productivity drives diversity to certain level (Palmer & white, 1994; Loreau *et al.*, 2002; Vallina *et al.*, 2014). Even though in reality productivity indicates biomass specific growth rate of a population or trophic level, most of the models use standing biomass (Chlorophyll *a*) as an alternative measure of productivity (Groner & Novoplansky, 2003; Vallina *et al.*, 2014). But, as smaller cells would be slower in converting nutrients into biomass (Maranon *et al.,* 2013), even though small sized producers are numerically abundant, their total biomass will be very low except they attain a very high biomass specific growth rate in comparison with larger producers. Thus, they become conspicuous in terms of biomass only in ecosystems where larger cells rarely survive. Consequently, the comparison of biomass between a smaller and larger algal cell is a futile task as both size fractions shows different assimilation rate. Hence, high biomass of larger cells in eutrophic waters is misinterpreted as their competitive success over smaller cells. How ever there are many other factors which determine the synthesis of biomass in various size fractions of algae. In spite of the advantage of high surface to volume ratio, smaller cells have a disadvantage of limited availability of enzymes to convert nutrients into biomass (Marañón *et al.,* 2013) which also implies that the rate of accumulation of biomass of an individual autotrophic picoplankton cell is independent of external nutrient status. However, in larger cells, lower efficiency in resource transport from the cell membrane to metabolic site also act against the rapid synthesis of biomass (Marañón *et al.*, 2013). Thus, the synergic effect of inefficient intrinsic nutrient transport and nutrient limitation in the system reduces the chance of survival of larger cells in nutrient deprived environments (Fig: 6. 14 and Fig: 6. 15). But the higher nutrient storage capacity of larger cells helps them to overcome the inefficient intrinsic nutrient transport in nutrient pulsed systems and hence allows them to uncouple their growth rate from the dynamics of external nutrient supply (Marañón *et. al*., 2013). Even though it can be considered as an advantage, the specialization narrows their niche and allows them to grow only in nutrient- rich systems or in nutrient pulsed regimes (bloom events). At the same time, as the growth of smaller cells is independent of the external nutrient concentration, they can easily establish in any nutrient gradient and coexist with larger cells and avoid competition pressure.

Does Small size promote co- existence?

In aquatic microbial world where all interaction occurs at cellular level, size and physiology is tightly coupled in such a way that size itself decides the survival of the organism in a particular environment (Banse, 1982; Chishlom, 1992; Raven, 1998). In most of the studies autotrophic picoplankton is considered as ‘ubiquitous’ (Waterbury *et al.,* 1979; Johnson & Sieburth, 1979; Chisholm *et al.*, 1988; Stockner *et al.*, 1988). The word ‘ubiquitous’ itself explains that they have been successful in invading most of the aquatic habitats irrespective of ecological differences (Callieri, 2007). The high surface to volume ratio of autotrophic picoplankton allows them to survive in low nutrient environments at the same time it is notable that their nutrient requirement is also very low (Raven, 1986; Raven, 1998). In coastal ecosystems, frequency of nutrient input determines the parameter combinations allowing coexistence. Larger the time interval between the nutrient pulses the more species coexist (Ebenhoh *et al.,* 1988). But in ecosystems like estuaries, the time interval between nutrient inputs is expected to be low due to the continuous riverine influx and anthropogenic activities. This can have a negative effect on diversity through the dominance of a single species (Spatharis *et al.,* 2007). Even then the numerical abundance of lower size spectra remains unaffected in coastal ecosystems (Menon *et al.*, 2000; Marshall, 2002; Badylak *et al.,* 2007). The results given in present chapter also confirms that the external nutrient concentration does not determine the distribution of autotrophic picoplankton in eutrophic environment and which can be attributed to the size dependent low nutrient requirement (Raven, 1986; Raven, 1998). In fact, an algal cell requires only a small nutrient quota, never becomes a competitor for a large cell in eutrophic coastal waters, instead they share a negligible part of the community niche and easily coexist with larger cells without applying any competition related pressure. Thus, size subsidized low nutrient requirement (in nutrient rich waters) allows them to avoid the deleterious effect of “occupying precisely the same ecological niche”, an essential condition suggested by Gause (1934) for competitive exclusion.

Sinking is found to be a major factor which limits the distribution of larger cells in nutrient deprived environments (Raven, 1998). In nutrient-rich environments, their high nutrient storage ability acts as an advantage which offers sinking resistance (Passy, 2007). At the same time low-nutrient requirement and high surface to volume ratio of smaller cells compensate the high storage ability of larger cells and keep them buoyant in all nutrient regimes. Above observations leads to the fact that smaller cells can survive better in productive nutrient-rich environments also. Additionally, it is well established that individuals with essential difference in resource requirements shows coexistence in spatial systems with resource gradient (Ryabov & Blasius, 2011). Thus smaller cells need not compete with the larger cells in nutrient- rich systems as their nutrient requirement is significantly low and hence they coexist with other size spectra.

In contrast, larger cells may not be able to survive in nutrient deprived waters due to their high nutrient requirement to resist sinking. Their low surface to volume ratio makes the scenario worse (Fig: 6. 14 and Fig: 6.15). As a result, in oligotrophic systems, we never get high values for their biomass. Therefore, smaller cells can be considered as habitat generalists who can co-exist with larger ones in any environment and larger ones as opportunistic species which only grow in nutrient-rich conditions. There are also experimental studies which prove that larger size taxa can't thrive under nutrient deprived conditions even in the absence of competitors (Irwin *et al.*, 2006., Maranon *et al.*, 2013) and both size spectra equally increase in terms of number with the elevated nutrient levels in oligotrophic systems (Barber & Hiscock, 2006). Thus, the dominance of autotrophic picoplankton in oligotrophic environment can never be related to their competitive success in less nutrient systems but to the inadaptability of larger cells to the nutrient deficient systems. Hence small size of autotrophic picoplankton can be considered as a factor which promot coexixtance rather than competition.

Does the size selective predation act as a mechanism for co-existence?

Synergic effect of selective predation on diversification of organisms put forward by McArthur in 1960 was only taken as a distant possibility by Hutchinson (1961). But Carpenter and Kitchel (1988) introduced hierarchical control of prey organisms or 'trophic cascade'. A trophic cascade is supposed to be achieved by a large-scale density variation in a trophic level and the strategy is dependent on time scale, ie. on the growth rate and generation time of both prey and predator. Temporal lag between growth and reproduction of phytoplankton and mesozooplankton controls the predator- prey equilibrium. Once the lag is more, phytoplankton biomass increases and when there is a reduced lag phase, the coupling becomes conspicuous (Cushing, 1981). If this is so, the major predators of autotrophic picoplankton comprising of heterotrophic nanoplankton and microzooplankton which exhibit a generation time close to their prey organisms, will produce a very short lag phase (Goldman, 1985). Hence the prey population is continuously checked by high predation rate. Thus it is obvious that in a phytoplankton assemblage, the predation effect varies up on diverse size strata depending on their generation time. This usually happens in bloom events. When diatoms and picophytoplankton assemblages equally respond to the elevated nutrient levels, diatoms accumulate more biomass than the quantity mesozooplankton grazers can consume (Martin *et al.*, 1994; Coale *et al.*, 1996; Landry, 2002; Barber & Hiscock., 2006). The rising tide hypothesis proposed by Barber and Hiscock (2006) gives the idea that during blooms autotrophic picoplankton shifts to higher autotrophic growth rate and biomass levels, however, grazing also increases and so a balance is maintained, and accumulation of biomass reduces. Therefore, succession by competition does not appear to be a satisfactory explanation for a bloom cycle. If the rising tide lift (Barber & Hiscock, 2006) is a reasonable elucidation, while the bottom - up control mechanism operates equally on all size strata of a phytoplankton assemblage, predation pressure or top-down control becomes size selective in such a way that larger cells with high biomass are consumed slowly and the smaller ones with low biomass are consumed rapidly irrespective of a high growth rate. Thus, the relative biomass contribution of different size fraction in a bloom situation can mislead us to the conclusion that larger cells dominate the phytoplankton assemblage.

Nutrient limitation increases the cell sinking rates several fold by stressing the energy producing pathways needed by the cells to maintain their buoyancy (Smayda, 1970; Bienfang and Harrison, 1984; Harrison *et al.*, 1986; Waite *et al.*, 1992; Sarthou *et al.*, 2005). Thus, towards the end of the bloom, nutrient deprivation rather than predation pressure act as a negative feedback leading to the crash of larger cell population (fig: 6.16). Consequently, the observer tends to hypothesise the elimination of larger cells by smaller ones and a steady climax in oligotrophic condition. The same mechanism can operate in a phytoplankton community of eutrophicated coastal waters as well. The only difference is that as the system rarely undergoes nutrient depletion, larger cells survive the population crash and at the same time biomass of smaller cells always remains in a static- quasi-equilibrium due to the constant predation pressure exerted by the predators with short generation time (fig: 6.16). This situation is completely opposite to the oligotrophic situation where larger cells only exist as an opportunistic population, but the scenario is misconstrued as the climax community formation by smaller cells (fig: 6.15 and fig: 6.16). The coastal waters are not only inhabited by large number of ciliates and phagotrophic protists but also by a wide variety of zooplankton larvae which is usually considered as microzooplankton. During the last decade, numerous studies confirmed the pronounced grazing of lower size spectra by smaller grazers of microbial food web outstripping the mesozooplankton grazing rate (Table: 6.4). Thus, the selective predation pressure can also act as a mechanism inhibiting competition between different size spectra and maintaining diversity irrespective of the trophic status of ecosystem. Therefore, in an ecosystem where the pyramid of biomass is inverted due to the faster multiplication and removal rate of phytoplankton, it is questionable that how we could analyze the dominance of a specific size spectrum purely depending on their biomass (chlorophyll) contribution as different size fractions shows different multiplication rate and removal rate. But unfortunately, most of the field studies rely up on relative biomass contribution to interpret the dominance of a particular size fraction in a given nutrient status (Martin *et al.*, 1994; De Baar *et al.*, 1995; Coale *et al.*, 1996; Boyd *et al.*, 2000; Blain *et al.*, 2001; Gall *et al.*, 2001; Tsuda *et al.*, 2003; Boyd *et al.*, 2004; Zarauz *et al.*, 2009; Maranon *et al.* 2013; Mochemadkar *et al.* 2013).

