

**Response of microzooplankton community to the hydrographical transformations in the coastal waters off Kochi, along the southwest coast of India**

**A. Anjusha<sup>a</sup>, R. Jyothibabu<sup>a\*</sup>, L. Jagadeesan<sup>b</sup>**

<sup>a</sup>CSIR - National Institute of Oceanography, Regional Centre, Kochi - 682018

Phone +91 (0) 484 2390814, Fax +91 (0) 484 2390618

\*Corresponding author: rjyothibabu@nio.org

**Abstract :**

The response of microzooplankton to the hydrographical transformations in the coastal waters off Kochi, along the South-west coast of India, has been presented in this study. Sampling was carried out during January - December 2014 at four locations along a transect up to a depth of 30m perpendicular to the Kochi coastline. Seasonal hydrographical features in the study region were chiefly influenced by two processes - estuarine flux in the surface layers and coastal upwelling in the subsurface layers. Coastal upwelling prevailed during the Southwest Monsoon, but its impact was impeded in the surface waters by the estuarine influx. Relatively high phytoplankton biomass was obtained in the offshore locations during the Southwest Monsoon which was primarily associated with the coastal upwelling. On the other hand, in the near-shore locations, plankton production was mainly associated with the high-nutrient, low-saline estuarine plume water. During the Southwest Monsoon, high estuarine influx and phytoplankton biomass led to increased abundance of microzooplankton community in the surface waters. The abundance of microzooplankton was low during the pre-monsoon, which seems to be impacted by the high top-down control of carnivorous copepods. A total of 59 species of microzooplankton were identified, of which 49 were species of ciliates and 10 were heterotrophic dinoflagellates. This study reveals the important role of aloricate ciliates in the coastal waters off Kochi, which was hitherto unknown. The overall results suggest the existence of a multivorous food web in the study region, which could be a general feature along the west coast of India.

**Key words** - Microzooplankton, Arabian Sea, coastal waters, upwelling, estuarine flux, aloricate ciliates

## 1. Introduction

South-eastern Arabian Sea (SEAS) experiences seasonally reversing winds and currents, which influence the plankton production and fisheries in the region. The general hydrography and the phytoplankton stock in the SEAS is reasonably well-studied; the basic understanding that has emerged from these studies indicates a significantly high phytoplankton biomass during the Southwest Monsoon (June - September) as compared to the rest of the year (Jyothibabu et al., 2010). The high plankton stock in the SEAS during the Southwest Monsoon is closely linked to the coastal upwelling, the signatures of which are the surfacing of cool, nutrient-rich, hypoxic waters towards the coast. Prior to the Southwest Monsoon (Pre-monsoon: March - May), SEAS has high SST ( $>30^{\circ}\text{C}$ ), which generates thermally-stratified, low-nutrient ocean surface layers, resulting in low phytoplankton biomass (Nair et al., 1992; Madhupratap et al., 2001; Jyothibabu et al., 2010). In the near-shore waters along the Southwest coast of India, large freshwater influx from numerous rivers (around 50) leads to a significant increase in nutrient concentration and plankton production (Jyothibabu et al., 2010).

Microzooplankton (MZP) are heterotrophic microplankton (size 20-200  $\mu\text{m}$ ), which includes both protozoan and metazoan components (Dussart, 1965). Ciliates are the major protistan component of microzooplankton in estuaries (Dolan and Gallegos, 2001; Jyothibabu et al., 2006), coastal bays (Yang et al., 2008; Burkil et al., 1987; Anjusha et al., 2013) and open ocean waters (Calbet, 2008; Montagnes et al., 2010). Several studies have been extensively carried out on microzooplankton from different parts of the world (Dolan et al., 2002; Verity et al., 2002; Thompson, 2004; Urrutxurtu, 2004; Godhantaraman and Uye, 2003). Studies from India are mostly focused on tintinids, the loricate ciliates that are abundant in estuaries and coastal waters (Damodara Naidu, 1977; Krishnamurthy and Santhanam, 1975; Srinivasan et al., 1988; Godhantaraman, 1994, 2001, 2002). However, considering the difficulties in sampling and identification of the aloricate ciliates due to their small size and delicate body structure, these components are usually missed out or remain unaccounted for in the routine quantification of microzooplankton. The seasonal ecology of microzooplankton as a whole, in the Arabian Sea, was addressed by Gauns et al., (1996); Jyothibabu et al., (2008a) and Ashadevi et al., (2010). On the other hand, the microzooplankton community and its seasonal ecology in the near-shore waters along the Indian Southwest coast remains unknown. Therefore, in this paper, the microzooplankton community and its ecology in the near-shore waters along the Southwest coast of India have been addressed. The objectives of the present study are (a) to study the seasonal ecology of microzooplankton in the coastal waters off Kochi; (b) to understand the impact of freshwater influx on the microzooplankton community structure in the near-shore

waters along the Southwest coast of India and (c) to understand the interrelationship between the microzooplankton and mesozooplankton, especially copepods inhabiting the coastal waters off Kochi.

## **2. Materials and methods**

### **2.1. Study area**

Hydrography of the study area is significantly influenced by seasonal changes during the Southwest Monsoon-associated rainfall. During Southwest Monsoon (June- September), wind-driven upwelling occurs in the study region, which brings cool, nutrient-enriched subsurface water to the surface, enhancing the phytoplankton production (Bhattathiri et al., 1996; Jyothibabu et al., 2008a). During the Southwest Monsoon, in addition to the upwelling, a large amount of estuarine /river influx influences the quality of surface waters of the coastal Arabian Sea (Banse, 1959; Muraleedharan and Prasannakumar 1996; Jyothibabu et al., 2008a). During the Northeast Monsoon (December-February), Northeast winds blow over the region bringing significantly low rainfall in the study domain compared to the Southwest Monsoon and leading to low phytoplankton production. Pre-monsoon (March – May) is characterized by weak winds and high solar radiation leading to a thermally stratified water column (Prasannakumar and Prasad, 1996). As a result, the phytoplankton production is lowest during the Pre- Southwest Monsoon compared to the rest of the period.

### **2.2. Sampling**

Four locations were sampled in the shelf waters perpendicular to the Kochi coastline, for a period of one year (January - December of 2014) (Figure 1). Stations 1 and 2 were closer to the coast and shallower (~3 and 5 Km from the coastline and located at 6 m and 12 m depth, respectively), whereas locations 3 and 4 were further from the coast and deeper (~25 and 40 Km and located at 25 and 30 m depth, respectively). Therefore, for convenience, locations 1 and 2 have been denoted as ‘inshore locations’ and locations 3 and 4 as ‘offshore locations’. Due to technical reasons, the field sampling was interrupted in June and November. For generalizing the hydrographical conditions and explaining the biological observations with more clarity, the sampling periods were classified into 3 seasons, namely, Pre-monsoon (March – May), Southwest Monsoon (June - September) and Northeast Monsoon (December - February).

### **2.3. Hydrographical parameters**

The vertical profiles of temperature and salinity in the study area were recorded by a Conductivity Temperature Depth (CTD) profiler (Seabird Electronics Sea sat, SBE 911 Plus, USA). Ocean surface

wind data (ASCAT) was retrieved from the Ocean Watch LAS server (<http://oceanwatch.pifsc.noaa.gov/las/servlets/index>). Monthly rainfall in Ernakulum and Alappuzha, two major districts surrounding the catchment areas of the Koch backwaters were downloaded from Indian Meteorological Department (IMD). Water samples were collected from discrete depths in the water column for measuring chemical and biological parameters using Niskin samplers. Water samples for chemical parameters (dissolved oxygen and nutrients) were collected from surface, middle and near-bottom (1m above from sea bottom), whereas, biological samples (chlorophyll *a* and micro-zooplankton) only from the surface and near-bottom. Surface salinity was measured using an autosal (Model TSK, accuracy  $\pm 0.001$ ). Dissolved oxygen was estimated following Winkler's titration method. Macronutrient (nitrate) was measured spectrophotometrically following standard methods (Grasshoff et al., 1983). The turbidity of the water column was measured using a turbidity meter (Eutech TN100) based on nephelometric principles.

## **2.4. Biological parameters**

### **2.4.1. Phytoplankton biomass (Chlorophyll *a*)**

2-5 L water samples were collected from two depths (surface and subsurface) for the estimation of chlorophyll *a*. The total chlorophyll *a* (Chl*a*) was measured by concentrating 1 L of water samples on Whatman GF/F filters (0.7 $\mu$ m) and subsequent extraction using 10 ml 90% acetone. The extracted Chl*a* was measured using a Trilogy Turner fluorometer following the standard procedure (UNESCO, 1994). The size-fractionated (macro, micro, nano and pico) Chl*a* was estimated adopting the serial filtration of water samples (Jyothibabu et al., 2013). The Chl*a* present in the phytoplankton cells was extracted in 90% acetone and measured using a calibrated Turner designed fluorometer (UNESCO, 1994).

### **2.4.2. Microzooplankton**

For the collection of microzooplankton, water samples (1L) were collected from the same depths as that for chlorophyll *a*. Subsequently, 3–8% of acid Lugol's iodine was added into these samples for preservation, post which the samples were brought to the laboratory for further analysis. These samples were then concentrated by gravity settling up to 40 ml and then up to 10 ml over the next 2 days. 3 subsamples of one ml each were analyzed in a Sedgwick rafter counting chamber under an inverted epifluorescence microscope (Olympus IX 51) equipped with an image analyzer. The organisms present in the samples were identified as functional groups viz., ciliates (CTS), heterotrophic dinoflagellates (HDF), crustacean nauplii (CNP), crustacean eggs (CES), molluscan larvae (MLL), sarcordines (SDS) and rotifers (RFS). CTS and HDF were identified up to species

level following available literature (Kofoid and Campell, 1939; Steidinger and Williams, 1970; Subrahmanyam, 1971; Maeda, 1986; Krishnamurthy et al., 1995) and photomicrographs were taken. The biovolume of ciliates and heterotrophic dinoflagellates were estimated using the image analyzer, and the organic carbon content was calculated by adopting standard conversion factors (UNESCO, 1994). The organic carbon content of the copepod nauplii was estimated using standard conversion factor available in the literature (UNESCO, 1994). Among dinoflagellates, only obligate heterotrophic individuals were considered in the present study, whereas the mixotrophic ciliate *Myrionectum rubrum* was included.

### **2.4.3. Mesozooplankton**

Mesozooplankton (20- 200  $\mu\text{m}$ ) samples were collected using horizontal hauls of WP-2 net (mesh size: 200  $\mu\text{m}$  and mouth area 0.28  $\text{m}^2$ ). 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 zooplankton biomass was measured following the standard procedure of displacement volume method after removing large detritus particles (Harris et al., 2000). The samples were then preserved in 4% formalin in seawater for further analysis. Sub-samples (50%) of the zooplankton were made using a Folsom splitter and they were sorted up to various taxonomic groups. The density of each group was calculated as per the standard procedure (Postel et al., 2000). Copepods were identified down to the species level based on standard literature (Conway et al., 2003; Kasturirangan, 1963; Sewell, 1999; Tanaka, 1956). Feeding habit of major copepod species were determined based on standard literature (Rakshesh et al., 2008; Richardson et al., 2006; Broglio et al., 2004; McKinnon and Ayukai, 1996; Jagadeesan et al., 2017) to understand the impact of the copepod feeding on microzooplankton.

## **2.5. Statistical analysis**

### **2.5.1. Diversity indices**

Diversity is an expression of how individuals in a community are distributed in subsets/ groups. Diversity decreases in cases where one or a few groups dominate in a community. To mathematically analyze and compare changes in aquatic communities due to environmental influence, species diversity indices are used as important tools. The diversity of plankton communities were represented using three common diversity indices (i) Pielou evenness ( $J^0$  – Pielou, 1969), (ii) Margalef richness, ( $d$  - Margalef 1968) and (iii) Shannon-Wiener diversity ( $H^0$  – Shannon and Wiener, 1949).

### **2.5.2. Redundancy analysis**

The interconnection between the microzooplankton components and hydrographical parameters were analyzed using redundancy analysis (RDA, CANOCO 4.5). For the present statistical treatment, the detrended correspondence analysis (DCA) was carried out initially to select the most suitable ordination technique. The DCA showed axis gradient length  $<2$ , which suggested that linear multivariate RDA was suitable for the present case (Leps and Smilauer, 2003). The biological variables were log transformed prior to the analysis. Monte Carlo permutation tests (499 unrestricted permutations) were carried out to test the significance of ordination ( $p < 0.05$ ). The RDA analysis results were represented in the form of Triplots with environmental variables represented by arrows and stations by points. The direction of arrow coincides with the increase in corresponding parameters, species density and environmental variables (Leps and Smilauer, 2003).

## **3. Results**

### **3.1. Environmental parameters**

#### **3.1.1. Wind speed and Rainfall**

Wind was weak ( $<3 \text{ ms}^{-1}$ ) during the Pre-monsoon period, whereas it was strong ( $>6 \text{ ms}^{-1}$ ) during the Southwest Monsoon period; later during that period, the wind speed decreased. The rainfall pattern showed a dry period during Jan- May and a wet period during the rest of the year. The peak rainfall was noticed during June - August period (Supplementary Figure 1).

#### **3.1.2. Temperature and salinity**

The vertical distribution of temperature in the study area is presented in Figure 2. The entire water column was warm and temperature recorded was  $>29^\circ\text{C}$  during the Pre-monsoon, which decreased gradually during the Southwest Monsoon period and was found to be  $25^\circ\text{C}$ . The surface and subsurface temperature differences were minimal ( $<1^\circ\text{C}$ ) during the Pre-monsoon but during the Southwest monsoon, this difference was  $1\text{-}2^\circ\text{C}$  in inshore location and  $3\text{-}5^\circ\text{C}$  in the offshore locations. The prominent up-sloping of the cool subsurface waters was observed in July and September in the entire study area, which indicated that coastal upwelling processes were active there during the Southwest Monsoon. Spatially, inshore locations were warmer compared to offshore locations due to the freshwater influx in the former. Temperature gradually increased after the Southwest Monsoon and reached  $\sim 29^\circ\text{C}$  during the Northeast Monsoon.

Freshwater/estuarine influx from the adjacent Kochi backwaters chiefly influenced the distribution of salinity in the study area (Figure 3). During the Pre-monsoon period, low rainfall and

estuarine flux in the study area led to lesser freshwater dilution and surface salinity was found to be  $32.89\pm 0.73$  (location 1) &  $34.3\pm 0.21$  (location 2) in the inshore locations while it was  $34.17\pm 0.30$  (location 3) and  $34.30\pm 0.04$  (location 4) in the offshore regions. The changes in estuarine influx associated with the seasonal rainfall drastically altered salinity distribution in the entire study area, especially during the Southwest Monsoon. The surface salinity significantly declined ( $<15$ ) in the inshore locations during the peak discharge period during the Southwest Monsoon. During the Northeast Monsoon period, the estuarine flux to the study area gradually decreased and the salinity became  $29.93\pm 0.85$  (location 1) and  $33.69\pm 0.32$  (location 2) at the inshore regions and  $33.35\pm 1.04$  (location 3) and  $33.75\pm 0.98$  (location 4) in the offshore region (Figure 3). Throughout the study, there was a gradient in salinity from the inshore to the offshore locations. However, the temporal variations in salinity at all four locations were governed by the seasonal change in the climate, especially rainfall in the region. During the Pre-Monsoon period, the spatial difference of salinity at all locations was the lowest, whereas, during the Southwest Monsoon period, the spatial differences in salinity was quite significant in the study region. The surfacing of the high saline (35) water masses was observed during the Southwest Monsoon period; this even reached the surface waters in September, especially in the offshore regions.