Fig: 6.14. A schematic representation of well stratified oligotrophic condition where large cells exist as an opportunistic population only during nutrient enrichment

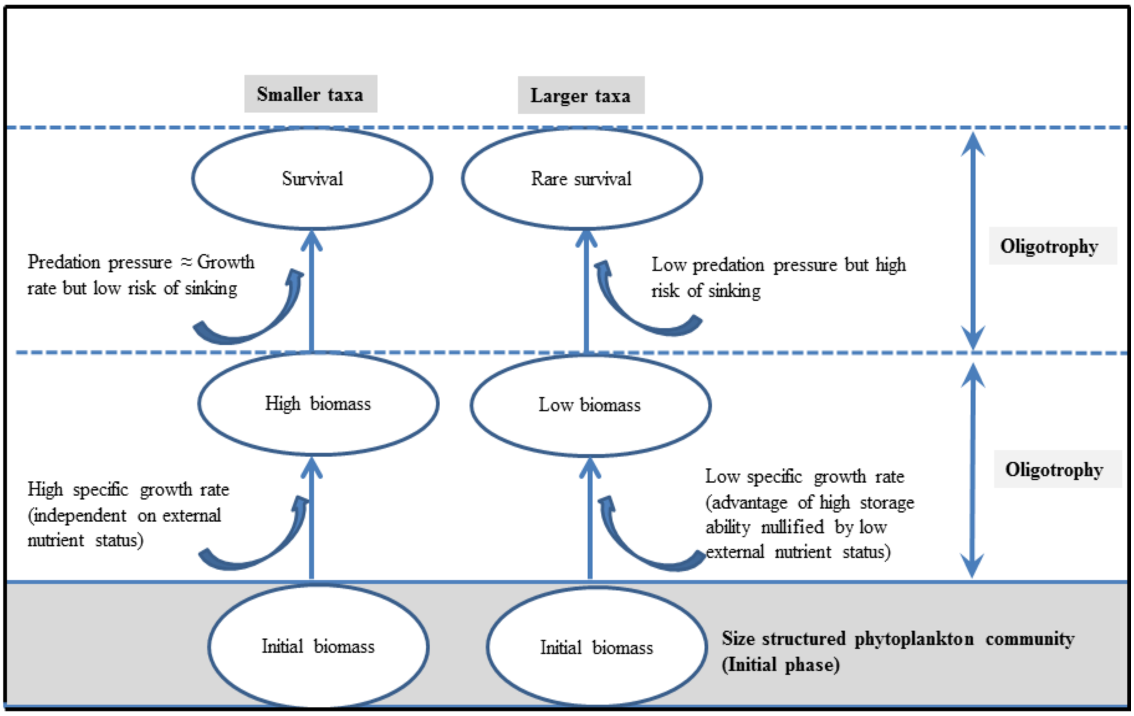


Fig 6.15- Simplified depiction of population control of two different size strata in a bloom event. Even though both size fractions respond equally, lower size spectrum is controlled by predation pressure towards the end and never allowed to outcompete the larger diatoms with in the time period of bloom, whereas larger cells (opportunistic population) disappear due to totally different mechanism of buoyancy loss during nutrient depletion.

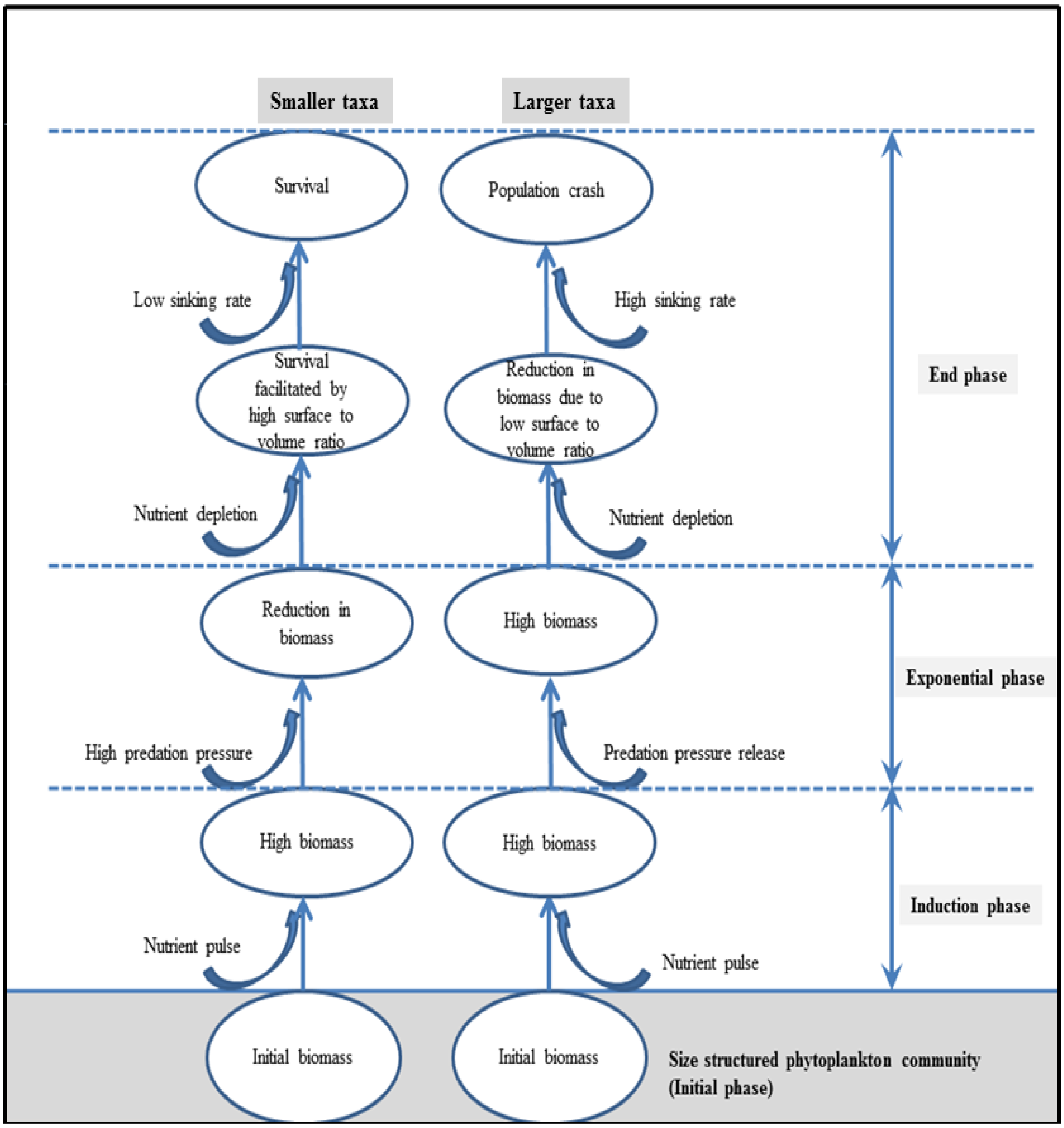
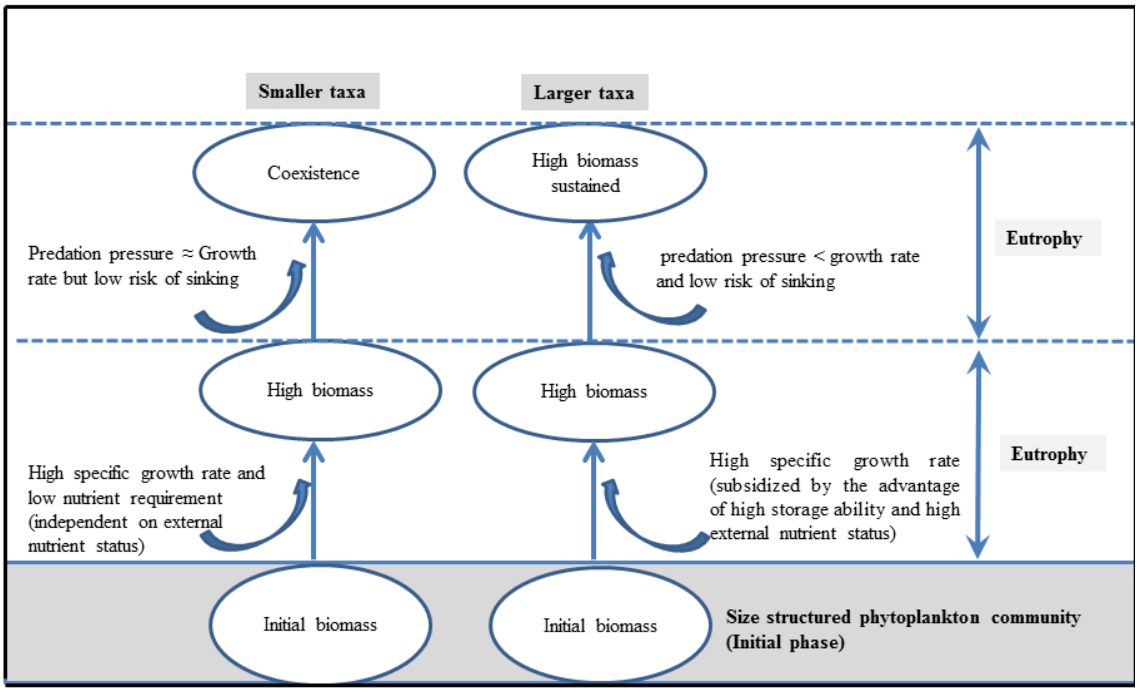


Fig: 6.16. Population control of two different size strata in eutrophic coastal waters. Eventhough both size fractions respond equally to the elevated nutrient levels, lower size spectrum is controlled by predation pressure and never allowed to outcompete the larger diatoms, but as there is no nutrient limitation, the larger cells are able to sustain high biomass throughout the season by avoiding sinking.



Do the laws of terrestrial ecosystem are applicable to marine environment?

Odum's explanation of ecological succession (Odum,1969) was a major breakthrough in the history of ecosystem development studies and had a great positive impact on the forest conservation strategies, sustainable agriculture practises, landscape planning etc. Until now the typical temporal phases of succession has been widely accepted as one of the finest explanations for the archetypal evolution of any ecosystem (Würtz& Annila, 2010., Delang & Li, 2013; Dini *et al.*, 2016) and the dynamics of marine microalgal blooms were also elucidated based on the same explanation (Odum, 1977; Cushing, 1989; Sarmiento *et al.*, 2004; Le Que´re´ *et al.*, 2005; Veldhuis *et al.*, 2005). But a few authors could observe that diatoms do not replace the ambient autotrophic picoplankton assemblage in an algal bloom (Ryther, 1963; Landry, 2002; Barber & Hiscock 2006). As Odum himself stated in his classic paper that the ideas belong to the ecosystem development are based on the changes of biotic communities over long periods and many of them lack experimental proof

(Odum, 1969). The assumptions of succession theory are applicable to terrestrial environment perfectly as most of the changes in these systems occur in a long-time scale. In contrast to the terrestrial ecosystems, spatial and temporal variations in the oceanic upper mixed layer is often more visible in short term scale which can be attributed to the sea atmosphere interactions and short generation time of algal cells (seasonal blooms, upwelling associated blooms etc.). But unfortunately, these visible short scale variations directed the observers to the conclusion that only the prominent size fraction with the highest relative biomass respond to the varying environment quickly (Martin *et al.*, 1994; Coale *et al.*, 1996, 2004; Boyd *et al.*, 2000; Blain *et al.*, 2001; Gall *et al*., 2001; Smetacek, 2001; Boyd *et al.*, 2004; Zarauz *et. al.*, 2009; Maranon *et al.* 2013; Mochemadkar *et al.,* 2013). It is a truth that the competitive exclusion of one algal species by the other can happen in a microcosm or mesocosm experimental set up which simulate only the microenvironment of an algal community with a handful of species. The phenomenon can be explained by the high degree of overlapping of niches which impose only a narrow niche opportunity to each species and thus reduce the possibility of coexistence in a short time scale. But the likelihood of overlapping of niches is greatly reduced in natural conditions with unlimited nutrient supply and constantly varying physical environment (Hutchinson, 1961). Disappointingly it is very difficult to manipulate a mixed layer with its exact degree of dynamism and hence to prove the coexistence of different size spectra experimentally. Still we can see that the exact process in the progression of a bloom varies in certain ways with respect to the definition of succession given by Odum. The first statement in the definition is that the succession is an *'orderly process of community development that is reasonably directional and therefore predictable'* (Odum, 1969). But a bloom formation is not an orderly process of community development but a simultaneous increase in population of each species in a community in response to a sudden nutrient input which is then maintained and stabilized by size selective predation and sinking (Barber & Hiscock, 2006). The second aspect of succession is that *'it is community controlled even though the physical environment determines the pattern, the rate of change, and often sets a limit to how far development can go'* (Odum1969). On the other hand, the marine microbial community is profoundly influenced by the cell size of the organism and thus the pattern, rate of change and upper limit of the development is often determined by the intrinsic factors which is related to its size rather than the physical environment (Raven, 1998).The modification of the physical environment by a pelagic micro algal community can only bring out a short term impact (nutrient depletion) which could be easily recoverable by the highly dynamic mixed layer particularly in coastal ecosystems. The third rule regarding the process of succession is that *'it culminates in a stabilized ecosystem in which maximum biomass (or high information content) and symbiotic function between organisms is maintained per unit of available energy flow'*. In a microalgal assemblage as the biomass accumulates the community becomes more destabilized in contrast to the terrestrial community and physical environment neither achieve stability except in highly stratified condition. Thus, small algal cells in oligotrophic condition with high relative biomass can never be inferred as a climax community which has replaced the less adaptive previous community but as a community which could survive a large scale nutrient fluctuation due to its wide adaptability subsidized by the particular size range. Hence, even though the system closely resemble the 'mature stage' of succession described by odum (1969) and Margalef (1958) in many ways (e.g.P/R 1, complex food web structure, greater capacity of nutrient cycling within the system, increase in the variety of plant pigments etc.) it would be more appropriate to call the final algal assemblage as an *'outlive community'* which could survive a high gradation in nutrient disparity rather than a 'climax community'.

Table: 6.4. List of studies that confirmed the pronounced grazing of lower size spectra by smaller grazers of microbial food web

Ecosystem	Results	A
Southern north sea in spring	Vigorous grazing by MZP in nearshore than offshore on <200µm phytoplankton	StelfoxWiddicombe (2004)
Surface layer of Logy bay	40-100% carbon ingestion from <1µm phytoplankton by MZP even at low temperature and low salinity.	Putland J. N (2000), Putland and Tracey (2010).
Florida continental shelf	Reduced grazing impact of MSP on phytoplankton community	Sutton *et al.* (2001)
Southern ocean	Preferential selection of small cells by MSP in bloom condition	Perissinotto (1992)
Coastal gulf of Alaska	MZP directly consume much of the production of <20 µm	Strom *et al.* (2007)
Subtropical convergence region off east coast of South island New Zealad	57% of measured grazing impact on picophytoplankton sized particles by mixotrophic nanoflagellates	Karl and Julie (1999)
Spring bloom in the Bay of Biscay	Small autotrophic cells channeled most of the available carbon to pelagic fish production	Marquis *et al.* (2011)
Southern Ocean	Top down control play an important part in regulating the equilibrium standing stocks of smaller taxa	Smith and Lancelot (2004)
Global ocean	MZP act as an important source of phytoplankton mortality	Calbet and Landry (2004)
Subtropical oligotrophic marine ecosystem	Close coupling between trophic relationship between picoplankton and nanoflagellates	Chiang *et al.* (2013)

6.7. Conclusion

In summary, the study call attention to the limitation in using relative biomass as a measure of competitive success in microalgae. As large cells are adapted only to nutrient- rich conditions, their lower biomass in oligotrophic waters force us to conclude that they are outcompeted by smaller cells in such systems. Whereas, in eutrophic waters low nutrient requirement of smaller cells allow them to co-exist easily with larger fraction regardless of high trophic status. Additionally, rapid increase in absolute biomass of smaller cells can be balanced by an increase in predation pressure since nutrient -rich waters harbor an active microbial loop. Hence the estimation of percentage contribution of biomass to define the competitive success in algae seems to indicate an assumption rather than the reality. The relevance of trait-based approaches in ecology is widely accepted as it can unify mechanisms of community assembly, ecosystem functioning and evolutionary dynamics into a single plane (Litchman & Klausmeier, 2008; Krause *et. al.*, 2014; Madin *et al.*, 2016). Recent researches dependent on trait based mathematical models draw attention to the ambiguity of explanations given to the species presence, abundance and diversity in microalgal community (Ruokolainen *et al.*, 2009; Edwards *et al.*, 2012; Litchman *et al.*, 2015; Mutshinda *et al.* 2016). Considering the facts discussed in this chapter the vagueness regarding the size constrains and diversity of microalgal community could be resolved if we can develop an alternative index which integrate numerical abundance, size dependent growth rate and removal rate instead of using relative contribution of biomass in trait dependent models. We also emphasize that **e**mpirical results only bring out what an observer perceives while experimenting. Although mathematical models are useful tools for ecological studies, it can only explain the deductions of an observer rather than facts. That means, models explain not what actually happens in the system but what we see in the system. Therefore, it is important how to perceive an ecosystem process precisely. In this context we propose that the methods which are currently used to define interactions in the plankton community of highly dynamic aquatic systems have to undergo an inevitable re-evaluation which adopts a broad perspective rather than using strategies which are predominantly suitable for more stable terrestrial environment.

Chapter VII

SUMMARY AND CONCLUSION

The Cochin backwaters constitute one of the largest productive ecosystems in the country, encompassing an area of approaximately 250km^2 interspaced with numerous islands and networks of canals and receiving freshwater from seven rivers. The ecology and food web dynamics of backwater is found to be profoundly influenced by regular monsoonal and tidal cycles.