### **3.1.3. Turbidity, Nitrate and Dissolved oxygen**

During the Southwest Monsoon, both estuarine influx associated with the increased rainfall and coastal upwelling processes altered nutrient availability and turbidity in the study locations. During Pre-monsoon, the water column was clear in the environment except in the near-shore locations ( $\sim 5$  NTU in location 1) and had relatively less nutrient (Figure 4 and Supplementary Table 1) in the surface ( $<1 \mu\text{M}$  in nitrate) and subsurface layers ( $<2 \mu\text{M}$  in nitrate). During the Southwest Monsoon, water column became more turbid ( $\sim 8$  NTU in inshore waters and  $\sim 2.6$  NTU in coastal locations) and nitrate concentration was high (2- 5 folds higher than Pre-monsoon) due to combined effect of the coastal upwelling and estuarine influx. During the Northeast Monsoon period, the turbidity in this study area was moderate ( $\sim 5$  NTU in inshore locations) and the nutrient concentrations in surface and subsurface layers decreased compared to the levels observed during the Southwest Monsoon period (Figure 4; Supplementary Table 1). Irrespective of the season, inshore locations were more turbid and richer in nutrients as compared to the offshore locations. The surface water column was well-oxygenated during the entire study period (Figure 5). Subsurface oxygen values were found to be saturated during the Pre-monsoon period, later decreasing during the peak Southwest Monsoon. In July and September, dissolved oxygen concentrations reached hypoxic levels in the subsurface waters. Spatially, dissolved oxygen concentration in surface waters was higher at inshore locations as

compared to offshore ones, due to their closeness to the estuarine inlet. In subsurface waters, hypoxic conditions were more prominent in the offshore locations compared to the inshore ones, indicating its linkage with the coastal upwelling process (Figure 5).

## **3.2. Biological parameters**

### **3.2.1. Phytoplankton biomass (Chlorophyll *a*)**

Chlorophyll *a* (Chl*a*) was low during the Pre-monsoon period, increasing by 2 to 5 folds during the Southwest Monsoon period. The seasonal increase was much higher in the inshore locations compared to the offshore ones (Figure 6). During most of the sampling periods, Chl*a* was higher in the inshore locations compared to the offshore ones. During the peak Southwest Monsoon, high chl.*a* was found at locations 2 and 3, which was related to the mixing of estuarine flux and coastal upwelling inputs. The highest concentration of Chl*a* in the entire study period was found in September at location 3 (27.6  $\mu\text{g L}^{-1}$ ) followed by location 2 (22.3  $\mu\text{g L}^{-1}$ ); this was associated with a mixed bloom of diatoms (*Fragilaria*, *Coscinodiscus*) and *Chattonella marina* (Raphidophyceae).

In terms of Chl*a* contribution to the total autotrophic community, nano-plankton contributed the highest, followed by micro-plankton, pico-plankton and macro-plankton (Supplementary Figure 2). During the pre-monsoon, the micro- and macro-phytoplankton chlorophyll was low, but their concentrations increased several folds during the Southwest Monsoon period as a response to the high nutrient and light availability. During the peak Southwest Monsoon period, larger diatoms (*Fragilaria sp.* and *Coscinodiscus sp.*) formed a bloom in the entire study area, which contributed to the noticeable increase in the macro-fraction of Chl*a* during the period. In general, smaller phytoplankton forms dominated (nano) the contribution to total chlorophyll *a* content during the pre-monsoon and Northeast Monsoon period due to low nutrient availability. On the other hand, during the Southwest Monsoon, both micro and meso-sized phytoplankton forms increased several folds due to high nutrient availability. Seasonal variations in the subsurface Chl*a* (total and fractionated) distribution pattern was in accordance with the surface Chl*a*.

### **3.2.2. Microzooplankton**

#### **3.2.2.1. Composition**

Microzooplankton (MZP) community was composed of both protozoans and metazoans. Protozoans were the dominant MZP group and were composed mainly of ciliates (~76%) and heterotrophic dinoflagellates (~23%). Crustacean nauplii (copepod nauplius) and fish eggs were the dominant metazoans. Altogether, 59 species of microzooplankton were recorded from the surface waters (49 ciliates and 10 heterotrophic dinoflagellates) and 57 species from the subsurface waters



(50 ciliates and 7 heterotrophic dinoflagellates). Out of the 49 species of ciliates recorded in the surface waters, 29 were loricate ciliates (tintinnids) while, significantly, as many as 20 of the remaining were aloricate ciliates (Table 1). Loricate ciliates were represented by the order Choreotrichida with 11 families included under it. Based on the morphology of lorica, ciliates (tintinnids) were grouped into agglomerated and hyaline (non-agglomerated). Agglomerated tintinnids were comprised mainly of *Codonellopsis ostenfeldii*, *Tintinnidium primitivum* and *Tintinnopsis beroidea*. Hyaline tintinnids recorded in the present study include *Dadayiella bulbosa* and *Eutintinnus lusus undae*. Importantly, *Tintinnidium primitivum* was found to be the most dominant tintinnid during the entire study.

During the Pre-monsoon, a total of 38 microzooplankton species were recorded in which 17 species were loricate ciliates (10 agglomerated and 7 hyaline), 12 were aloricate ciliates while the remaining 9 species were heterotrophic dinoflagellates (Supplementary Table 2). During the Southwest Monsoon, a total of 47 species of microzooplankton were recorded, in which 20 species were loricates (13 agglomerated and 7 hyaline), 18 were aloricates and 9 were heterotrophic dinoflagellates (Supplementary Table 3). During the Northeast Monsoon, a total of 40 species of microzooplankton were recorded in which 21 (13 agglomerated and 8 hyaline) species were loricates, 12 were aloricates and 6 were heterotrophic dinoflagellates (Supplementary Table 4). *Noctiluca scintillans* was present in the study area during the Southwest Monsoon, with their abundance increasing in July and September. The highest contribution of heterotrophic dinoflagellates to the total microzooplankton community was found to be during the Southwest Monsoon (23%). Spatial and seasonal variations were evident in the microzooplankton composition. Irrespective of seasons, aloricate ciliates dominated the near-shore locations (Figure 7 and 8). In the surface waters, the highest number of aloricate ciliate species was found during the Southwest Monsoon and the Northeast Monsoon (12 each) followed by the Pre-monsoon (10). Aloricate ciliates were composed of 8 families and 15 species.

The orders of aloricate ciliates that contributed significantly were Choreotrichida, Oligotrichida, and Cyclotrichida, whereas the contribution from orders Hypotrichida, Tontonnida and Halteridae was low. Oligotrich ciliates occurring during the Southwest Monsoon (eg. *Strombidium conicum* and *S. wulffi*) were found to have larger size than those observed during the Pre-monsoon. Cyclotrich mixotrophic ciliate *Myrionectarubra* and hypotrich ciliate *Euplotes sp.* were observed only during the Southwest Monsoon and their density was generally high in the month of September at location 1 (~350 No.L<sup>-1</sup>). Small ciliate *Lohmaiella spiralis* and *Strobilidium minimum* were the dominant aloricate choreotrichid during the Southwest Monsoon. Aloricate choreotrich,

*Strombidinopsis acuminatum* dominated in this study area during the Northeast Monsoon & Pre-monsoon periods (Supplementary Tables 2-4).

### 3.2.2.2. Microzooplankton abundance

Spatial and temporal variations in microzooplankton abundance were evident in the study area. Irrespective of seasons, total microzooplankton abundance was higher at the inshore locations compared to the offshore ones (Figure 7 and 8). Both loricates and aloricates were more abundant in the inshore locations, where their abundance was significantly higher than in the offshore locations (Figure 7 and 8). The microzooplankton abundance in the surface waters was maximum during the Southwest Monsoon (av.  $3100 \pm 938$  No.L<sup>-1</sup>) and the lowest during the Pre-monsoon (av.  $800 \pm 208$  No.L<sup>-1</sup>). The microzooplankton abundance in the subsurface waters was the exact opposite (Figure 8), with the highest abundance of microzooplankton found during Pre-monsoon (av.  $1967 \pm 615$  No.L<sup>-1</sup>) and the lowest during the Southwest Monsoon (av.  $442 \pm 391$  No.L<sup>-1</sup>).

The aloricate ciliate abundance was noticeably higher during the Southwest Monsoon (av.  $1425 \pm 928$  No.L<sup>-1</sup>) as compared to Pre-monsoon (av.  $866 \pm 152$  No.L<sup>-1</sup>). At inshore locations, the abundance of loricate and aloricate ciliates was significantly higher during the Southwest Monsoon as compared to the pre-monsoon period (Figure 7). High abundance of agglomerated tintinnids were found in the inshore locations compared to the offshore location. Hyaline tintinnids were almost equally distributed in the entire study area during the Pre-monsoon. They were comparatively less in abundance during the Southwest Monsoon and completely absent during the Northeast Monsoon at inshore locations.

Temporal variations in the abundance of microzooplankton in the subsurface waters differed from the surface water (Figure 8). The highest abundance of microzooplankton in the subsurface layer was found during the pre-monsoon and the least during the Southwest Monsoon, an observation that appears related to the upwelling-associated hypoxic conditions during the latter period. During the Southwest Monsoon, the total abundance of microzooplankton in the subsurface waters was almost half of the levels observed during Pre-monsoon (Figure 8). The abundance of both loricate and aloricate ciliates were found to have diminished in the subsurface waters during the Southwest Monsoon (Figure 8). In the subsurface layer, the lowest abundance of both loricate and aloricate ciliates was observed at location 4 during the Peak Southwest Monsoon period.

The abundance of heterotrophic dinoflagellate was higher at the inshore locations as compared to the offshore locations. During the Pre-monsoon period, the abundance of heterotrophic dinoflagellates in the surface and subsurface waters were comparable, but was not so during the

Southwest Monsoon, when noticeably higher abundance of heterotrophic dinoflagellates was found in the surface water. On the other hand, the abundance of heterotrophic dinoflagellates during the Northeast Monsoon was found to be higher in the subsurface waters compared to the surface (Figure 7 and 8). The most abundant heterotrophic dinoflagellate during the Pre-monsoon and Northeast Monsoon was *Protoperidinium divergence*, whereas *Noctiluca scintillans* was the most abundant one during the Southwest Monsoon.

### 3.2.2.3. Microzooplankton Biomass

Like abundance, the microzooplankton biomass also was generally higher during the Southwest Monsoon period compared to the pre-monsoon and Northeast Monsoon periods (Table 2). Biomass of microzooplankton during the present study period ranged from 6.8-25.6 mg C m<sup>-3</sup>. Spatially, microzooplankton biomass was higher at the inshore locations. The highest microzooplankton biomass recorded during the Pre-monsoon, Southwest Monsoon and Northeast Monsoon periods were 15 mg C m<sup>-3</sup>, 25.6 mg C m<sup>-3</sup> & 15.2 mg C m<sup>-3</sup>, respectively. Ciliates were the major contributors of the total microzooplankton biomass, followed by the copepod nauplius (Table 2). Among ciliates, >50% of the biomass was contributed by the aloricate ciliates during the pre-monsoon and Southwest Monsoon, whereas it was done so by loricate ciliates during the Northeast Monsoon. The heterotrophic dinoflagellate contribution to the total microzooplankton biomass was comparatively low throughout the study period. The highest biomass value of heterotrophic dinoflagellate was obtained at location 1 (1 mg C m<sup>-3</sup>) during the Southwest Monsoon and the lowest at location 4 during the Pre-monsoon (0.22 mg C m<sup>-3</sup>). The contribution of copepod nauplii to the total microzooplankton biomass was the highest during the Southwest Monsoon (9.6 mg C m<sup>-3</sup>) at location 1 and the lowest at location 4 during the Northeast Monsoon (2.4 mg C m<sup>-3</sup>).

### 3.2.2.4. Microzooplankton diversity, richness & evenness

Microzooplankton species diversity was maximum during the Southwest Monsoon (3.3) and the minimum value was obtained during the Pre-monsoon (Table 3). MZP diversity gradually decreased from inshore to coastal locations. The overall maximum MZP diversity was obtained at location 2 (4.4) during the Southwest Monsoon while the minimum value was obtained at location 4 during the pre-monsoon. The MZP group richness was comparable in the entire study area, with the species evenly distributed throughout the study area. Ciliate diversity and richness showed a trend similar to that of MZP during pre-monsoon. The highest loricate and aloricate species diversity (2.4) and richness values (2.1 & 1.9 respectively) were obtained at location 2 during the Southwest Monsoon (Table 3). The maximum diversity value of the heterotrophic dinoflagellate was obtained at location

While the minimum value was obtained at location 4 (0.6) during the Pre-monsoon; overall maximum value was obtained during the Southwest Monsoon (1.7).

### 3.3. Mesozooplankton

#### 3.3.1. Composition and abundance

Altogether 15 zooplankton groups were recorded in the present study. Copepods contributed >50 % to the total density. Other than copepods, decapods and larvae, fish eggs and larvae, gastropods and bivalves, chaetognaths and lucifers were the major mesozooplankton groups recorded during the present study. Zooplankton abundance and biomass showed significant temporal variations and maximum values were obtained during the peak Southwest Monsoon (July and August). Spatially, zooplankton biomass and abundance was higher at the inshore locations compared to the offshore locations. Zooplankton abundance in pre-monsoon and Northeast Monsoon periods were comparable in magnitude. Copepods abundance also showed almost the same trend (Figure 9) with the highest (2438 No.m<sup>3</sup>) during the Southwest Monsoon, followed by the Pre-monsoon (1828 No.m<sup>3</sup>) and the Northeast Monsoon (1755 No.m<sup>3</sup>). Copepod species composition was found to be different during different seasons.

#### 3.3.2. Feeding behavior of copepods

Dominant copepods and their feeding behaviors in different seasons have been presented in Table 4. The feeding behavior of copepods can alter the microzooplankton compositions. During the pre-monsoon, omnivorous copepods like *Paracalanus parvus* (26%), *Acartia danae* (20%), *A. erythraea*, and *Acrocalanus gracilis* dominated in the environment. On the other hand, herbivorous/ omnivorous copepods dominated in this study area during the Southwest Monsoon. During the peak Southwest Monsoon, the major copepod species present was *Oithona similis* (63%) along with the upwelling indicator, *Temora turbinata* (13%). During the Late - Southwest Monsoon, *Temora turbinata* (25%), *Pseudodiaptomus serricaudatus* (29%) and *Paracalanus parvus* (14%) were the major copepods. Many of the common omnivore/carnivorous copepods found during the pre-monsoon become dominant again during the Northeast Monsoon; these included *Paracalanus parvus* (22%), *Acartia danae* (16%), *Acartia erythraea* (15%) and *Corycaeus sp.* (12%). *Paracalanus parvus*, *Acartia danae*, *Acartia erythraea*, and *Acrocalanus sp.* have the ability to change their food preferences in accordance with the availability of food resources in the surroundings; during the low productivity period, they prefer micro-zooplankton while they rely mostly on phytoplankton biomass when phytoplankton dominate the production.