The studies show that Cochin backwater sustains surplus nutrients supporting phytoplankton production at consistently high level through out the year. However, the relation between chlorophyll and primary production was found to be significant only at lower size fraction level, which indicates the importance of smaller phytoplankton as producers in the system. Since the smaller size fraction can be utilized only by smaller predators, it is thought that microbial foodweb could be one of the pathways transferring energy to the higher trophic levels. The fact that Cochin backwater sustains independent cycles of phytoplankton and mesozooplankton again confirms the existence of alternative pathways of energy transfer. However, the current hypothesis is that the high freshwater input during monsoon leads to a general weakening of the foodweb due to the density decrease in planktonic components associated with reduction in salinity. The hypothesis also supports the dominance of microbial foodweb during Premonsoon which is linked with the classic pathway at secondary trophic level as the increased salinity during this season can sustain many marine planktonic grazers in the system. The microbial foodweb of the system is thought to be primarily dependent on bacteria during premonsoon due to the excessive allochthonous input. Still, the contribution of smallest phytoplankton groups to the foodweb, especially that of autotrophic picoplankton is unknown due to the ambiguities regarding their seasonality and ecological efficiency in the eutrophic systems.

Moreover, most of the existing studies are either based on the discontinuous data or addressing only a few planktonic components in relation with the seasonal variability of hydrographic parameters. This can lead to many perceptional errors or ecological fallacies related to the system dynamics. Therefore, the present study was mainly intented to delineate the role of autotrophic picoplankton (the smallest phytoplankton size fraction of the system) in the foodweb of Cochin backwater based on a systematic time series data set which integrates all the possible physiochemical and biological parameters. The study was designed to analyse even the minor spacial and temporal variations associated with tidal cycle and the major seasons (Spring intermonsoon and Southwest monsoon) in various ecological zones of the backwater. The present study also quantifies the carbon contribution of autotrophic picoplankton to the higher trophic levels during both seasons which has never been addressed before. Apart from that, the study skeptically analyses the artefacts in using the percentage contribution of biomass of various size fractions as an index of competitive exclusion in microalgal community. The thesis also point out some limitations in using the laws of terrestrial ecosystems to interpret highly dynamic marine environments.

Salient findings of the study

In agreement with previous studies there was a general reduction in the density of all planktonic components during monsoon. The mesohaline region in the system was found to be harbouring most of the planktonic components and thereby an efficient food web during both seasons. There was clear spatial shift in the region of active plankton food web (region shows close coupling between plankton consumers and their potential prey) in the Cochin backwater between the seasons. This shift was associated with the affinity of the planktonic component towards the mesohaline region. The entire planktonic components except autotrophic nanoplankton shifted from upstream to downstream as the mesohaline patch moves from upper reaches to downstream during monsoon.

In contrast to the previous works, present study confirms that only the linear food web undergoes reduction in efficiency during monsoon due to the spatial disparity between autotrophic nanoplankton and its predator population. This spatial mismatch was found to be the reason for the presence of unconsumed carbon in Cochin backwater during monsoon. At the same time, in spite of the regional shift, the orientation of both predator and prey organisms showed the presence of an efficient microbial food web in monsoon also. In spring intermonsoon period the dependency of microbial food web was towards heterotrophic bacteria (HPP) while in southwest monsoon microbial food web was dependent on the autotrophic picoplankton population. This explains the reason for the switch over of backwater system from net autotrophy to net heterotrophy during monsoon which was evident in earlier studies. The grazing and clearance rate of autotrophic picoplankton was found to be very high during southwest monsoon (1.08 and 59%) than the spring intermonsoon (0.44 and 37%) and the grazers of microbial food web also showed high affinity towards autotrophic picoplankton as their prey. Thus, it is clear that the carbon contribution of autotrophic picoplankton to the food web of backwater system is much significant than the earlier approximation. The results show that they pump considerable amount of carbon to the higher trophic levels through microbial food web especially during monsoon and hence buffer the effect of general weakening of food web during the season by acting as an alternate food source. Hence their ecology need special attention and need to be explored further.

The present study also proposes that there is a limitation in considering relative biomass as a measure of competitive exclusion in microalgae and suggests that a more accurate index which integrates numerical abundance, size dependent growth rate and removal rate is essential to explain competitive success. The study also proposes that the methods which are currently used to define interactions in the plankton community of highly dynamic aquatic systems has to undergo an inevitable re-evaluation which adopts a broad perspective rather than using strategies which are predominantly suitable for more stable terrestrial environment.

The present scenario of food web research involves the development of ecosystem simulation models using highly resolved food webs as a tool. Now food web approaches have taken hold in many applied management endeavors, such as fisheries and conservation biology by encouraging a more dynamic, interaction driven view of ecosystems (Zavaleta et al. 2010). Adopting a food web perspective will provide valuable insight in to ecological restoration that would not otherwise be attained from a more static community-based approach. In India, an ecosystem approach to analyses pelagic food webs is increasingly valued to develop predictive whole ecosystem simulation models; still effort in this area is in early stages. As Cochin estuary is the largest monsoonal estuary on Indian west coast, the inferences given in present theses will have several applications in designing the seasonal food web models for monsoonal estuaries.

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Appendix

Table 1. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 1 (Fort Kochi) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 1. Fort Kochi	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	0	10000	8000	0	0	500	0	800	2400
Tintinnopsis cylindrica	0	500	0	1200	600	800	0	400	800
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	0	0	0	400	0
T. beroidea	800	500	1600	800	800	600	400	1200	800
T. uruguayensis	0	600	0	600	0	600	400	400	0
T. lohmanni	0	0	0	800	0	0	0	0	0
Tintinnidium incertum	1200	1300	4000	1400	2400	400	0	2400	1200
T. primitivum	400	0	900	4000	1600	900	1600	1200	800
T. radix	0	0	0	400	0	0	0	400	0
T. tocantinensis	400	0	0	0	800	0	0	0	0
Codonella sp.	0	0	0	400	0	0	800	0	0
Codonellopsis pusilla	400	0	400	800	0	0	0	0	0
Stenosemella sp.	1200	800	0	0	400	0	400	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha sp.	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	400	0	0	0	0	0
Dileptus sp.	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	600	0	0	400	0	0	0	0
Laboea strobila	0	4000	0	1600	1200	800	600	1200	0
Strombidium bilobum	0	800	400	0	0	0	0	800	0
S. conicum	0	400	800	0	900	0	0	1200	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	900	0	0	400	0	0	0	0
Strobilidium minimum	0	0	1600	800	0	0	400	0	0
Lohmaniella spiralis	0	1200	1200	800	1200	1400	0	800	0
L. oviformis	0	900	800	600	800	0	0	0	0
Didinium nasutum	0	3200	0	1400	600	0	1600	800	800
Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0

Holophyra marina	0	800	400	0	0	0	400	0	0
Halteria gradinella	0	0	0	400	0	0	0	0	0
H. chlorelligera	0	800	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	400	1800	600	1600	400	800	400	400	800
Gymnodinium sp.	0	0	600	0	0	0	0	0	0
Prorocentrum gracile	800	2800	800	600	0	0	800	0	0
P. micans	0	800	0	400	0	0	0	0	0
P. lima	400	400	800	0	400	0	0	800	0
Gyrodinium glacialis	400	1400	400	0	400	0	400	400	400
G. spirale	400	0	800	1200	400	0	0	0	400
Alexandrium insuetum	400	0	0	0	0	0	0	400	0
A. tropicale	1200	0	400	0	400	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	400	0
P. leonis	0	0	0	400	0	0	0	0	400
P. globulus	400	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	400	400	0
Pyrophacus sp.	400	0	0	0	0	0	0	0	0
Rotifer							800	400	
Radiolaria		0	0	0	0	0	400	0	400
Crustacean nauplii		0	800	0	0	400	800	0	0
unidentified		0	0	0	0	0	0	400	0
Total density (no./L)	9200	45300	25300	20600	14100	7200	10600	15600	9200

Table 2. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 2 (Azheekode) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 2. Azheekode	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	0	800	400	800	800	400	0	800	0
Tintinnopsis cylindrica	0	0	0	0	0	400	0	400	0
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	600	0	800	0	900	600	1200	400	0
T. uruguayensis	0	400	0	0	0	0	0	0	0
T. lohmanni	0	0	400	0	0	400	0	0	0
Tintinnidium incertum	2400	800	1200	900	400	900	800	1400	800
T. primitivum	900	800	1400	400	800	1200	400	800	1600
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	400	0	0	800	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	800	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	200	0	0	800	0	400	0	0	0
Laboea strobila	1200	400	800	400	800	400	1600	400	400
Strombidium bilobum	400	800	0	400	0	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	400	0	0	0	0	0	0
Lohmaniella spiralis	0	1200	400	0	400	0	800	0	0
L. oviformis	0	0	0	0	0	0	0	0	0

Didinium nasutum	1200	900	3200	800	400	1200	800	1400	2400
Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	400	0	800	1200	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	2400	0	0	0
P. micans	1200	900	800	400	1200	400	0	0	400
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	400	800	400	600	400	0	400	900	800
G. spirale	400	0	800	400	400	0	0	0	0
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Rotifer	0	400	800	0	400	400	0	0	0
Radiolaria	400	800	400	400	600	400	900	800	400
Crustacean nauplii	0	400	400	900	400	0	0	0	800
unidentified	0	0	0	0	800	0	0	0	0
Total density (No. / L)	9700	10200	13000	8000	9500	10700	6900	7300	7600

Table 3. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 3 (Nedungadu) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 3. Nedungadu	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	800	3200	800	400	2400	800	0	1600	400
Tintinnopsis cylindrica	400	0	800	800	400	0	400	0	0
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	1600	3200	2400	800	1400	800	400	800	400
T. uruguayensis	400	800	0	0	0	900	400	800	0
T. lohmanni	0	400	400	800	0	0	400	0	0
Tintinnidium incertum	3400	12000	2400	800	1200	1600	400	400	1600
T. primitivum	1200	3400	1200	400	1200	800	800	800	3400
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	400	0	0	400	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	400	0	800	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	1200	800	1600	1600	900	400	0	400	0
Rhimostrombidium sp.	800	400	0	0	0	0	0	400	
Strombidium bilobum	0	0	0	0	0	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0	0	0	0

Lohmaniella spiralis	1200	3400	900	400	0	800	1600	400	400
L. oviformis	0	0	0	0	0	0	0	0	0
Didinium nasutum	800	3400	800	900	800	400	1200	400	800
Spaerophrya magna	0	0	0	0	400	0	0	0	0
Lagynphrya salina	0	0	0	400	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	400	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	400	1200	400	800	400	1200	800	400	400
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	800	0	400	0	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	1600	900	800	0	0	0	0	400	0
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	800	0	0	0	0	0	0	0	0
Rotifer	0	0	400	0	0	0	800	0	0
Radiolaria	0	400	0	0	0	0	0	0	0
Crustacean nauplii	0	200	400	0	0	0	0	0	0
Unidentified	0	0	800	0	0	1600	0	0	0
Total density (No./L)	15800	34500	14900	8900	9100	9300	7200	6800	7400

Table 4. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 4 (Varapuzha) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 4. Varapuzha	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	1400	800	800	400	0	1200	3400	400	800
Tintinnopsis cylindrica	0	0	0	0	0	0	0	0	0
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	800	0	0	0	400	0	0	0	900
T. uruguayensis	0	0	0	200	0	0	0	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	3400	800	1600	900	200	0	800	400	800
T. primitivum	1200	900	800	1200	800	400	400	800	900
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	6000	3400	1200	3400	4000	800	1200	900	0
Strombidium bilobum	0	0	0	0	0	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0	0	0	0
Lohmaniella spiralis	800	900	400	0	0	160	0	0	0
L. oviformis	900	800	1600	0	800	0	0	400	0
Didinium nasutum	1200	3400	1800	900	800	400	1600	400	800

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	400	1200	900	400	400	0	800	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	2400	3400	800	0	400	0	400	800	800
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Rotifer	200	0	0	0	400	0	0	800	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
unidentified	400	0	0	0	0	0	0	0	800
Total density (No./L)	18700	14800	10200	7900	8200	3360	7800	5700	5800

Table 5. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 5 (Arookutty) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 5. Arookutty	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	1400	800	400	200	0	1600	1200	800	400
Tintinnopsis cylindrica	800	400	2400	1200	800	400	0	400	800
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	400	900	600	400	0	3400	1200	600	800
T. uruguayensis	900	1200	400	3400	400	0	800	1600	900
T. lohmanni	0	0	0	0	400	0	0	0	0
Tintinnidium incertum	12000	24000	10000	3400	800	1600	2400	800	400
T. primitivum	6400	8200	4000	3400	600	1200	900	24000	800
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	2400	800	0	0	400	0	0	0	400
Codonellopsis pusilla	0	0	0	0	0	0	400	0	0
Stenosemella sp.	0	0	0	0	0	0	0	800	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	400	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	1200	1600	3400	800	400	800	0	400	1600
Strombidium bilobum	400	800	400	0	0	800	1200	800	0
S. conicum	4000	2400	1600	800	400	0	1200	400	800
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0		0	0
Lohmaniella spiralis	800	400	900	1400	800	600	0	0	400
L. oviformis	0	0	0	0	0	0	0	0	0
Didinium nasutum	0	1200	0	900	800	400	0	0	0

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	1600	3200	1400	600	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	1200	800	400	0	0	400	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	400	800	0	0	400	0	0	0	0
G. spirale	1200	3400	800	400	0	0	400	800	400
Alexandrium insuetum	0	0	0	0	0	0	0	800	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	800	0	400	0	400	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	400	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Rotifer	400	0	0	0	800	400	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	400	800	1200	0	800	1400	0	0	0
unidentified	0	0	2400	0	1600	0	0	0	800
Total density (No. / L)	35100	49300	29300	17900	13000	14400	10300	32200	8500

Table 6. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 6 (Thanneermukkam) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 6. Thanneermukkam	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	24000	1200	800	400	0	600	3400	1200	1600
Tintinnopsis cylindrica	0	0	0	0	0	0	0	0	0
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	0	0	0	0	0	0	0	400	0
T. uruguayensis	0	0	0	0	0	0	0	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	3400	6000	4000	900	400	800	1600	800	400
T. primitivum	1200	4000	1600	800	400	400	900	400	800
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	6000	4800	1600	800	1600	800	400	400	800
Strombidium bilobum	400	0	0	0	0	0	0	0	0
S. conicum	2000	1200	3400	900	800	0	400	800	1800
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	800	0	0	400	0	0	0	0
Lohmaniella spiralis	1200	900	400	0	800	400	0	0	0
L. oviformis	0	0	0	0	0	0	0	0	0
Didinium nasutum	800	1200	800	3400	900	400	0	800	600
D. garguanta	400	0	0	0	0	0	0	0	0

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	800	400	0	0	0	900	400	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	0	0	600	0	0	0	0	0
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	400	0	200	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	400	0	800	400	0	0	0	0
unidentified	0	0	0	0	0	0	0	0	0
Total density (No./L)	40600	20900	12800	8600	5700	4300	7100	4800	6000

Table 7. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 1 (Fort Kochi) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 1. Fort Kochi	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	1200	800	600	400	0	800	400	800	0
Tintinnopsis cylindrica	0	500	0	800	0	400	0	400	800
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	0	400	800	400	0	0	400	600	0
T. uruguayensis	0	0	0	400	0	800	400	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	3400	1600	1400	1600	800	900	400	3200	4000
T. primitivum	0	400	800	600	400	0	0	400	600
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	400	0	0
Stenosemella sp.	0	0	0	0		0	100	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	400	0	0	0	0	0	0	0	0
Laboea strobila	4500	3000	800	600	1300	800	400	600	0
Strombidium bilobum	400	600	0	600	800	400	0	0	0
S. conicum	0	0	4000	0	800	0	400	4000	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	400	0	200	0	400	800	0	0
Lohmaniella spiralis	800	900	400	0	400	600	1400	0	0
L. oviformis	0	0	0	0	0	0	0	0	0
Didinium nasutum	4800	1200	0	600	400	0	3400	200	0
Spaerophrya magna	0	0	0	0	0	0	0	0	0

Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	600	1400	400	0	0	0	0	0	400
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	400	200	0	0	0	0	0
P. micans	0	400	800	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	600	3400	0	800	0	0	0	400	400
G. spirale	0	0	0	600	0	0	0	0	0
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	800	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	400	400	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Rotifer	**0**	0	0	0	0	0	0	0	0
Radiolaria		0	0	0	0	0	400	0	400
Crustacean nauplii		200	0	400	0	0	0	0	0
unidentified		0	0	0	0	0	0	0	0
Total density (No. / L)	16700	15200	10400	8200	4900	5900	9300	11000	6600

Table 8. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 2 (Azheekode) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 2. Azheekode	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	0	0	400	0	0	800	0	400	0
Tintinnopsis cylindrica	400	0	0	0	0	0	0	200	0
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	200	400	0	0	0	0	800	0	0
T. uruguayensis	0	0	0	0	0	0	0	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	3400	2100	800	0	4000	600	0	400	400
T. primitivum	900	1400	400	3400	2400	600	100	0	300
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	4000	2400	400	0	0	0	600	400	0
Strombidium bilobum	200	400	0	0	0	0	200	0	0
S. conicum	0	800	0	0	0	800	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	800	200	0	0	600	400	0	0	0
Lohmaniella spiralis	0	400	0	200	0	600	400	0	400
L. oviformis	0	0	0	0	0	0	0	0	0
Didinium nasutum	3200	6000	1200	4000	900	1400	400	0	1200

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	400	0	0	0
P. micans	200	0	0	400	0	0	0	0	400
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	600	0	1200	800	0	0	200	0	0
G. spirale	400	0	800	400	400	0	0	0	0
Alexandrium insuetum	0	0	0	400	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Rotifer	0	0	400	0	0	0	0	0	0
Radiolaria	600	200	200	0	0	0	200	400	0
Crustacean nauplii	800	0	200	0	0	0	400	0	0
unidentified	0	0	0	0	0	0	0	0	0
Total density (No. / L)	15700	14300	6000	9600	8300	5600	3300	1800	2700

Table 9. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 3 (Nedungadu) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 3. Nedungadu	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	3400	0	0	800	0	400	0	0	200
Tintinnopsis cylindrica	0	0	0	0	0	0	0	0	0
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	200	0	0	0	0	0	0	0	0
T. beroidea	200	1600	800	0	0	400	0	800	0
T. uruguayensis	0	400	0	0	0	200	0	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	2000	4000	800	1200	600	800	400	1200	400
T. primitivum	3400	1200	800	200	0	0	0	600	1400
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	600	400	0	0	200	0	0	200	0
Rhimostrombidium sp.	0	0	0	0	0	0	0	0	0
Strombidium bilobum	0	0	0	0	0	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0	0	0	0
Lohmaniella spiralis	600	800	400	0	0	0	400	0	0
L. oviformis	0	0	0	0	0	0	0	0	0