### 3.4. Interrelationships of microzooplankton with other parameters

Seasonal and spatial variations in environmental (salinity, DO, nitrate) and biological (Chl*a*, MZP and MSP) parameters and their interactions have been depicted in the RDA Triplot (Figure 10). A clear demarcation of the sampling periods (pre-monsoon, Southwest Monsoon and Northeast Monsoon) in relation to the distribution of environmental and biological parameters was observed in the RDA plot at all the sampling locations. The RDA full model showed that the environmental variables altogether explained 65%, 75%, 89%, and 75% variances in the plankton components at locations 1, 2, 3 and 4, respectively. Monte Carlo test showed that all the ordinations attempted in the RDA analysis were significant ( $F = 4.915$ ,  $P = 0.006$  during the pre-monsoon and  $F = 5.215$ ,  $P = 0.008$  during the Southwest Monsoon); the noticeable environmental features evidenced in the analysis have been summarized below. The two processes of estuarine flux and coastal upwelling mainly influenced the distribution of the environmental parameters in the study area, leading to changes in the biological parameters. During the pre-monsoon, estuarine flux was low and the entire study area was characterized by warm, high-saline and low-nutrient waters, which was clear in the RDA plot. This was reflected as increasing gradients of temperature and salinity axes in left hand side of the Triplot showing an inverse relationship with the nutrients.

During the Southwest Monsoon, estuarine flux was high, which resulted in low saline conditions in the surface and the upwelling waters (cool, nitrate-rich and oxygen-deficient) in the subsurface waters. The increasing gradients of nutrient axis was oriented at the right-hand side of the plot, in the opposite direction of the temperature and salinity axes indicating seasonal changes in the water column characteristics. Northeast Monsoon conditions were found to be significantly different from the Southwest Monsoon, but somewhat similar to the Pre-monsoon conditions; therefore, observations during this period were also oriented to the left-hand side of the plot. The increasing gradient of nutrient and phytoplankton biomass axes oriented in the right-hand side of the plot showing their mutual positive relationship, whereas, the phytoplankton biomass axis showed a negative relationship with both salinity and temperature, indicating that both estuarine influx and upwelling process had contributed to the increase in phytoplankton biomass. The microzooplankton axes representing the surface waters was oriented along with the phytoplankton axis, indicating their affinity to phytoplankton biomass. On the other hand, the axes representing the density of microzooplankton in the subsurface layers were observed to be in the right-hand side of the plot and positively related to the dissolved oxygen, indicating the negative impact of hypoxic waters on microzooplankton during the Southwest Monsoon. The strongly positive relationship between MZP and MSP with the phytoplankton indicates their favourable food availability.

## 4. Discussion

The Pre- Monsoon period along the southwest of India is characterized by a warmer ( $>32^{\circ}\text{C}$ ), highly-illuminated, low-nitrate water column with low phytoplankton biomass (Qasim 1970; Jyothibabu et al., 2008a). As the Southwest Monsoon sets in the region by June, coastal upwelling also begins to be active, which is usually indicated by the presence of hypoxic and nitrate-rich waters surfacing towards the coast (Jyothibabu et al., 2010). Prominent upwelling features like surfacing of low-oxygenated cool subsurface water mass towards the coast was evident in the present study area during the Southwest Monsoon. However, at the inshore locations, the estuarine /freshwater influx was dominant especially in the surface waters during the upwelling period. This low saline water during the Southwest Monsoon had a tendency to inhibit surfacing of the subsurface waters along the southwest coast of India (Banse, 1968, de Souza et al., 1996). In the present case, even though there was certain level of physical inhibition of low saline waters on the upwelling of nutrient-enriched waters to the surface, the high nutrient concentration present in the estuarine water itself made the surface waters of the entire study region eutrophic, supporting the existence of high phytoplankton biomass during the Southwest Monsoon. The low saline (estuarine) water spread is a characteristic feature of the coastal waters adjacent to the estuarine mouths along the southwest coast during the Southwest monsoon and plays a significant role in the distribution of plankton. The large freshwater influx associated with heavy precipitation during the Southwest Monsoon and associated river runoff ensured that the surface waters in the study region were oxygen-saturated. On the other hand, during the Southwest Monsoon, subsurface waters of the entire study area was characterized by the hypoxic ( $<1.6 \text{ ml L}^{-1}$ ) waters and this oxygen-deficient water represented the upwelled waters. The low-nutrient condition observed in the surface layer during the pre-monsoon was due to the thermal stratification that develops in the study area during the period (Jyothibabu et al., 2008a, 2010). It was observed in the present study that during the pre-monsoon, high salinity, temperature and low turbidity prevailed in the environment and phytoplankton biomass was high in the subsurface waters, as compared to the surface waters. During the Southwest Monsoon, low salinity, high nutrient and high turbidity found in the study region significantly increased the phytoplankton biomass, especially in the surface waters.

### 4.4.1. Influence of changing environment on microzooplankton

The vertical distribution of microzooplankton in the present study showed a low abundance in the subsurface waters during the Southwest Monsoon, which can be attributed to the upwelling of the associated oxygen-deficient condition there. On the other hand, the microzooplankton abundance was higher in the subsurface waters during the pre-monsoon period. Irrespective of seasons, the

microzooplankton abundance was found to be higher at the inshore locations compared to the offshore locations. It was noticed that the low saline water discharge from estuaries create noticeable spatial variability in ciliate distribution in coastal waters. The earlier studies of Chiang et al., (2003), Christakiet al., (2009) and Tsai et al., (2011) also recorded that low saline water discharge into the coastal waters trigger increased ciliate abundance. The present study also analyzed the effects of the river/low saline water discharge on the abundance of aloricates and loricate (tintinnid) ciliates separately in the coastal waters off Kochi. The contribution of aloricate ciliates to the microzooplankton community has seldom been evaluated in detail from the Indian waters.

Loricate and aloricate ciliates showed different responses to the estuarine water influx. During the Southwest Monsoon, aloricate ciliates showed a drastic increase, whereas loricates (tintinnids) remained unaltered in their abundance. It was very clear in the present study that the abundance of aloricate ciliates has a positive response to the low saline water influx. An earlier study of Yu et al., (2015) showed the importance of fresh water influx on the density of aloricate ciliates. The less influence of the low saline plume water on tintinnids observed in the present study might be due to low mobility of tintinnids and also due to the high predator pressure from copepods during the period. During the Southwest Monsoon, the two-fold increase in total microzooplankton abundance in the surface waters caused by the peak abundance of aloricate ciliates could be the result of the significant increase in phytoplankton stock in the region (Parsons and Kessler, 1986).

The high abundance of loricate ciliate in the inshore surface waters during the Northeast Monsoon and the Southwest Monsoon could be the result of the high availability of lorica-making sediment particles in the environment. The distribution of hyaline tintinnids also showed seasonal and spatial variation, but in general, their abundance was low in the study area probably due to the location's proximity to the shoreline. It has been observed elsewhere that the high abundance of aloricates occurs during the upwelling period and is in association with high availability of plastidic flagellates in this study area (Chang, 1990; Jyothibabu et al., 2008a; Yu et al., 2015). An earlier study of Verity, (1986), revealed the importance of ciliates as predators of phytonanoflagellates, which are usually abundant in the present study area during the upwelling period. The aloricate ciliates closely followed the trend in the total microzooplankton abundance and phytoplankton biomass. It was noticed earlier that aloricate ciliates efficiently graze on phytoplankton (Verity, 1986). The high abundance of *Myrionectarubra*, a mixotrophic ciliate in the offshore locations during the Southwest Monsoon could be associated with the high nutrient content, preferred food availability and low light conditions, as noticed earlier elsewhere (Chang, 1990; Jhonson et al., 2013).

Comparatively low abundance of heterotrophic dinoflagellates than theciliates also indicate the coastal nature of the study area, as the former usually prefer high saline, open ocean waters. The high abundance of heterotrophic dinoflagellates, especially *Noctiluca scintillans* during the Southwest Monsoon, was due to the high availability of larger phytoplankton for their feeding (Arunpandi et al., 2017). The earlier study by Calbet, (2008) showed that heterotrophic dinoflagellates dominate in upwelling systems, as larger algae contribute significantly in the environment. In the present case, the low salinity present in the surface waters might have played an inhibitory effect on the predominance of the heterotrophic dinoflagellates in this study area. Three different types of feeding mechanisms occur among the mixo- and heterotrophic dinoflagellates: direct engulfment, pallium and tube feeding (Gaines and Elbrachter 1987; Hansen and Calado, 1999). Therefore, at times, heterotrophic dinoflagellates can be as significant as mesozooplankton in consuming bloom-forming diatoms (Sherr and Sherr 2007). Heterotrophic dinoflagellates like *Noctiluca scintillans* are considered as voracious feeders of larger organisms, also present in this environment during the Southwest Monsoon (Arunpandi et al., 2017).

#### **4.4.2. Interaction of microzooplankton with other plankton**

The diversity of microzooplankton is influenced significantly by the size-class of the phytoplankton community (Dolan et al., 2002). The nanoplankton (2-20  $\mu\text{m}$  size) was the dominant phytoplankton community during the present study and this size class of phytoplankton are the major feed of microzooplankton (Griniena et al., 2016). During the pre-monsoon conditions, when phytoplankton stock is usually very low, the microzooplankton prefer the microbial loop components found abundantly during the period (Jyothibabu et al., 2008a,b; Ashadevi et al., 2010; Anjusha et al., 2013). In the present study area also, microzooplankton might be heavily dependent upon heterotrophic picoplankton and heterotrophic nanoflagellates for nutrition during the pre-monsoon (Anjusha et al., 2018, unpublished).

Microzooplankton are the preferred food materials of copepods due to their optimal cell size and biochemical composition (Kleppel et al., 1993; Castellani et al., 2005). The major mesozooplankton (copepod) composition of the study period revealed that the omnivorous copepods dominate in this study area during the pre-monsoon and the Northeast Monsoon. Earlier experimental studies on copepod in the present study area showed that during the low phytoplankton biomass periods (Pre-Monsoon and Northeast Monsoon), copepods' grazing on phytoplankton was less than 10% of their daily ration (Jagadeesan et al., 2017). Since copepods generally consume biomass at least 60-100% of their body weight, the low phytoplankton ingestion rate of copepods in the study area during the Pre-monsoon indicated (Jagadeesan et al., 2017) that major grazers of phytoplankton during the period



might be microzooplankton (Anjusha et al., 2018, Unpublished). During the Pre-monsoon, only low phytoplankton biomass was available to the copepods and so they would feed on microzooplankton as an alternative food with high ingestion rate; this can be one of the reasons for the low density of the microzooplankton. The experimental study of Lynne and Timothy, (1994) in Oregon coastal waters showed that copepods usually feed on ciliates at higher rates than that of phytoplankton, except during upwelling-induced diatom blooms. In the open waters of the Arabian Sea, the dominance of the microbial loop during the pre-monsoon noticeably increases the abundance of microzooplankton; however, in the present study, their low abundance was found during the same period. This could be due to the fact that the present study area was very close to the coast compared to the earlier studies and in the present case, high top-down control of microzooplankton by the dominant carnivorous/omnivorous copepods could have decreased their abundance during the pre-monsoon period. This also points towards the significant role of copepods in structuring the microzooplankton community in the coastal waters along the west coast of India.

During the Southwest Monsoon period, high abundance of *Temora turbinata* and *Psuedodiaptomus serricaudatus* were reported in an earlier study; importantly, these copepods prefer to feed on phytoplankton (Jagadeesan et al., 2017). It was also found that their phytoplankton consumption rate was greater than 60% of their body weight. These two species are considered opportunistic and their high abundance has been reported during the upwelling associated with high productive conditions (Madhupratap et al., 1990; Goswami and Padmavati, 1996; Jagadeesan et al., 2013). The dominance of *Oithona similis* during the peak Southwest Monsoon observed in the present study might be the result of upwelling associated hydrography and the high abundance of phytoplankton and aloricate ciliates in the study area. During the Southwest Monsoon, the high availability of phytoplankton and estuarine oligotrichous ciliates and the dominance of herbivorous copepod may have eventually caused very high density of microzooplankton in this study area. In essence, the high microzooplankton abundance in the study area during the Southwest Monsoon was the result of the high availability of their preferred food and low top-down control exerted by copepods, which apparently preferred phytoplankton as their major food during the period. The importance of small copepod genera on ciliate grazing has been shown by several earlier studies. Studies of Stoecker and Sanders (1985), Gifford and Dagg, (1988, 1991) on *Acartia* sp., Nakamura and Turner (1997); Lonsdale et al., (2000) on *Oithona* sp and Suzuki et al., (1999) on *Paracalanus* sp., all indicated that small copepods have an important ecological effect on ciliates.

#### **4.4.3. Role of microzooplankton in the plankton food web**

Seasonal and spatial variations in microzooplankton density and composition are regulated mainly by the prey and predator abundance (Gauns et al., 1996; Jyothibabu et al., 2008a and b). During the pre-monsoon, microzooplankton play a major role in the microbial loop through the heterotrophic pathway, whereas during the high productive monsoon period, they adapt accordingly and contribute to the microbial food web through feeding on smaller phytoplankton (Jyothibabu et al., 2008a). The present study suggests the existence of a multivorous food web in the coastal waters off Kochi, extending from the microbial loop to the traditional food web, but the dominance of each of these pathways varies during different seasons. This can enhance the energy transfer to higher pelagic trophic levels in coastal upwelling systems. Cyclopid copepods are important grazers of ciliates, having clearance rates of 1.2- 50 ml per day (Sanders and Wickham, 1993; Wickham, 1995; Jurgens et al., 1996). Studies have also indicated that ciliates form an important diet of many gelatinous zooplankton, especially larval and post-larval stages of ctenophore (Stoecker et al., 1987). Similarly, tintinnids are also known to be one of the most important food items of the first feeding stages of chaetognaths (Graziano, 1989). The presence of all the above-mentioned predators were also recorded in the present study and the top-down control of these predators may have caused the low abundance of tintinnids in the present study area.

By virtue of a variety of feeding mechanisms including omnivorous, mixotrophy and bacterivorous (Dolan and Perez, 2000) and a fast reproduction cycle, microzooplankton is likely to be able to cope up with the changing environmental conditions. Plankton food webs in upwelling/nutrient rich environments are generally observed to be short in length, and thus, the massive production of large phytoplankton cells was observed to be transferred directly to mesozooplankton and to fishes. However, research during the last two decades has indicated that the traditional view of the food chain in the upwelling region does not correspond to the reality. In a real sense, it is important to understand the driving mechanisms (bottom - up or top - down) in the food web to characterize the trophic interactions in the ecosystem. So far, interactions between bottom - up and top - down control in the coastal Arabian Sea are poorly understood. From the bottom -up view, an increase in upwelling favors both small and larger phytoplankton, which may cause an increase in microzooplankton abundance. From the top-down view, an increase in mesozooplankton in response to the upwelling condition could control the microzooplankton density. Further focused studies are essential to unravel the specific role of each of these process in sustaining ecosystem functioning along the west coast of India during different seasons.