Didinium nasutum	1200	1600	0	400	0	200	0	200	0
Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	400	800	200	0	400	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	600	0	0	0	0	0	0	400	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	800	0	400	0	0	0	0	200	0
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Rotifer	0	0	0	0	0	0	0	600	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	0	0	200	0	0	0	0	0
Unidentified	0	0	0	0	0	0	0	0	0
Total density (No. / L)	13000	10400	4000	3000	800	2400	800	4200	2000

Table 10. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 4 (Varapuzha) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 4. Varapuzha	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	400	0	0	0	0	800	600	0	0
Tintinnopsis cylindrica	0	0	0	0	0	0	0	0	0
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	200	0	0	0	0	0	0	0	400
T. uruguayensis	0	0	0	0	0	0	0	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	1200	400	600	0	0	0	400	800	600
T. primitivum	2000	400	1200	3400	600	200	800	0	400
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	400	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	400	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	200	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	4000	400	200	800	0	0	400	0	0
Strombidium bilobum	0	0	0	0	200	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	400	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0	0	0	0
Lohmaniella spiralis	400	0	0	200	0	0	0	800	0
L. oviformis	0	0	0	0	0	0	0	200	0
Didinium nasutum	4000	1200	400	600	0	0	200	0	1200

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	200	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	400	0	0	200	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	400	0	0	0	0	0	200	0
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Rotifer	0	0	0	0	0	0	0	200	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
unidentified	400	0	0	0	0	0	0	0	0
Total density (No. / L)	12800	2800	3200	5200	1600	1200	2400	2200	2600

Table 11. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 5 (Arookutty) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 5. Arookutty	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	800	0	0	400	0	800	600	1200	0
Tintinnopsis cylindrica	1200	800	400	0	600	1200	0	0	0
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	200	0	0	0	0
T. beroidea	0	200	800	400	0	900	0	400	200
T. uruguayensis	0	800	200	0	0	0	0	0	400
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	24000	8000	2400	1200	800	900	1400	0	400
T. primitivum	8400	4000	600	2000	0	4000	800	900	0
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	200	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	0
Dictyocysta seshaiyai	0	200	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	200	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	900	1200	800	0	0	0	0	400	0
Strombidium bilobum	0	400	0	600	800	400	0	400	0
S. conicum	900	1200	0	200	400	0	800	400	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	800	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0		0	0
Lohmaniella spiralis	400	200	0	200	0	400	0	0	0
L. oviformis	0	0	0	0	0	0	0	0	0
Didinium nasutum	3400	800	0	0	0	1400	0	0	0

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	400	800	0	800	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	0	0	0	0	0	0	0	0
G. spirale	1400	2000	0	0	400	0	0	200	0
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Rotifer	0	0	0	0	200	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	800	600	400	0	200	0	0	0	0
unidentified	0	0	0	0	0	0	0	400	0
Total density (No. / L)	42200	21200	6200	6000	3600	10800	3600	4300	1000

Table 12. Density and distribution of various microzooplankton species encountered in bottom waters of Stn.6 (Thanneermukkam) with in 24-hour tidal cycle during Spring Intermonsoon

Stn. 6. Thanneermukkam	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	1200	800	0	0	0	400	200	0	400
Tintinnopsis cylindrica	0	0	0	0	0	0	0	0	0
T. nucula	0	0	0	0	0	0	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	0	0	0	0	0	0	0	0	0
T. uruguayensis	0	0	0	0	0	0	0	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	800	400	800	0	0	0	200	0	0
T. primitivum	400	4000	800	200	0	0	400	0	0
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	400	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	1200	800	0	0	200	0	0	200	0
Strombidium bilobum	0	0	0	0	0	0	0	0	0
S. conicum	400	600	0	0	400	0	200	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0	0	0	0
Lohmaniella spiralis	200	0	400	0	0	0	0	0	0
L. oviformis	0	0	0	0	0	0	0	0	0
Didinium nasutum	600	600	400	1200	0	0	0	400	0
D. garguanta	400	0	0	0	0	0	0	0	0

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	400	0	0	0	0	0
Gyrodinium glacialis	0	0	0	0	0	0	0	0	400
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	200	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	0	800	0	0	0	0	0	0
Unidentified	0	0	0	0	0	0	0	0	0
Total density (No. / L)	5200	7200	3200	1800	1200	400	1000	600	800

Table 13. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 1 (Fort Kochi) with in 24-hour tidal cycle during southwest monsoon

Stn. 1. Fort Kochi	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	1600	12000	1600	800	2400	0	0	1600	2400
Tintinnopsis cylindrica	3200	600	0	0	800	0	0	600	2400
T. nucula	6400	2400	0	4000	4000	0	4000	4000	4000
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	1600	0	0	1600	1600	0	0	1600	3200
T. uruguayensis	0	0	0	0	0	0	0	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	0	600	1600	800	0	0	0	0	0
T. primitivum	2400	0	0	0	2400	0	1600	600	800
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	600	0	0	0	0	0	0	0
Geleia nigriceps	0	600	0	0	0	0	0	0	0
Orthodonella sp.	0	6600	0	0	0	0	0	0	0
Euplotes sp.	0	600	0	0	0	0	0	0	0
Laboea strobila	0	0	0	800	0	900	800	0	0
Strombidium bilobum	0	0	0	0	0	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	1600	0	0	0	0	0	0
Lohmaniella spiralis	0	0	800	0	0	0	0	0	0
L. oviformis	0	0	0	0	0	900	600	0	0
Didinium nasutum	800	0	800	3200	1600	900	1600	800	1600

Spaerophrya magna	0	0	0	0	0	900	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	800
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	1800	0	800	0	900	0	600	1600
Gymnodinium sp.	0	600	0	0	0	0	0	0	0
Prorocentrum gracile	7200	2400	0	3200	3200	900	800	3200	5600
P. micans	0	1800	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	3200	1200	0	1600	1600	0	0	1200	2400
Alexandrium insuetum	0	600	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
unidentified	0	0	0	0	0	0	0	0	0
Total density (No. / L)	26400	32400	6400	16800	17600	5400	9400	14200	24800

Table 14. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 2 (Azheekode) with in 24-hour tidal cycle during southwest monsoon

Stn. 2. Azheekode	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	800	800	0	1600	1600	0	0	800	1600
Tintinnopsis cylindrica	1600	0	0	0	2400	0	0	2400	1600
T. nucula	2400	0	800	3200	3200	0	2400	0	3200
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	1600	0	0	1600	1600	800	0	0	0
T. uruguayensis	0	0	0	0	0	0	0	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	0	800	0	2400	0	0	0	0	0
T. primitivum	2400	0	0	0	800	2400	800	800	1600
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	800	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	0	0	0	0	0	0	0	0	0
Strombidium bilobum	0	0	0	800	0	0	3200	0	800
S. conicum	0	0	0	0	0	1600	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	400	0	0	0	0	0	0
Strobilidium minimum	0	0	400	0	0	0	0	0	0
Lohmaniella spiralis	0	800	800	0	0	0	0	0	800
L. oviformis	0	0	800	0	1600	0	0	0	0
Didinium nasutum	0	0	400	0	800	0	2400	0	0

Spaerophrya magna	0	0	0	1600	0	800	0	800	1600
Lagynphrya salina	0	0	0	0	0	1600	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	800
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	800	0	0	0	800
Gymnodinium sp.	0	0	0	0	0	0	0	800	1600
Prorocentrum gracile	0	0	0	0	0	2400	0	0	0
P. micans	3200	0	0	800	3200	0	800	2400	3200
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	0	0	0	0	800	0	0	0
Alexandrium insuetum	2400	800	0	1600	1600	0	0	1600	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis									
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Radiolaria	0	0	400	0	0	0	0	0	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
unidentified	0	0	1600	0	800	1600	0	0	0
Total density (No. / L)	14400	4000	5600	13600	18400	12000	9600	9600	17600

Table 15. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 3 (Nedungadu) with in 24-hour tidal cycle during southwest monsoon

Stn. 3. Nedungadu	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	800	2400	0	2400	0	0	0	2400	0
Tintinnopsis cylindrica	0	0	0	800	0	0	0	0	1600
T. nucula	0	0	0	0	2400	0	1200	1600	2400
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	0	0	0	0	800	2400	0	2400	0
T. uruguayensis	0	0	0	0	0	0	0	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	0	800	800	0	0	0	0	0	0
T. primitivum	0	0	0	0	1600	1600	0	800	800
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	800	0	0	0	0	0	0	0	0
Stenosemella sp.	3200	0	0	0	0	0	800	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	800	0	0	0	1600	0	800	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	0	0	0	1600	0	0	3200	0	0
Strombidium bilobum	0	0	0	0	0	800	0	400	0
S. conicum	800	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	2400	0	0	0
S. capitatum	0	0	0	0	0	0	800	0	0
Strobilidium minimum	800	0	800	0	0	0	0	0	800
Lohmaniella spiralis	0	0	800	0	0	0	0	0	0
L. oviformis	0	0	0	0	0	0	0	0	0
Didinium nasutum	800	0	0	800	0	0	0	1600	2400