#### **4.5. Conclusion**

The present study addressed the response of microzooplankton to the hydrographical conditions of the near-shore waters of the South-west coast of India. Coastal upwelling prevailed throughout the study area during the Southwest Monsoon, but their impact was impeded in the surface waters by the estuarine influx. Relatively high phytoplankton biomass obtained in the offshore locations during the Southwest Monsoon were associated with the coastal upwelling. On the other hand, in the near-shore locations, the productivity was associated mainly with the high-nutrient, low-saline estuarine plume water. During the Southwest Monsoon, high estuarine influx and phytoplankton biomass led to increased abundance of microzooplankton community in the surface waters. The abundance of microzooplankton was low during the pre-monsoon, contrary to the usual pattern in the open waters of the Arabian Sea, which was associated with the high top down control by the carnivorous copepods. A total of 59 species of microzooplankton were identified during the present study, which was composed of 29 species of loricate ciliates, 20 species of aloricate ciliates and 10 species of heterotrophic dinoflagellates. The present study reveals the important role of aloricate ciliates in the microzooplankton community in the coastal waters off Kochi, which was hitherto unknown. Seasonal and spatial variations in microzooplankton density and composition were regulated mainly by the low saline water plume, and prey and predator abundance. The results suggest the existence of a multivorous food web, extending from the microbial loop to the traditional food web, which could be a major ecological feature in the coastal upwelling system of the west coast of India.

#### **Acknowledgement**

The authors thank the Director, CSIR- National Institute of Oceanography, India for facilities and encouragement. The author thank the Scientist-in-Charge, CSIR NIO RCKochi for encouragement. The authors thank the Director, INCOIS, Hyderabad, India for the financial support for the Grant-in-Aid Project 'Advanced studies on the plankton food web in relation to the oceanographic environment in the Potential Fishing Zone (PFZ) off Kochi'. The author Anjusha thank the CSIR for SRF funding. This is NIO contribution XXXX.

## References

- Anjusha, A., Jyothibabu, R., Jagadeesan, L., Mohan, A.P., Sudheesh, K., Krishna, K., Ullas, N., Deepak, M.P. 2013. Trophic efficiency of plankton food webs: observations from the Gulf of Mannar and the Palk Bay, Southeast Coast of India. *Journal of Marine Systems* 115, 40-61.
- Arunpandi, N., Jyothibabu, R., Jagadeesan, L., Gireeshkumar, TR., Karnan, C., Naqvi, S.W.A., 2017. Noctiluca and copepods grazing on the phytoplankton community in a nutrient-enriched coastal environment along the southwest coast of India. *Environmental monitoring and assessment* 189, 351.
- Ashadevi, C.R., Jyothibabu, R., Sabu, P., Josia, J., Habeebrehman, H., Prabhakaran, M.P., Jayalakshmi, K.J., Achuthankutty, C.T., 2010. Seasonal variations and trophic ecology of microzooplankton in the south-eastern Arabian Sea. *Continental Shelf Research* 30, 1070-1084.
- Banse, K., 1959. On upwelling and bottom-trawling off the southwest coast of India. *Journal of the Marine Biological Association of India* 1, 33-49.
- Banse, K., 1968. Hydrography of the Arabian Sea shelf of India and Pakistan and effects on demersal fishes, *Deep sea research and oceanographic Abstracts*. Elsevier, pp. 45IN749-48IN1079.
- Bhattathiri, P.M.A., Pant, A., Sawant, S.S., Gauns., Matondkar S.G.P., Mahanraju, R., 1996. Phytoplankton production and chlorophyll distribution in the eastern and central Arabian Sea in 1994-1995. *Current Science* 71, 857-862.
- Broglio, E., Saiz, E., Calbet, A., Trepas, I., Alcaraz, M. 2004. Trophic impact and prey selection by crustacean zooplankton on the microbial communities of an oligotrophic coastal area (NW Mediterranean Sea). *Aquatic Microbial Ecology* 35, 65-78.
- Burkill, P.H., Mantoura, R.F.C., Liewellyn, C.A., Owens, N.J.P., 1987. Microzooplankton Grazing and Selectivity of Phytoplankton in Coastal waters. *Marine Biology* 93, 581-590.
- Calbet, A., 2008. The trophic roles of microzooplankton in marine systems. *ICES Journal of Marine Science* 65, 325-331.
- Castellani, C., Irigoien, X., Harris, R.P., Lampitt, R.S. 2005. Feeding and egg production of *Oithona similis* in the North Atlantic. *Marine Ecology Progress Series* 288, 173-182.
- Chang, F.H., 1990. Quantitative distribution of microzooplankton off Westland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 24, 187-195.
- Chiang, K.P., Lin C.Y, Lee, C.H., Shiah F.K., Chang, J., 2003. The coupling of oligotrich ciliate populations and hydrography in the East China Sea: spatial and temporal variations. *Deep Sea Research Part II: Topical Studies in Oceanography* 50, 1279-1293
- Christaki, U., Courties, C., Joux, F., Jeffrey, W.H., Neveux, J., Naudin, J.J., 2009. Community structure and trophic role of ciliates and heterotrophic nanoflagellates in Rhone River diluted mesoscale structures (NW Mediterranean Sea). *Aquatic Microbial Ecology* 57, 263-277.
- Conway, D., White, R., Hugues-Dit-Ciles, J., Gallienne, C., Robins, D., 2003. Guide to the coastal and surface zooplankton of the South Western Indian Ocean. Occasional publication No. 15, Marine Biological Association of the United Kingdom, pp. 354.

- Damodara Naidu, W., 1977. Studies on tintinnids (Protozoa: Ciliata) of Porto Novo region, S. India. Diss. PhD thesis, Annamalai University, Tamil Nadu, India, pp. 281.
- De Souza, S.N., Kumar, M.D., Sardesai, S., Sarma, V.V.S.S., Shirodkar, P.V., 1996. Seasonal variability in oxygen and nutrients in the central and eastern Arabian Sea. *Current Science* 71, 847-851.
- Dolan, J.R., Gallegos, C.L., 2001. Estuarine diversity of tintinnids (planktonic ciliates). *Journal of Plankton Research* 23, 1009-1027.
- Dolan, J.R., Claustre, H., Carlotti, F., Plounevez, S., Moutin, T., 2002. Microzooplankton diversity: relationships of tintinnid ciliates with resources, competitors, and predators from the Atlantic Coast of Morocco to the Eastern Mediterranean. *Deep Sea Research Part I: Oceanographic Research Papers* 49, 1217-32.
- Dolan, J.R., Parez, M.T., 2000. Costs, benefits and characteristics of mixotrophy in marine oligotrichs. *Freshwater Biology* 45, 227-238.
- Gains, G., Elbrachter, M., 1987. Heterotrophic nutrition. In: Taylor, F.J.R. (Ed.), *Biology of Dinoflagellates*. Blackwell Scientific Publications, Oxford 224-268.
- Gauns, M., Mohanraju, R., Madhupratap, M., 1996. Studies on the microzooplankton from the Central and eastern Arabian Sea. *Current Science* 71, 874-877.
- Gifford, D.J., Dagg, M.J., 1988. Feeding of the estuarine copepod *Acartia tonsa* Dana: carnivory vs. herbivory in natural microplankton assemblages. *Bulletin of Marine Science* 43, 458-468.
- Gifford, D.J., Dagg, M.J., 1991. The microzooplankton-mesozooplankton link: consumption of planktonic protozoa by the calanoid copepods *Acartia tonsa* Dana and *Neocalanus plumchrus* Murukawa. *Marine Microbial Food Webs* 5, 161-177.
- Godhantaraman, N., 1994. Species composition and abundance of Tintinnids and copepods in the Pichavaram mangroves (South India). *Ciencias Marinas* 20, 371-391.
- Godhantaraman, N., 2001. Seasonal variations in taxonomic composition, abundance and food web relationship of microzooplankton in estuarine and mangrove waters, Parangipettai region, south east coast of India. *Indian Journal of Marine Science*. 30, 151-160.
- Godhantaraman, N., 2002. Seasonal variations in species composition, abundance, biomass and estimated production rates of tintinnids at tropical estuarine and mangrove waters, Parangipettai, southeast coast of India. *Journal of Marine Systems* 36, 161-171.
- Godhantaraman, N., Uye, S., 2003. Geographical and seasonal variations in taxonomic composition, abundance and biomass of microzooplankton across a brackish-water lagoonal system of Japan. *Journal of Plankton Research* 25, 465-482.
- Goswami, S.C., Padmavati, G., 1996. Zooplankton production, composition and diversity in the coastal waters of Goa. *Indian Journal of Marine Sciences*, 25, 91-97.
- Grasshoff, K., Ehrhardt, M., Kremling, K., 1983. *Methods of Seawater Analysis*. Verlag Chemie, Weinheim, 419 pp.

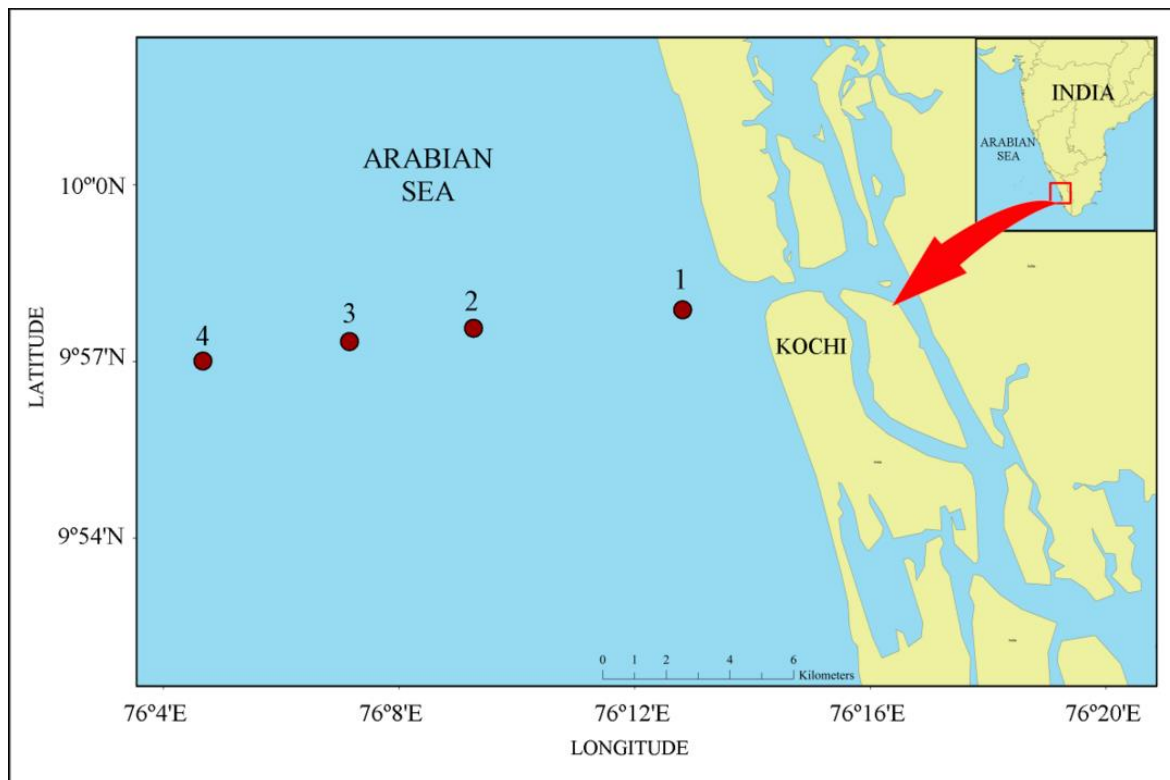
- Graziano, C., 1989. On the ecology of tintinnids (Ciliophora: Oligotrichida) in the North Irish Sea. *Estuarine, Coastal and Shelf Science* 29, 233-245.
- Griniene, E., Sulcius, S., Kuosa, H., 2016. Size-selective microzooplankton grazing on the phytoplankton in the Curonian Lagoon (SE Baltic Sea). *Oceanologia*, 58, 292-301.
- Hansen, P.J., Calado, A.N.J., 1999. Phagotrophic Mechanisms and Prey Selection in Free living Dinoflagellates. *Journal of Eukaryotic Microbiology* 46: 382-389.
- Harris, R.P., Wiebe, P.H., Lenz, J., Skjoldal, H.R., Huntley, M., 2000. ICES Zooplankton Methodology Manual. Academic Press. 684 pp.
- Jagadeesan, L., Jyothibabu, R., Anjusha, A., Arya P. Mohan., Muraleedharan, K. R., Sudheesh, K., 2013. Influence of ocean currents in structuring the mesozooplankton in the Gulf of Mannar and Palk Bay, southeast coast of India, *Progress in Oceanography* 110, 27-48.
- Jagadeesan, L., Jyothibabu, R., Arunpandi, N., Parthasarathi, S., 2017. Copepod grazing and their impact on phytoplankton standing stock and production in a tropical coastal water during the different seasons. *Environmental monitoring and assessment* 189, 105.
- Johnson, M.D., Stoecker, D.K., Marshall, H.G., 2013. Seasonal dynamics of *Mesodinium rubrum* in Chesapeake Bay. *Journal of Plankton Research* 35, 877-893.
- Jurgens, K., Matz, C., 2002. Predation as a shaping force for the phenotypic and genotypic composition of planktonic bacteria. *Antonie van Leeuwenhoek* 81, 413-434.
- Jyothibabu, R., Madhu, N.V., Jayalakshmi, K.V., Balachandran, K.K., Shiyas, C.A., Martin, G.D., Nair, K.K.C., 2006. Impact of freshwater influx on microzooplankton mediated food web in a tropical estuary (Cochin bckwaters, India). *Estuarine, Coastal and Shelf Science* 69, 505-518.
- Jyothibabu, R., Ashadevi, C.R., Madhu, N.V., Sabu, P., Jayalakshmy, K.V., Jacob, J., Habeebrehman, H., Prabhakaran, M.P., Balasubramanian, T. Nair., K.K.C., 2008a. The response of microzooplankton (20- 200  $\mu\text{m}$ ) to coastal upwelling and summer stratification in the southeastern Arabian Sea. *Continental Shelf Research* 28, 653-671.F
- Jyothibabu, R., Madhu, N.V., Maheswaran, P.A., Jayalakshmy, K.V., Nair, K.K.C., Achuthankutty, C.T., 2008b. Seasonal variation of microzooplankton (20–200  $\mu\text{m}$ ) and its possible implications on the vertical carbon flux in the western Bay of Bengal. *Journal of Continental Shelf Research* 28, 737-755.
- Jyothibabu, R., Madhu, N.V., Habeebrehman, H., Jayalakshmy, K.V., Nair, K.K.C., Achuthankutty, C.T., 2010. Re-evaluation of ~paradox of mesozooplankton in the eastern Arabian Sea based on ship and satellite observations. *Journal of Marine Systems* 81, 235-251.
- Jyothibabu, R., Mohan, A.P., Jagadeesan, L., Anjusha, A., Muraleedharan, K.R., Lallu, K.R., Kiran, K., Ullas, N., 2013. Ecology and trophic preference of picoplankton and nanoplankton in the Gulf of Mannar and the Palk Bay, southeast coast of India. *Journal of Marine Systems* 111, 29-44.
- Kasturirangan, L. R, 1963. A key for the identification of the more common planktonic Copepoda of the Indian coastal waters, Publication No.2. Indian National Committee on Oceanic Research, 1-87.