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	800
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	800	800	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	0	800	0	800	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	2400	0	800	0	3200
P. micans	0	0	0	0	0	2400	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	0	0	0	1600	0	0	1600	0
Alexandrium insuetum	2400	0	0	800	0	0	0	0	0
A. tropicale	8800	0	0	2400	0	0	800	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	800	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	800	0	0	0	0	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
Unidentified	12800	800	0	1600	0	800	0	0	0
Total density (No. / L)	32800	4800	2400	10400	10400	12000	9200	11600	12000

Table 16. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 4 (Varapuzha) with in 24-hour tidal cycle during southwest monsoon

Stn. 4. Varapuzha	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	0	0	0	0	0	1600	0	0	800
Tintinnopsis cylindrica	0	0	800	0	0	0	0	0	0
T. nucula	5600	1120	0	224	0	800	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	0	0	0	0	0	0	0	800	0
T. uruguayensis	0	0	0	0	0	0	0	0	0
T. lohmanni	800	160	0	32	0	0	0	0	0
Tintinnidium incertum	0	0	0	0	1600	0	800	0	0
T. primitivum	0	0	0	0	0	0	0	0	0
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	1600	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	2400	0	0	0	0
Geleia nigriceps	800	160	0	32	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	0	0	0	0	0	0	1600	800	0
Strombidium bilobum	0	0	0	0	0	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0	0	0	0
Lohmaniella spiralis	0	0	0	0	0	0	0	0	0
L. oviformis	800	160	0	32	0	0	800	800	0
Didinium nasutum	0	0	0	0	0	1600	0	0	800

Spaerophrya magna	1600	320	0	64	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	1600	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	0	0	800	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	0	0	0	0	0	0	0	0
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	800	0
P. globulus	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
unidentified	0	0	0	0	0	0	0	0	0
Total density (No. / L)	9600	1920	2400	384	4000	4000	4000	4800	1600

Table 17. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 5 (Arookutty) with in 24-hour tidal cycle during southwest monsoon

Stn. 5. Arookutty	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	0	0	0	0	1600	0	0	0	0
Tintinnopsis cylindrica	0	800	1600	1600	0	0	1600	800	0
T. nucula	0	0	800	800	800	2400	0	0	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	800	1600	2400	800	2400	0	1600	0	1600
T. uruguayensis	800	2400	0	1600	0	0	0	0	0
T. lohmanni	0	0	0	3200	0	0	0	0	0
Tintinnidium incertum	2400	800	0	0	0	0	800	800	1600
T. primitivum	0	0	0	3200	1600	1600	0	0	0
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	2400	1600	0	0	0	0	0
Codonellopsis pusilla	0	800	0	0	0	0	800	0	0
Stenosemella sp.	0	0	3200	800	800	1600	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	0	1600	0	0	0	800	1600	0	0
Strombidium bilobum	0	0	0	800	1600	800	0	0	0
S. conicum	800	2400	0	0	0	0	2400	0	800
S. sphericum	0	0	0	0	0	0	0	800	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	800	1600	0	0	0	1600	0	0
Lohmaniella spiralis	800	0	3200	0	0	0	0	2400	1600
L. oviformis	0	0	0	800	0	1600	0	0	0
Didinium nasutum	0	1600	0	0	0	0	0	0	0
Spaerophrya magna	0	0	0	0	0	0	0	0	0

Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	800	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	1600	3200	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	0	0	0	0	0	0	0	0
Alexandrium insuetum	0	0	800	0	0	0	0	800	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	800	1600	0	1600	0	800	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	800	1600	0	0	0	1600	0	0
unidentified	2400	0	0	800	0	0	0	0	800
Total density (No. / L)	8000	14400	19200	18400	13600	8800	12800	5600	6400

Table 18. Density and distribution of various microzooplankton species encountered in surface waters of Stn. 6 (Thanneermukkam) with in 24-hour tidal cycle during southwest monsoon

Stn. 6. Thanneermukkam	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	0	0	0	800	0	800	0	0	800
Tintinnopsis cylindrica	0	0	0	0	0	0	0	0	0
T. nucula	0	0	800	0	0	0	0	0	0
T. minuta	0	0	0	0	800	0	800	0	0
T. beroidea	0	0	0	1600	0	0	0	800	0
T. uruguayensis	0	0	0	800	0	0	0	0	0
T. lohmanni	800	0	0	0	0	0	0	0	0
Tintinnidium incertum	0	0	0	0	0	0	0	0	0
T. primitivum	0	0	0	0	0	0	0	0	0
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	800	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	800	1600	0	0	0	0	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	800	0	0	0	0	0
Polykrikos kofoidi	0	0	0	1600	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	800	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	1600	800	0
Laboea strobila	0	0	0	0	0	0	0	0	0
Strombidium bilobum	800	0	0	800	0	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	3200	0	1600	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0	0	0	0
Lohmaniella spiralis	1600	0	0	0	0	1600	800	800	0
L. oviformis	0	800	0	0	0	0	0	0	800
Didinium nasutum	0	0	0	0	0	0	0	0	0

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	800	800	0	0	0	0
Halteria gradinella	800	800	0	0	800	0	0	1600	0
H. chlorelligera	0	0	0	0	0	800	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	0	0	800	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	0	0	0	0	0	0	0	0
Alexandrium insuetum	0	0	0	0	1600	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	800	0	0	800	0
Protoperidinium depressum	0	0	0	0	800	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	800	0	0	0	0
Noctiluca scintillans	800	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
unidentified	0	0	0	0	0	0	0	0	0
Total density (No. / L)	4800	5600	2400	8800	8000	3200	4000	4800	1600

Table 19. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 1 (Fort Kochi) with in 24-hour tidal cycle during southwest monsoon

Stn. 1. Fort Kochi	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	0	0	800	1600	0	800	1200	1600	0
Tintinnopsis cylindrica	0	0	0	2400	800	0	0	0	800
T. nucula	0	5600	1600	800	16000	8000	0	1600	1600
T. minuta	0	0	4000	0	0	0	0	0	0
T. beroidea	1600	0	4000	1600	0	800	0	2400	800
T. uruguayensis	800	2400	1600	0	800	800	0	0	0
T. lohmanni	1600	1600	0	0	2400	0	0	0	0
Tintinnidium incertum	0	800	800	2400	4000	0	1600	0	0
T. primitivum	3200	1600	800	800	0	800	2400	0	0
T. radix	0	800	0	0	0	800	0	0	0
T. tocantinensis	800	0	0	0	0	0	0	0	0
Codonella sp.	0	800	0	0	800	1600	0	0	0
Codonellopsis pusilla	1600	0	0	0	0	0	0	0	0
Stenosemella sp.	800	0	0	1600	0	800	0	800	0
Dictyocysta seshaiyai	0	0	0	0	800	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	0	0	0	0	0	800	0	0	0
Strombidium bilobum	800	0	0	0	800	0	0	0	0
S. conicum	0	0	0	0	0	0	1600	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	800	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0	2400	3200	0
Lohmaniella spiralis	800	2400	0	0	0	0	800	0	0
L. oviformis	0	800	0	0	800	0	1600	0	0
Didinium nasutum	0	1600	800	0	0	1600	2400	0	5600

Spaerophrya magna	0	0	800	0	0	0	0	0	0
Lagynphrya salina	0	800	0	0	0	0	0	0	0
Holophyra marina	1600	0	800	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	800	0	0	0	0
H. chlorelligera	800	0	0	0	0	800	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	0	0	0	0	2400
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	800	1600	0	800	0	0	0
P. micans	800	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	800	1600
Gyrodinium glacialis	800	0	1600	2400	2400	800	0	0	4000
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	800	0	0	0	0
P. leonis	0	0	0	0	800	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
unidentified	2400	0	800	0	0	800	0	0	1600
Total density (No. / L)	19200	19200	19200	15200	32000	20000	14000	10400	18400

Table 20. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 2 (Azheekode) with in 24-hour tidal cycle during southwest monsoon

Stn. 2. Azheekode	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	0	0	1600	800	0	2400	800	0	3200
Tintinnopsis cylindrica	0	0	0	0	0	0	0	0	0
T. nucula	0	0	800	0	0	0	0	0	0
T. minuta	800	160	0	1600	0	800	0	800	0
T. beroidea	1600	320	0	800	1600	0	0	0	0
T. uruguayensis	0	0	0	0	0	0	0	0	0
T. lohmanni	0	0	800	0	0	0	0	0	0
Tintinnidium incertum	0	0	800	0	2400	1600	800	1600	0
T. primitivum	1600	320	0	0	0	0	800	1600	0
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	800	0	1600
Codonella sp.	0	0	0	0	800	0	0	2400	0
Codonellopsis pusilla	800	160	0	800	0	0	0	800	800
Stenosemella sp.	1600	320	0	1600	0	800	0	0	1600
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	800	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	0	0	0	1600	0	0	800	0	0
Strombidium bilobum	0	0	0	0	0	0	0	0	0
S. conicum	0	0	0	0	0	0	1600	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	800	160	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	0	0	800	0	0
Lohmaniella spiralis	2400	480	800	0	2400	0	1600	0	0
L. oviformis	0	0	0	0	0	0	1600	0	800
Didinium nasutum	0	0	800	800	0	0	800	0	0