- Kleppel, G. S., Holliday, D. V., Pieper, R. E., 1993. Trophic interactions between copepods and microplankton: A question about the role of diatoms. *Limnology and Oceanography* 36, 172-178.
- Kofoed, C. A., and Campbell, A. S. 1939. Reports on the scientific results of the expedition to the Eastern Tropical Pacific, in charge of Alexander Agassiz, US Fish Commission steamer "Albatross" from October 1904 to March 1905. University California Publications in Zoology, 34, 1-403.
- Krishnamurthy, K., Santhanam, R., 1975. Ecology of Tintinnids (protozoa:Ciliata) on Porto Novo Region. *Indian Journal of Marine Sciences*, 181-184.
- Krishnamurthy, K., Naidu, D.W., Godhantaraman, N., Kannan, L., Kathiresan, K., 1995. Microzooplankton with special reference to Tintinnida (Protozoa: Ciliata: Tintinnida). Plankton of Parangipettai (Porto Novo), India. Fascicle No1, New Series: Memoirs of the Centre for Advanced Study in Marine Biology, (Annamalai University), Parangipettai, Tamilnadu, India: 27.
- Leps, J., Smilauer, P., 2003. Multivariate analysis of ecological data using CANOCO. Cambridge University press, Cambridge, United Kingdom, 169 pp.
- Lonsdale, D.J., Caron, D.A., Dennett, M.R., Schaffner, R., 2000. Predation by *Oithona* spp. on protozooplankton in the Ross Sea, Antarctica. *Deep Sea Research Part II: Topical Studies in Oceanography* 47, 3273- 3283.
- Lynne, F., Timothy, J.C., 1994. Predation on phagotrophic ciliates in Oregon coastal waters. *Marine Ecology Progress Series* 107, 103-111.
- Mc Kinnon, A. D., Ayukai, T., 1996. Copepod egg production and food resources in Exmouth Gulf, Western Australia. *Marine and Freshwater Research* 47, 595-603.
- Madhupratap, M., Nair, S.R.S., Haridas, P., Padmavati, G., 1990. Response of zooplankton to physical changes in the environment: coastal upwelling along the central west coast of India. *Journal of Coastal Research*, 413-426.
- Madhupratap, M., Gopalakrishnan, T.C., Haridas, P., Nair, K.K.C., 2001. Mesozooplankton biomass, composition and distribution in the Arabian Sea during the Fall Intermonsoon: implications of oxygen gradients. *Deep Sea Research Part II: Topical Studies in Oceanography* 48, 1345-1368.
- Maeda, M., 1986. An illustrated guide to the species of the Family Halteridae and Strombilidae (Oligotrichida, Ciliophora), free swimming protozoa common in the aquatic environments. Ocean Research Institute, Ocean Research Institute. University of Tokyo, 21, 1-2.
- Margalef, R., 1968. Perspectives in ecological theory. Chicago: University of Chicago Press. pp. 111.
- Montagnes, D.J.S., Allen, J., Brown, L., Bulit, C., Davidson, R., Fielding, S., Heath, M., Holliday, N.P., Rasmussen, J., Sanders, R., 2010. Role of ciliates and other microzooplankton in the Irminger Sea (NW Atlantic Ocean). *Marine Ecology Progress Series* 411, 101-115.
- Montagnes, D., 2013. The user – friendly guide to coastal planktonic ciliates. [http:// www. Zooplankton. cn/ciliate](http://www.Zooplankton.cn/ciliate).
- Muraleedharan, P. M., Prasannakumar, S., 1996. Arabian sea upwelling - A comparison between coastal and open ocean regions. *Current science* 71, 842-846.

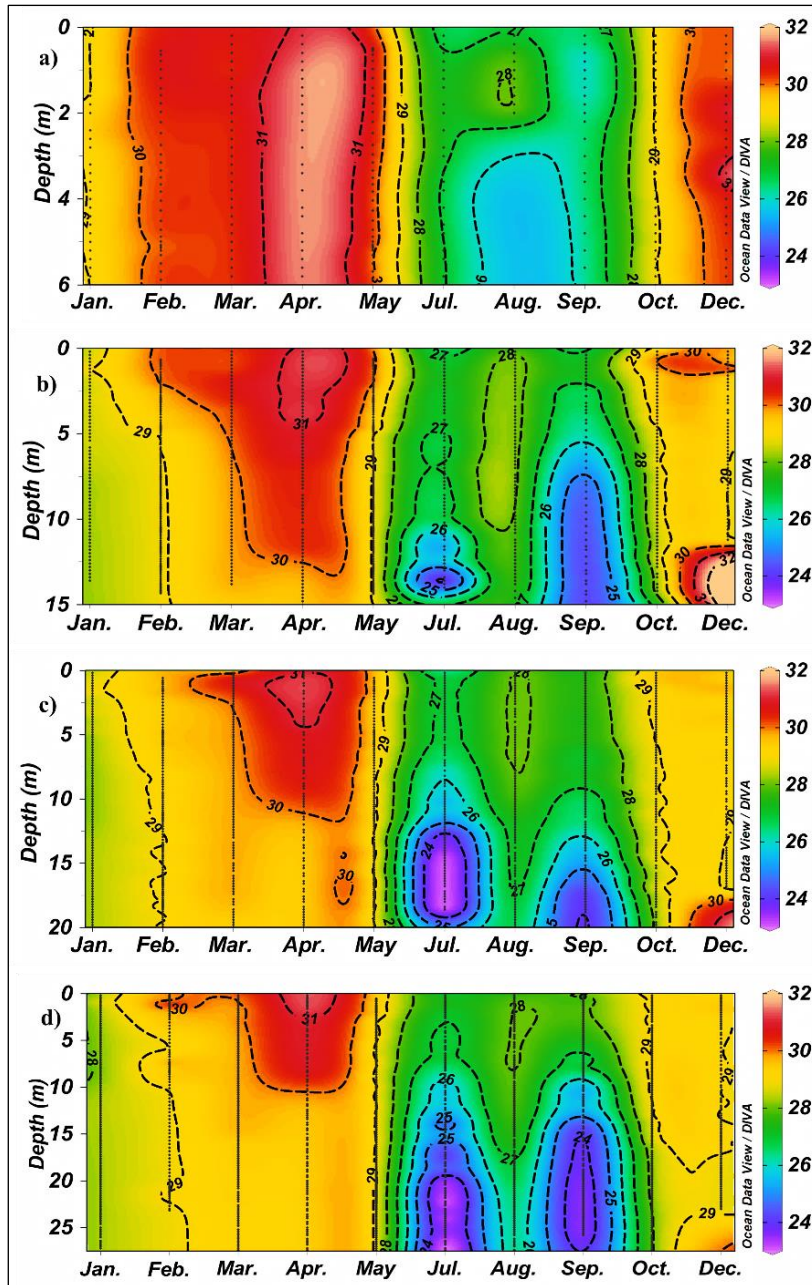
- Naik, R.K., Anil A.C., Narale, D.D., Chitari, R.R., Kulkarni., V.V., 2011. Primary description of surface water phytoplankton pigment patterns in the Bay of Bengal. *Journal of Sea Research* 65, 435-441.
- Nair, S.R.S., Devassy, V.P., Madhupratap, M., 1992. Blooms of phytoplankton along the west coast of India associated with nutrient enrichment and the response of zooplankton. *Science of the total environment*, 819-828.
- Nakamura, Y., Turner, J.T., 1997. Predation and respiration by the small cyclopoid copepod *Oithona similis*: How important is feeding on ciliates and heterotrophic flagellates? *Journal of Plankton Research* 19: 1275-1288
- Parsons, T.R., Kessler, T.A., 1986. Computer model analysis of pelagic ecosystems in estuarine waters. The role of freshwater outflow in coastal marine ecosystems. *Springer* 161-181.
- Pielou, E.C., 1969. An introduction to mathematical ecology. An introduction to mathematical ecology.
- Prasannakumar, S., Prasad, T.G., 1996. Winter cooling in the northern Arabian Sea. *Current Science* 834-841.
- Postel, L., Fock, H., Hagen, W., 2000. Biomass and abundance. In: Harris, R.P., Wiebe, P.H., Lenz, J., Skjoldal, H.R., Huntley, M. (Eds.), *ICES Zooplankton Methodology manual*, pp. 684.
- Qasim, S.Z., 1970. Some problems related to the food chain in a tropical estuary. *Marine food chains* 1970, 45-51.
- Rakesh, M., Raman, A.V., Kalavati, C., Subramanian, B.R., Sharma, V.S., Sunitha Babu, E., Sateesh, N., 2008. Zooplankton community structure across an eddy- generated upwelling band close to a tropical bay-mangrove ecosystem. *Marine Biology* 154, 953-972.
- Richardson, A.J., Walne, A.W., John, A.W.G., Jonas, T.D., Lindley, J.A., Sims, D.W., Stevens, D., Witt, M., 2006. Using continuous plankton recorder data. *Progress in Oceanography* 68, 27-74.
- Sanders, R.W., Wickham, S.A., 1993. Planktonic protozoa and metazoa: predation, food quality and population control. *Aquatic Microbial Ecology* 7, 197-223.
- Sewell, R., 1999. The copepoda of Indian seas. *Biotech Books, Delhi, India*, pp. 407.
- Shannon, C.E., Wiener, W., 1949. The mathematical theory of communication. *University of Illinois press, Urbana*, pp. 117.
- Sherr, E.B., Sherr, B.F., 2007. Heterotrophic dinoflagellates: a significant component of microzooplankton biomass and major grazers of diatoms in the sea. *Marine Ecology Progress Series* 352, 187-197.
- Srinivasan, A., Santhanam, R., Jegatheesan, G. 1988. Biomass and seasonal distribution of planktonic tintinnids of Pullavazhi Estuary, southeast coast of India. *Indian Journal of Marine Sciences* 17, 131-133.
- Steidinger, K. A., Williams, J., 1970. *Dinoflagellates, Memoirs of the Hourglass Cruises, Volume II.* Florida Department Nat. Res. Mar. Res. Laboratory, St. Petersburg, Florida, 251 pp.



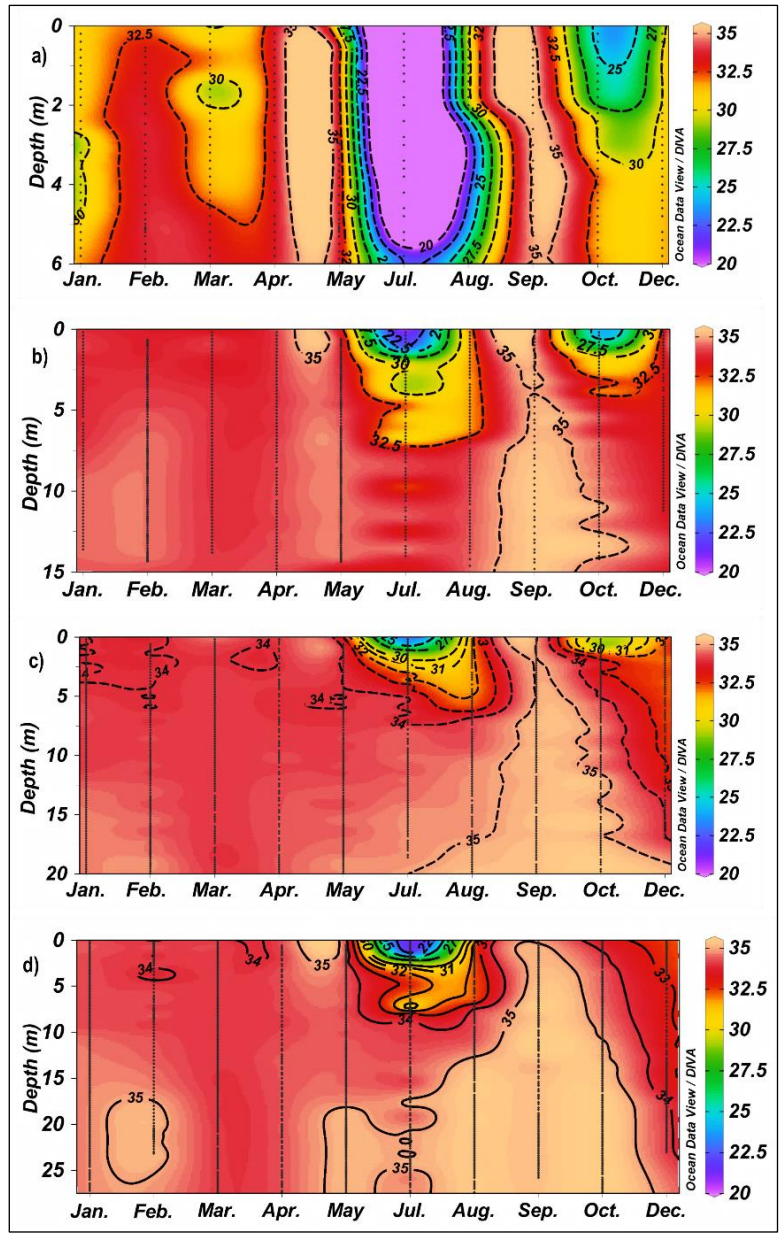
- Stoecker D.K, Sanders N.K., 1985. Differential grazing by *Acartia tonsa* on a dinoflagellate and a tintinnid. *Journal of Plankton Research* 7, 85-100.
- Stoecker, D.K., Verity, P.G., Michaels, A.E., Davis, L.H., 1987. Feeding by larval and post-larval ctenophores on microzooplankton. *Journal of Plankton Research*, 9, 667-683.
- Subrahmanyam, R.T., 1971. The Dinophyceae of the Indian Seas, Memoir II, Part 2, Family Peridineacea. Marine Biological Association of India, Cochin, India. 334 pp.
- Suzuki, K., Nakamura, Y., Hiromi, J., 1999. Feeding by the small calanoid copepod *Paracalanus* sp. on heterotrophic dinoflagellates and ciliates. *Aquatic Microbial Ecology* 17, 99-103.
- Tanaka, O., 1956. The pelagic copepods of the Izu region, Middle Japan, Systematic account I. *Publications of the Seto Marine Biological Laboratory* 5, 525.
- Thompson, G.A., 2004. Tintinnid diversity trends in the southwestern Atlantic Ocean (29 to 60 S). *Aquatic Microbial Ecology* 35, 93-103.
- Tsai, A.Y., Gong, G.C., Chiang, K.P., Chao, C.F., Guo, H.R., 2011. Long-term (1998–2007) trends on the spatial distribution of heterotrophic ciliates in the East China Sea in summer: effect of the Three Gorges Dam construction. *Journal of Oceanography* 67, 725-737.
- UNESCO, 1994. Protocols for the Joint Global Ocean Flux Study, Manual and Guides, 29, UNESCO, Paris, pp. 170.
- Urrutxurtu, I., 2004. Seasonal succession of tintinnids in the Nervion River estuary, Basque Country, Spain. *Journal of Plankton Research* 26, 307-314.
- Verity, P. G., 1986. Grazing on phototrophic nanoplankton by microzooplankton in Narragansett Bay, Rhode Island. *Marine Ecology Progress Series* 29, 105-115.
- Verity P.G., Wassmann, P., Frischer, M.E., Howard-Jones, M.H., Allen, A.E., 2002. Grazing of phytoplankton by microzooplankton in the Barents Sea during early summer. *Journal of Marine Systems* 38, 109-123.
- Wickham, S.A., 1995. Cyclops predation on ciliates: species. Specific differences and functional responses. *Journal of Plankton Research* 17, 1633-1646.
- Yang E.J., Choi J.K., Hyun, J.H., 2008. Seasonal variation in the community and size structure of nano- and microzooplankton in Gyeonggi Bay, Yellow Sea. *Estuarine, Coastal and Shelf Science*. 77, 320-330.
- Yu, Y., Zhang, W., Feng, M., Zhao, Y., Zhang, C., Zhou, F., Xiao, T. 2015. Differences in the vertical distribution and response to freshwater discharge between aloricate ciliates and tintinnids in the East China Sea. *Journal of Marine Systems* 154, 103-109.