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	800	0	0	0	800	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	800	160	0	0	0	1600	0	0	800
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	800	160	0	0	0	0	0	0	0
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	800	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	800	0	0
Radiolaria	0	0	800	0	0	0	0	0	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
unidentified	800	160	1600	0	0	0	0	0	0
Total density (No. / L)	12000	2400	8800	8800	7200	7200	12000	8000	8800

Table 21. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 3 (Nedungadu) with in 24-hour tidal cycle during southwest monsoon

Stn. 3. Nedungadu	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	1600	0	2400	0	0	0	1600	0	2400
Tintinnopsis cylindrica	0	800	0	1600	0	0	0	0	0
T. nucula	0	3200	0	2400	800	0	0	0	0
T. minuta	800	0	0	0	0	0	0	0	0
T. beroidea	0	0	0	800	0	800	0	0	0
T. uruguayensis	0	0	0	0	0	800	0	0	0
T. lohmanni	0	1600	0	0	0	0	0	2400	800
Tintinnidium incertum	0	0	0	0	0	2400	1600	1600	0
T. primitivum	0	0	0	1600	0	0	0	0	0
T. radix	0	0	0	0	800	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	800	0	0	0	0	0	0
Stenosemella sp.	0	1600	0	800	1600	800	0	0	0
Dictyocysta seshaiyai	800	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	2400	0	1600	0	800	1600	0	0	0
Strombidium bilobum	0	800	0	0	0	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	3200	0	1600	0	0	800	0	0
Lohmaniella spiralis	0	0	0	0	0	0	0	0	0
L. oviformis	0	0	0	0	0	0	0	0	0
Didinium nasutum	0	0	0	0	1600	0	0	0	0

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	1600	0	0	0	800	0	0	0	0
Halteria gradinella	0	0	800	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	1600	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	1600	3200	0	0	0	0	2400	0
P. micans	0	0	0	0	0	800	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	0	0	0	1600	0	0	0	800
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	800	0	0	0	800	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Radiolaria	800	0	0	0	0	0	0	0	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
Unidentified	0	0	0	0	1600	0	0	0	800
Total density (No. / L)	8000	12800	9600	8800	9600	7200	6400	6400	4800

Table 22. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 4 (Varapuzha) with in 24-hour tidal cycle during southwest monsoon

Stn. 4. Varapuzha	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	0	0	800	0	0	0	0	0	0
Tintinnopsis cylindrica	800	0	0	0	0	0	0	0	0
T. nucula	0	4000	0	1600	0	1600	800	0	3200
T. minuta	0	0	0	800	0	800	0	0	0
T. beroidea	800	0	1600	0	0	0	0	0	800
T. uruguayensis	0	0	0	0	0	0	0	0	0
T. lohmanni	0	0	0	0	0	0	0	0	0
Tintinnidium incertum	0	0	0	800	1600	800	0	1600	800
T. primitivum	0	0	0	0	0	0	1600	0	0
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	800	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	0	0	2400
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	800	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	0	0	0	0	0	0	800	0	0
Strombidium bilobum	0	0	0	0	0	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	0	0	2400	0	0	1600	0
Lohmaniella spiralis	0	0	1600	0	0	0	0	0	800
L. oviformis	0	0	0	0	0	0	2400	0	0
Didinium nasutum	0	0	800	0	0	0	0	0	0

Spaerophrya magna	800	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	800	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	0	0	0	3200	800	0	0	1600
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	0	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
unidentified	2400	0	0	2400	0	0	0	800	0
Total density (No./ L)	4800	5600	4800	5600	8000	4000	5600	4000	9600

Table 23. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 5 (Arookutty) with in 24-hour tidal cycle during southwest monsoon

Stn. 5. Arookutty	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM	9:00 AM
Ciliates									
Mesodinium rubrum	0	0	0	800	0	1600	0	0	0
Tintinnopsis cylindrica	0	0	1600	0	0	0	800	1600	0
T. nucula	0	14400	0	4800	0	3200	2400	0	4000
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	800	0	0	800	0	800	0	0	0
T. uruguayensis	800	2400	1600	800	0	0	1600	0	3200
T. lohmanni	0	800	0	0	0	1600	0	0	800
Tintinnidium incertum	800	1600	800	0	800	0	0	800	800
T. primitivum	2400	3200	2400	800	0	0	0	1600	4000
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	800	800	0	0	0	0	0	0	0
Codonella sp.	0	1600	800	0	0	800	0	800	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	1600	0	0	1600	1600	0	2400	0	2400
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	800	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	0	0	0	0	0	0	0	0	0
Strombidium bilobum	0	0	0	0	0	0	0	0	0
S. conicum	0	0	0	0	0	0	0	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	0	0	1600	0	800	0	1600	800	0
Lohmaniella spiralis	800	800	0	0	0	2400	0	0	0
L. oviformis	0	0	0	0	0	800	0	0	800
Didinium nasutum	0	800	1600	2400	0	0	800	0	0

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	0	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	0
Dinoflagellates									
Amphidinium sp.	0	0	0	4000	0	0	0	0	0
Gymnodinium sp.	0	0	0	1600	0	0	0	0	0
Prorocentrum gracile	0	0	800	4000	0	0	2400	800	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	800	0	1600	0	2400	800	0	1600	800
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	800	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	800	0	0	0	0	0	0	0	0
Pyrophacus sp.	0	0	0	0	0	0	0	0	800
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	1600	1600	0	0	0	0	0	0	800
unidentified	6400	0	0	0	0	0	0	0	4800
Total density (No./ L)	17600	28000	13600	21600	6400	12000	12000	8000	23200

Table 24. Density and distribution of various microzooplankton species encountered in bottom waters of Stn. 6 (Thanneermukkam) with in 24-hour tidal cycle during southwest monsoon

Stn. 6. Thanneermukkam	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	**12:00 AM**	**3:00 AM**	**6:00 AM**	**9:00 AM**
Ciliates									
Mesodinium rubrum	0	0	800	0	800	800	0	0	1600
Tintinnopsis cylindrica	0	0	0	0	0	0	0	0	0
T. nucula	1600	0	0	1600	0	0	3200	1600	0
T. minuta	0	0	0	0	0	0	0	0	0
T. beroidea	0	0	1600	0	0	0	800	0	0
T. uruguayensis	0	1600	0	0	0	0	0	0	0
T. lohmanni	0	0	0	0	0	0	1600	800	800
Tintinnidium incertum	0	0	0	0	0	0	0	0	0
T. primitivum	0	0	0	0	1600	0	0	0	0
T. radix	0	0	0	0	0	0	0	0	0
T. tocantinensis	0	0	0	0	0	0	0	0	0
Codonella sp.	0	0	0	0	0	0	0	0	0
Codonellopsis pusilla	0	0	0	0	0	0	0	0	0
Stenosemella sp.	0	0	0	0	0	0	1600	0	0
Dictyocysta seshaiyai	0	0	0	0	0	0	0	0	0
Petalotricha ampulla	0	0	0	0	0	0	0	0	0
Polykrikos kofoidi	0	0	0	0	0	0	0	0	0
Dileptus bivacuolatus	0	0	0	0	0	0	0	0	0
Nassula notata	0	0	0	0	0	0	0	0	0
Geleia nigriceps	0	0	0	0	0	0	0	0	0
Orthodonella sp.	0	0	0	0	0	0	0	0	0
Euplotes sp.	0	0	0	0	0	0	0	0	0
Laboea strobila	0	0	0	800	0	0	0	0	0
Strombidium bilobum	800	0	0	0	0	0	800	2400	0
S. conicum	0	0	0	0	1600	0	800	0	0
S. sphericum	0	0	0	0	0	0	0	0	0
S. capitatum	0	0	0	0	0	0	0	0	0
Strobilidium minimum	1600	0	0	0	0	800	0	0	0
Lohmaniella spiralis	800	800	1600	0	0	1600	1600	0	1600
L. oviformis	0	0	0	0	0	800	800	0	0
Didinium nasutum	0	0	800	0	0	0	0	0	0

Spaerophrya magna	0	0	0	0	0	0	0	0	0
Lagynphrya salina	0	0	0	0	0	0	0	0	0
Holophyra marina	0	0	0	0	0	0	1600	0	0
Halteria gradinella	0	0	0	0	0	0	0	0	0
H. chlorelligera	0	0	0	0	0	0	0	0	800
Dinoflagellates									
Amphidinium sp.	0	0	0	800	0	0	0	0	0
Gymnodinium sp.	0	0	0	1600	0	0	0	0	0
Prorocentrum gracile	0	0	0	0	0	0	0	0	0
P. micans	0	0	0	0	0	0	0	0	0
P. lima	0	0	0	0	0	0	0	0	0
Gyrodinium glacialis	0	0	0	0	0	0	0	0	0
Alexandrium insuetum	0	0	0	0	0	0	0	0	0
A. tropicale	0	0	0	0	0	0	0	0	0
A. monilatum	0	0	0	0	0	0	0	0	0
Protoperidinium depressum	0	0	0	0	0	0	0	0	0
P. leonis	0	0	0	0	0	0	0	0	0
P. globulus	0	0	0	0	0	0	0	0	0
Noctiluca scintillans	5600	0	0	800	0	0	0	0	800
Pyrophacus sp.	0	0	0	0	800	800	0	0	0
Radiolaria	0	0	0	0	0	0	0	0	0
Crustacean nauplii	0	0	0	0	0	0	0	0	0
unidentified	2400	800	0	0	0	0	5600	0	1600
Total density (No./L)	12800	3200	4800	5600	4800	4800	18400	4800	7200