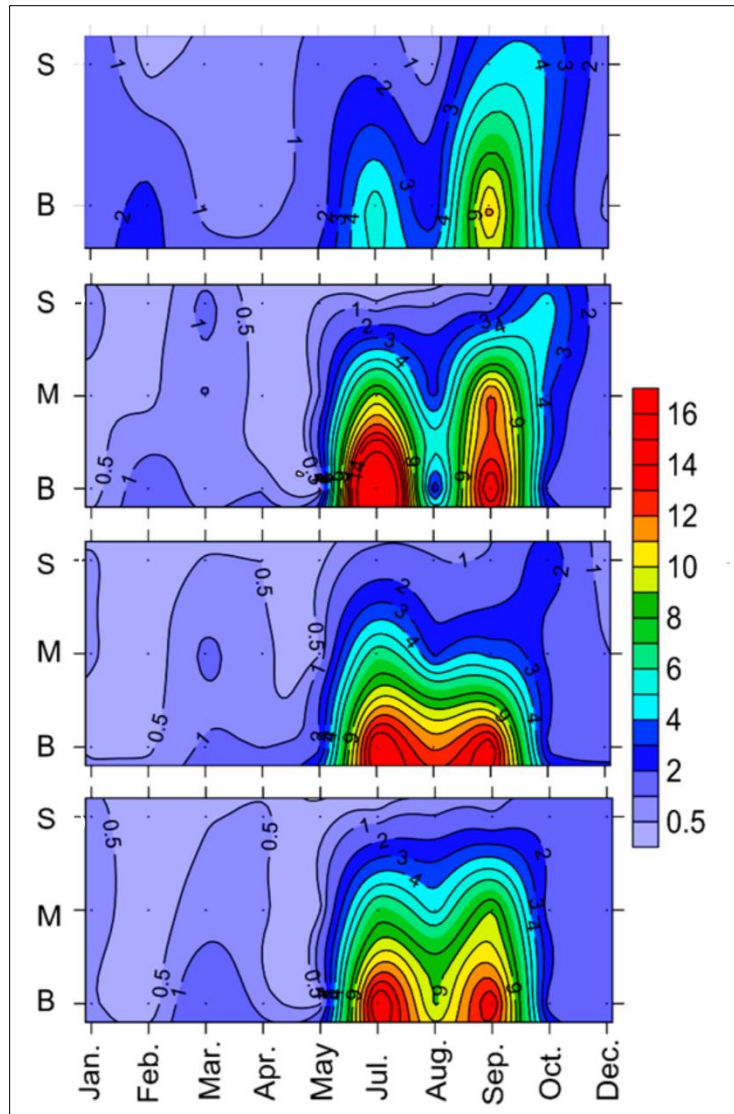
**Figure 1** - Study area and sampling locations. Monthly sampling was carried out in four locations (1-4) in a transect perpendicular to the coastline during January to December 2014.



**Figure 2** - Vertical distribution of temperature (°C) during January - December period in sampling locations (a) 1, (b) 2, (c) 3 and (d) 4. No sampling in June and November.

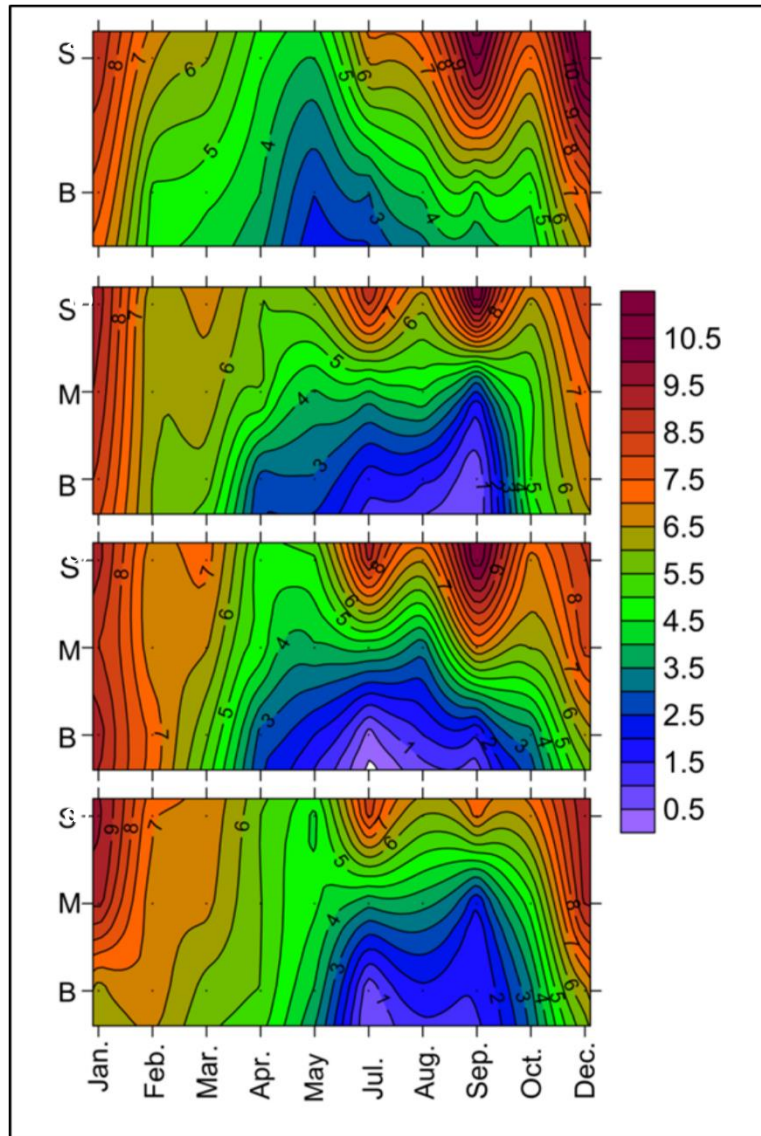


**Figure 3-** Vertical distribution of salinity during January- December period in sampling locations (a)1, (b)2, (c) 3 and (d) 4. No sampling in June and November.

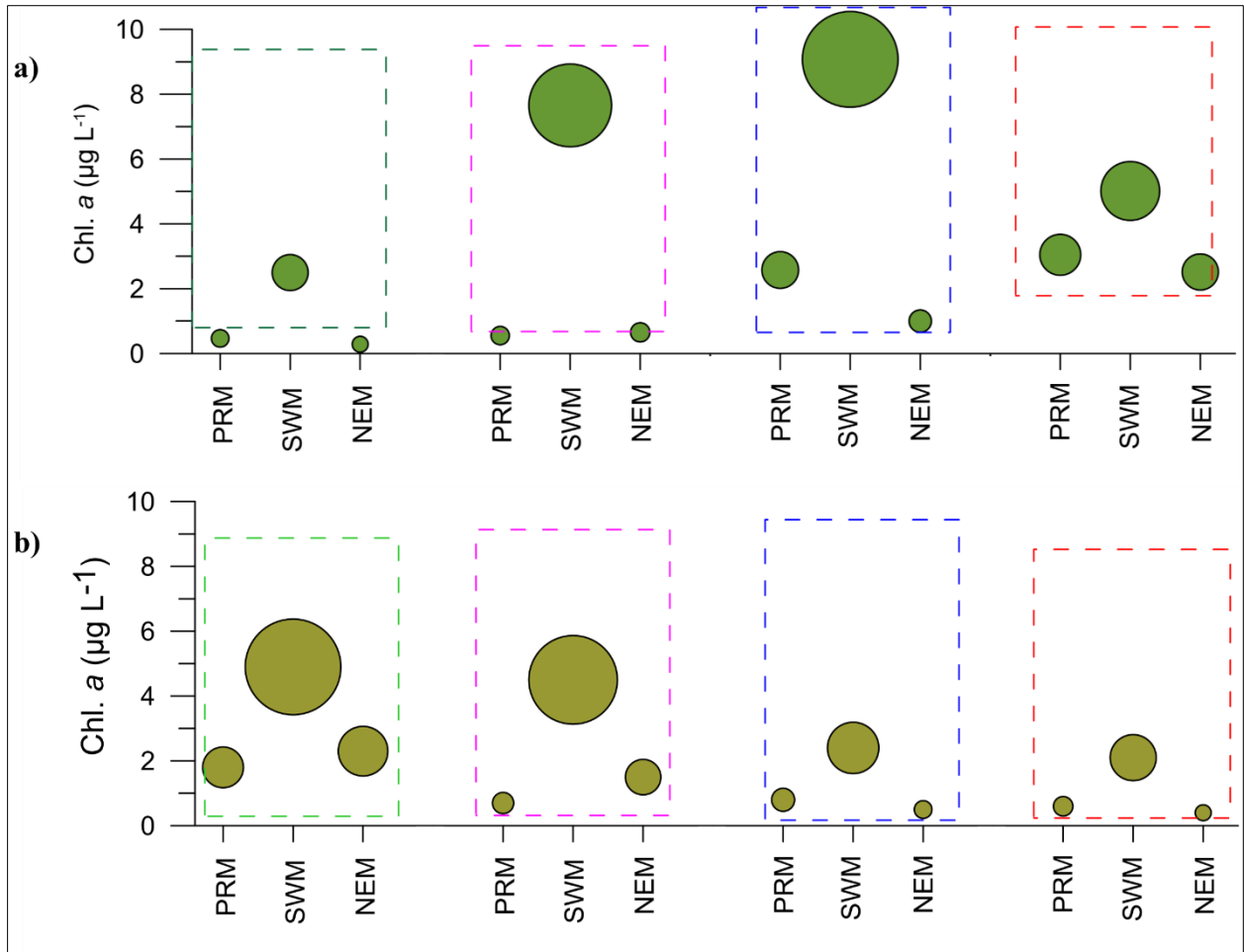


**Figure 4** - Vertical distribution of nitrate ( $\mu\text{M L}^{-1}$ ) in the monthly sampling during January-December period in sampling locations (a)1, (b)2,(c) 3 and (d) 4. No sampling in June and November. Abbreviations: S - surface waters, M - Mid - waters and B - Near-bottom waters. Due to very shallow depth, only the surface and near-bottom waters were sampled in location 1

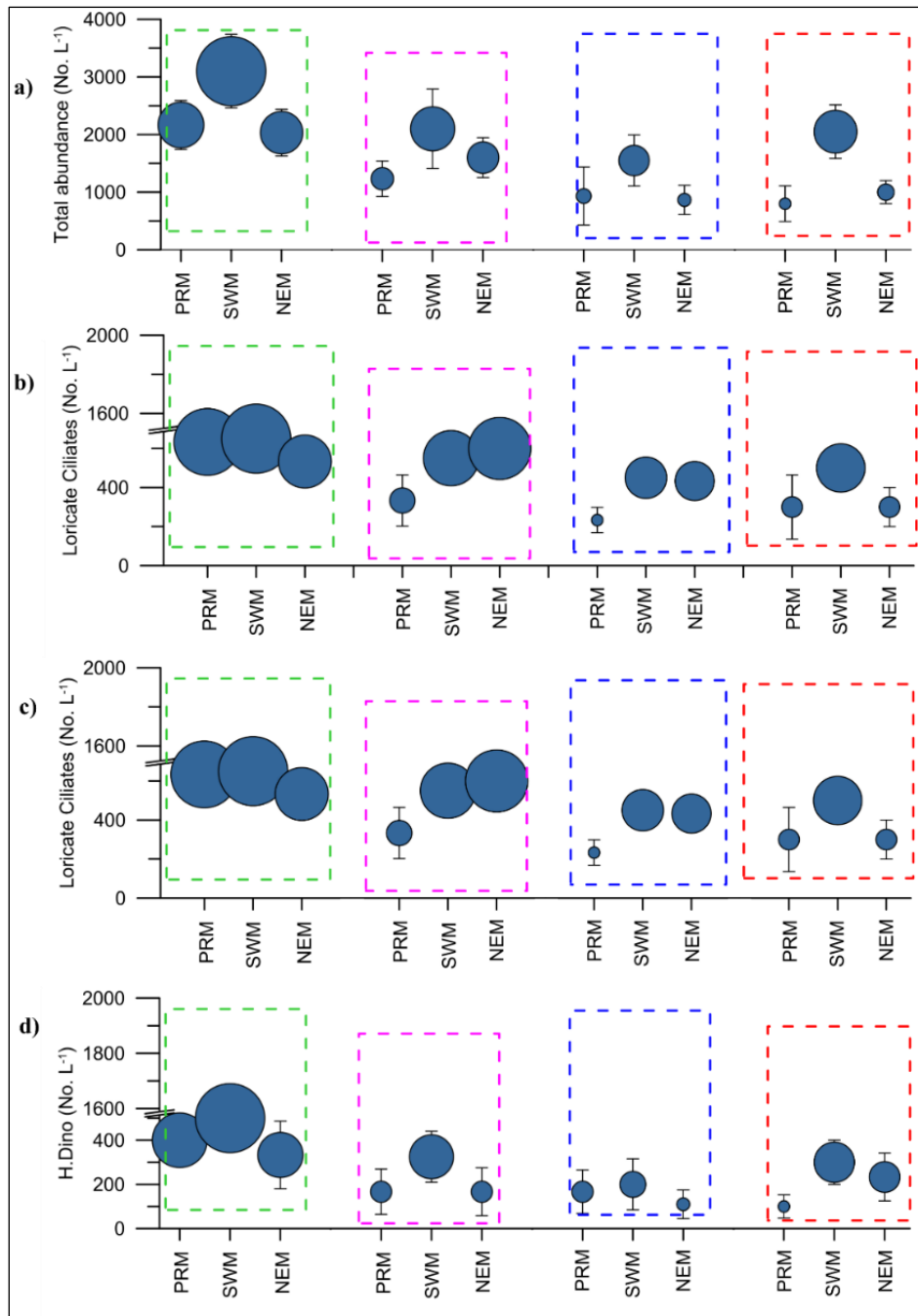




**Figure 5** -Vertical distribution of dissolved oxygen during the monthly sampling during January-December period in locations (a) 1, (b) 2, (c) 3 and (d) 4. No sampling in June and November. Abbreviations: S - Surface, M - Mid-waters and B - Near-bottom. Due to very shallow depth, only the surface and near-bottom waters were sampled in location 1

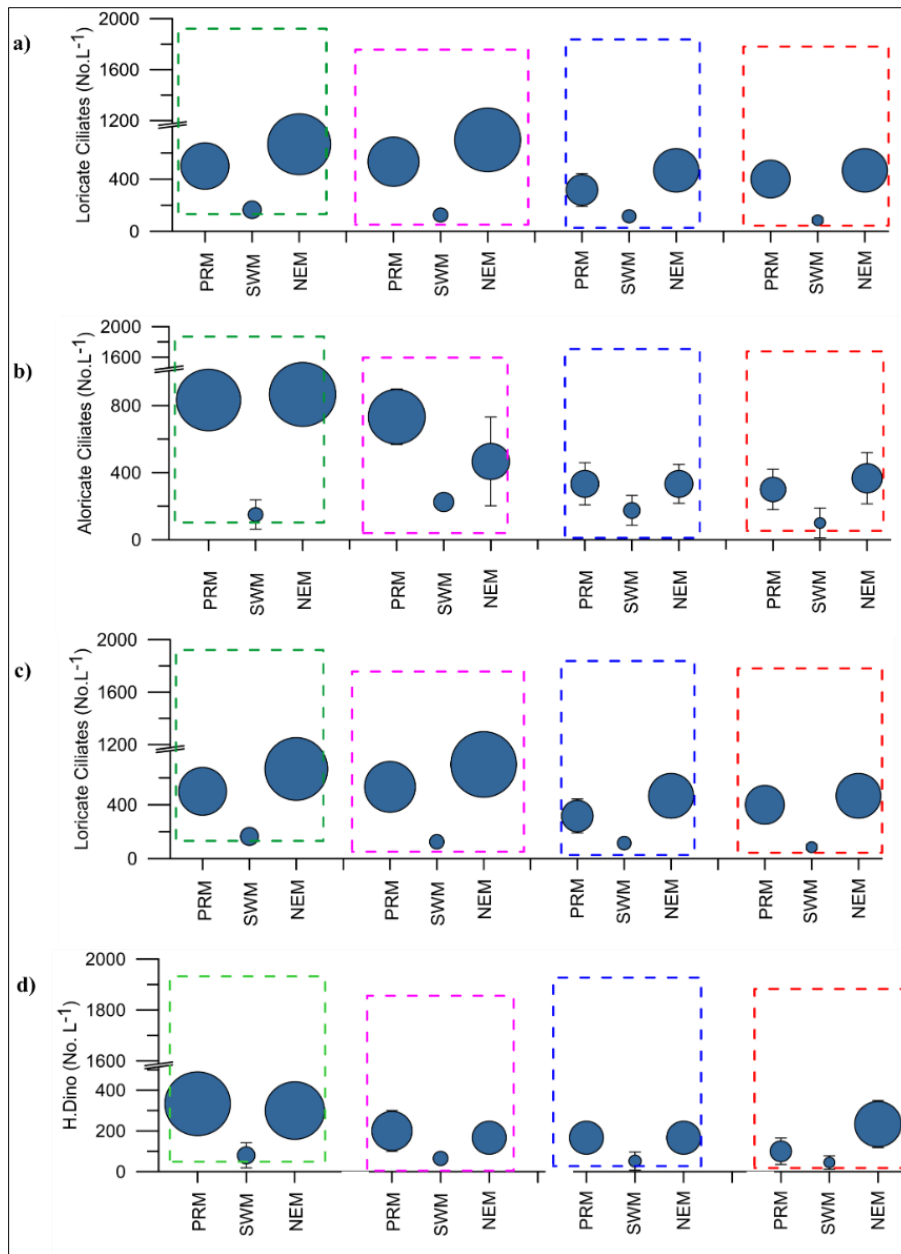


**Figure 6** -Seasonal variations of chlorophyll *a* in the (a) surface and (b) near-bottom waters in locations 1 (green dotted line rectangle), 2 (pink dotted line rectangle), 3 (blue dotted line rectangle) & 4 (red dotted line rectangle)

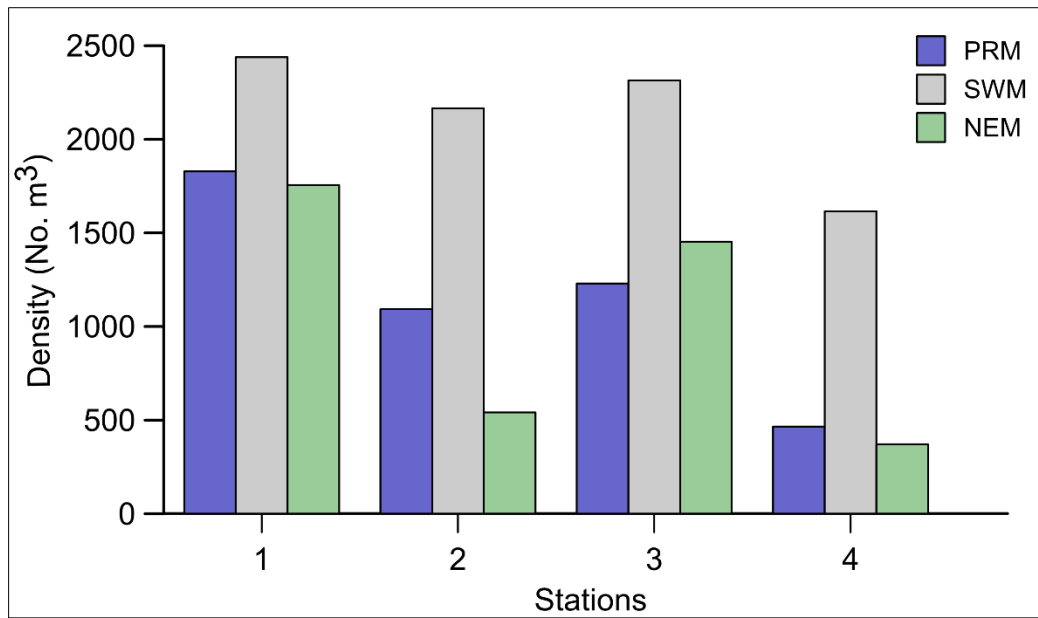


**Figure 7 -** Microzooplankton community abundance and its major constituent groups in the surface waters during the Pre-Monsoon (PRM), Southwest Monsoon (SWM) & Northeast Monsoon (NEM). Locations 1 (in green dotted line rectangle box), 2 (pink dotted line rectangle box), 3(blue dotted line rectangle box) and 4 (red dotted line rectangle box).

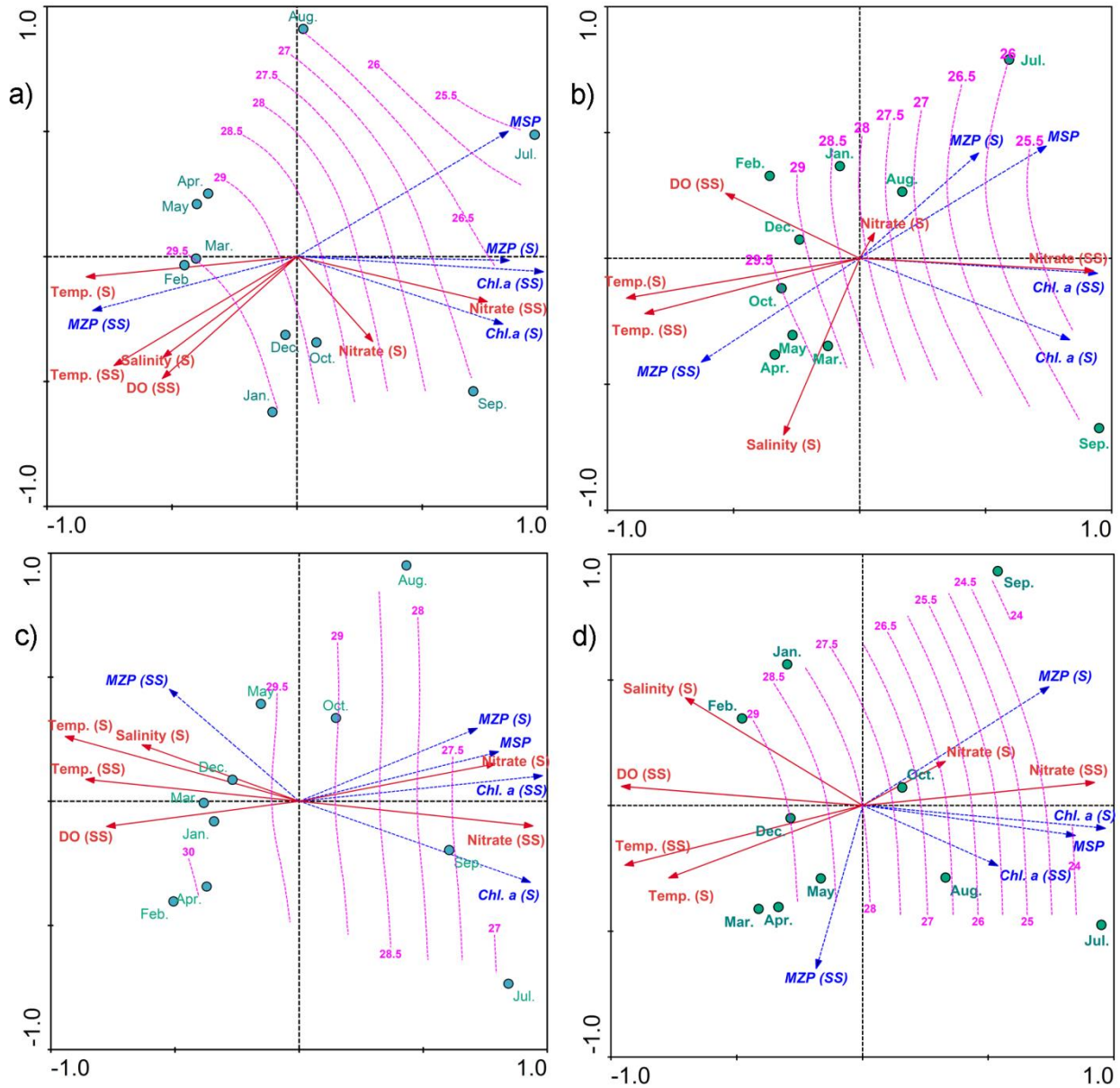




**Figure 8** - Abundance of microzooplankton and its major components during the Pre-Monsoon (PRM), Southwest Monsoon (SWM) & Northeast Monsoon (NEM) in the sub surface waters of the sampling locations. Location 1 (in green dotted line rectangle box), location 2 (pink dotted line rectangle box), location 3 (blue dotted line rectangle box) and location 4 (red dotted line rectangle box).



**Figure 9** - Seasonal variations in copepod density during the Pre-Monsoon(PRM), Southwest Monsoon (SWM) & Northeast Monsoon(NEM) periods.



**Figure 10** - RDA Triplot showing the distribution of seasonal environmental variables and biological parameters of the locations 1-4 (a-d). The overlaid attribution contours represent the subsurface temperature. Sampling months are displayed by green circles, biological and environmental variables are shown by arrows: the blue dotted arrows indicate the former and the red ones indicate the latter. Abbreviations (DO-Dissolved Oxygen, Temp.-Temperature, MZP - Micro-zooplankton, MSP-Mesozooplankton, Chl. *a* - Chlorophyll *a*, S- surface and SS - subsurface)

	Order	Family	Species	PRM	SWM	NEM		
Loricata ciliates	Choreotrichida	Hyaline						
		Ptychocyclididae	<i>Favella ehernbergii</i>	+	-	-		
			<i>F. philippinensis</i>	+	+	-		
		Metacyclididae	<i>Helicostemella acuta</i>	-	+	+		
			<i>Metacylis sp</i>	-	+	+		
		Petalotrichidae	<i>Petalotricha ampulla</i>	-	+	-		
		Rhabdonellidae	<i>Rhabdonella sp</i>	-	-	+		
			<i>R. spiralis</i>	+	-	+		
		Undellidae	<i>Undella sp</i>	+	-	+		
			<i>Amphorellaquadrilineata</i>	-	+	+		
		Tintinnidae	<i>Amphorellopsis acuta</i>	+	-	-		
			<i>Dadayiella ganymedes</i>	+	+	+		
			<i>Eutintinnus lusus undae</i>	+	+	+		
		Agglomerated						
		Codonellopsidae	<i>Codonellopsis ostenfeldii</i>	+	+	+		
			<i>C. schabii</i>	-	+	+		
		Codonellidae	<i>Stenosemellanivalis</i>	+	+	-		
			<i>Dictyoscystaelelgans</i>	-	+	-		
			<i>Tintinnopsis bermudensis</i>	+	-	-		
			<i>T. beroidea</i>	+	+	+		
			<i>T. cylindrica</i>	+	+	+		
		Tintinnidae	<i>T. directa</i>	-	-	+		
			<i>T. lohmanni</i>	+	-	+		
			<i>T. minuta</i>	+	+	+		
			<i>T. mortensenii</i>	-	-	+		
			<i>T. tocaninensis</i>	+	+	+		
			<i>T. uruguayensis</i>	+	+	+		
			<i>Tintinnidium primitivum</i>	+	+	+		
			<i>T. incertum</i>	-	+	+		
			<i>Leprotintinnus nordquistii</i>	-	+	+		
			<i>L. simplex</i>	-	+	-		
		Lohmaniellidae	<i>Lohmaniella oviformis</i>	+	+	+		
		Aloricate ciliates	Choreotrichida	Strobilidiidae	<i>L. spiralis</i>	+	+	+
<i>Rimostrombidium conicum</i>	+				+	-		
<i>Strobilidium acuminatum</i>	+				-	+		
<i>Strombidium acutum</i>	+				+	-		
<i>S. bilobum</i>	+				+	+		
Oligotrichida	Strombidiidae		<i>S. conicum</i>	+	+	+		
			<i>S. cornicopicum</i>	-	+	+		
			<i>S. minimum</i>	+	+	+		
			<i>S. sphericum</i>	+	+	-		
			<i>S. wulffi</i>	+	+	+		
Halterida	Halteridae		<i>Strombidium sp</i>	-	+	+		
			<i>Halteriachlorelligera</i>	+	+	+		
Euplotida	Euplotidae		<i>H. grandinella</i>	-	+	+		
			<i>Euplotesmoebusi</i>	-	+	-		
			<i>E. affinis</i>	-	+	-		
Haptotroidea	Didinidae		<i>Didiniumgaragarantua</i>	-	+	-		
Cyclotrichiida	Mesodiniidae		<i>Myrionectarubrum</i>	-	+	+		
Tetrahymnida	Tetrahymnidae		<i>Tetrahymneapyriformis</i>	-	+	-		
Tontonnida	Tontonnidae		<i>Labeo strobila</i>	+	-	+		
H. dinoflagellates	Peridinales		Protoperidiniaceae	<i>Protoperidinium conicum</i>	+	+	+	
		<i>P. globulus</i>		+	+	+		
		<i>P. oceanicum</i>		+	+	+		
		<i>P. steini</i>		-	+	-		
		<i>P. divergens</i>		+	+	+		
		<i>P. depressum</i>		+	-	+		
		<i>Protoperidinium sp</i>		+	+	-		
		Dinophysiales		Dinophysiceae	<i>Ornithocirus sp</i>	+	+	-
		Gymnodiniales		Gymnodiniaceae	<i>Gyrodinium spiralis</i>	+	+	+
		Noctilucales		Noctilucaceae	<i>Noctiluca scintillans</i>	+	+	-

**Table 1-** Seasonal variations in microzooplankton composition during the Pre-Monsoon (PRM), Southwest Monsoon (SWM) & Northeast Monsoon (NEM)

Seasons	Groups	1	2	3	4
PRM	MZP	15.02	9.25	8.60	6.84
	LCS	2.35	1.04	2.61	3.91
	ACS	1.61	1.61	4.14	5.99
	HDF	0.22	0.37	0.37	0.88
	CNS	3.20	4.80	2.13	3.73
SWM	MZP	25.63	16.31	11.81	14.60
	LCS	4.30	3.33	4.11	3.91
	ACS	5.70	4.32	5.87	8.64
	HDF	0.71	0.49	0.88	0.93
	CNS	5.20	4.40	5.60	9.60
NEM	MZP	15.16	10.16	0.73	4.27
	LCS	2.74	3.33	6.85	5.48
	ACS	2.42	1.38	1.21	4.66
	HDF	0.44	0.38	0.33	0.55
	CNS	2.40	3.20	7.60	3.20

**Table 2** - Seasonal variations in biomass of microzooplankton and its major components (mg C m<sup>-3</sup>) in the surface waters during different seasons. Abbreviations, PRM- Pre Monsoon, SWM Southwest Monsoon, NEM- NEM Northeast Monsoon, MZP- Microzooplankton, LCS- Loricata ciliates. ACS - aloricate ciliates, HDF- Heterotrophic dinoflagellates, CNS - Crustacean nauplius

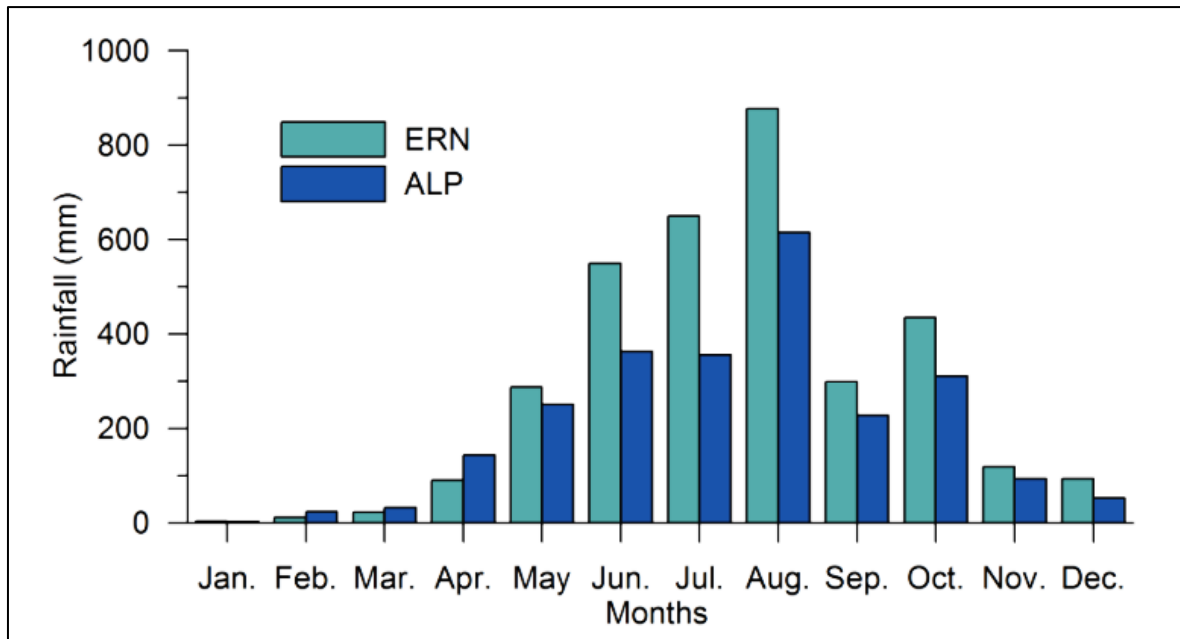
		PRM				SWM				NEM			
		1	2	3	4	1	2	3	4	1	2	3	4
MZP	H'	2.3	2.7	2.8	3.2	2.8	2.8	3.3	2.9	2.9	2.5	2.6	3.1
	d	1.6	2.3	2.4	3.6	2.9	2.7	4.4	3.2	2.8	1.8	2.1	3.4
	J'	1	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1	1	0.9	0.9
CTS	H'	1.6	1.7	1.6	2.2	1.4	1.9	2.4	1.9	1.9	1.9	1.9	2.4
	d	0.7	0.9	0.7	1.4	0.6	1.1	2.1	1.2	1.1	1.2	1	1.8
	J'	1	1	1	0.9	0.8	0.9	0.9	0.9	1	0.9	0.9	1
HDF	H'	0.6	1.3	1.3	1.7	1.6	1.2	1.6	1.7	1.6	0	0.7	1.5
	d	0.2	0.6	0.6	0.8	0.9	0.6	0.9	1	0.7	0	0.2	0.7
	J'	0.9	1	1	0.9	0.9	0.9	0.9	0.9	1		1	0.9
LCS	H'	1.6	1.7	1.6	2.2	1.4	1.9	2.4	1.9	1.3	1.2	1.6	2.1
	d	0.7	0.9	0.7	1.4	0.6	1.1	2.1	1.2	0.5	0.5	0.7	1.3
	J'	1	1	1	0.9	0.8	0.9	0.9	0.9	1	0.9	0.9	1
ACS	H'	1.2	1.7	2.1	2.2	2.1	1.9	2.4	2	2	1.3	1.7	2
	d	0.6	0.9	1.3	1.6	1.5	1.1	1.9	1.2	1.2	0.6	0.9	1.2
	J'	0.8	1	0.9	0.9	0.9	0.9	0.9	0.9	1	1	1	0.9

**Table 3** - Diversity indices of microzooplankton and its components in locations 1-4. Abbreviations. Pre-Monsoon (PRM), Southwest Monsoon (SWM) and Northeast Monsoon (NEM). MZP - Microzooplankton, LCS- Loricated ciliates. ACS - aloricate ciliates, HDF- Heterotrophic dinoflagellates. H' - Shannon-Wiener diversity, d-Margalef species richness, J' -Pielou evenness

Species name	Occurrence	Feeding habit
<i>Acartia danae</i>	PRM <sup>##</sup> , SWM <sup>+</sup> , NEM <sup>#</sup>	Omn <sup>2</sup>
<i>A. erythraea</i>	PRM <sup>#</sup> , SWM <sup>+</sup> , NEM <sup>#</sup>	Omn <sup>1</sup>
<i>Acrocalanus gracilis</i>	PRM <sup>#</sup> , SWM <sup>++</sup> , NEM <sup>#</sup>	Her <sup>1</sup> , Omn <sup>4</sup>
<i>Centropages furcatus</i>	PRM <sup>+</sup> , NEM <sup>+</sup>	Omn <sup>1,2</sup>
<i>C. orsinii</i>	PRM <sup>+</sup> , NEM <sup>+</sup>	Omn <sup>5,6</sup>
<i>C. tenuiremis</i>	SWM <sup>+</sup>	Omn <sup>5,6</sup> , Her <sup>5,6</sup>
<i>Corycaeus danae</i>	PRM <sup>+</sup> , SWM <sup>+</sup> , NEM <sup>#</sup>	Car <sup>1,2</sup>
<i>Euterpina acutifrons</i>	LSWM <sup>+</sup> , NEM <sup>++</sup>	Her <sup>1</sup> , Omn <sup>3</sup> , Det <sup>6</sup>
<i>Labidocera acuta</i>	PRM <sup>+</sup>	Car <sup>1,2</sup>
<i>Macrosetella sp</i>	PRM <sup>+</sup> , SWM <sup>+</sup>	Her <sup>6</sup> , Det <sup>6</sup>
<i>Microsetella sp</i>	PRM <sup>+</sup> , SWM <sup>+</sup>	Her <sup>1</sup> , Det <sup>6</sup>
<i>Oithona rigida</i>	SWM <sup>+</sup>	Car <sup>6</sup> , Omn <sup>6</sup>
<i>O. similis</i>	PRM <sup>+</sup> , SWM <sup>*</sup> , NEM <sup>+</sup>	Car <sup>6</sup> , Omn <sup>1,3</sup>
<i>Paracalanus parvus</i>	PRM <sup>##</sup> , LSWM <sup>#</sup> , NEM <sup>##</sup>	Her <sup>2</sup> , Omn <sup>3</sup>
<i>Pseudodiaptomus serricaudatus</i>	SWM <sup>##</sup>	Her <sup>2</sup> , Omn <sup>1</sup>
<i>Temora turbinata</i>	LSWM <sup>##</sup>	Her <sup>2</sup> , Omn <sup>1,3</sup>
<i>Undinula vulgaris</i>	NEM <sup>+</sup>	Omn <sup>7</sup>

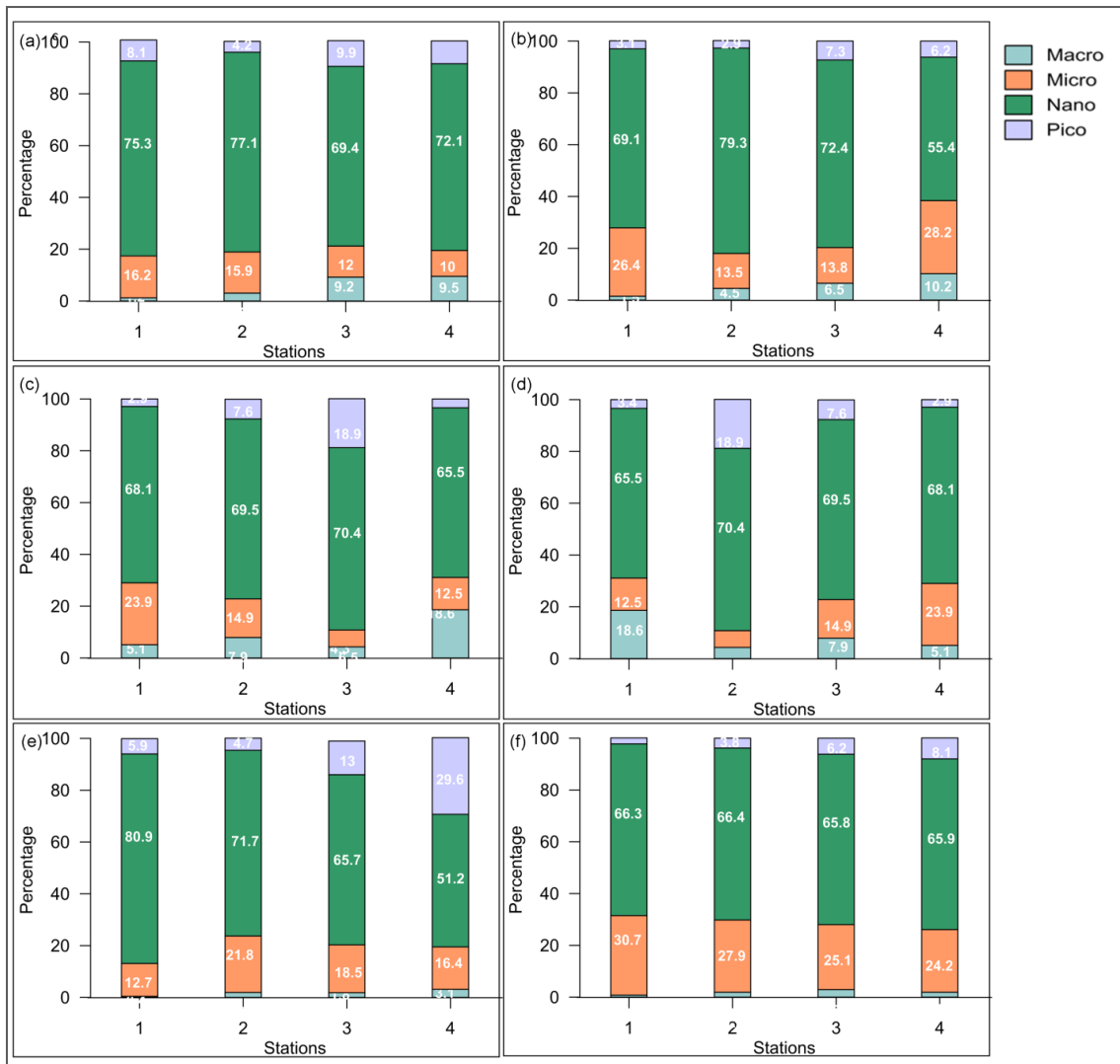
**Table 4** - Copepod abundance and their feeding behavior. Abbreviations: Pre-Monsoon (PRM), Southwest Monsoon (SWM) and Northeast Monsoon (NEM). Symbols: > 1% to the total density in any one of the sampling periods and their feeding habit. Symbols: + indicates >1-5%, ++ indicates >5-10 %, # indicates >10-20 %, ## indicates >20-30 %, \* indicates > 60-70%.<sup>1</sup>Rakesh et al., 2008.,<sup>2</sup>Richardson et al., 2006.,<sup>3</sup>Broglia et al., 2004.,<sup>4</sup>Mc Kinnon and Ayukai., 1996.,<sup>5</sup>Calbet et al., 2007;<sup>6</sup>Jagadeesan et al., 2017.,<sup>7</sup>Goswami and Padmavati., 1996

## Supplementary Materials



**Supplementary Figure 1** - Monthly rainfall in Ernakulum (ERN) and Alappuzha (ALP), two major revenue districts encompassing the catchment areas of the Kochi backwaters.





**Supplementary Figure 2** - Percentage contribution of fractionated chlorophyll *a* in locations 1, 2, 3 & 4 during the Pre-Monsoon (upper panel), Southwest Monsoon (middle panel) & Northeast Monsoon (lower panel). Figure a, c, e represent surface waters and b, d, f represent the subsurface waters

Parameters	Stations	PRM		SWM		NEM	
		S	SS	S	SS	S	SS
Salinity	1	32.89 (0.73)	34.34 (0.21)	24.64 (11.68)	28.44 (9.33)	29.93 (0.85)	32.92 (1.44)
	2	34.03 (0.21)	34.33 (0.28)	27.97 (6.52)	34.68 (0.66)	33.69 (0.32)	34.25 (0.59)
	3	34.17 (0.30)	34.51 (0.5)	30.04 (4.66)	35.28 (0.32)	33.35 (1.04)	34.48 (0.39)
	4	34.30 (0.04)	34.57 (0.52)	30.65 (6.05)	35.40 (0.24)	33.75 (0.98)	34.72 (0.51)
Temperature (°C)	1	30.88 (0.48)	29.74 (0.49)	27.53 (1.35)	26.70 (1.43)	31.33 (1.57)	29.36 (0.52)
	2	30.52 (0.63)	29.52 (0.54)	28.04 (1.33)	26.21 (2.14)	29.49 (0.77)	28.74 (0.38)
	3	30.36( 0.74)	29.25 (0.34)	27.94 (1.15)	25.46 (2.34)	29.28 (0.59)	28.82 (0.40)
	4	30.26 (0.96)	29.16 (0.28)	28.07 (0.69)	25.33 (2.15)	29.12 (0.76)	28.69 (0.30)
Turbidity (NTU)	1	5.22 (2.60)	7.64 (1.82)	8.91 (3.35)	21.24(13.15)	5.27 (1.13)	23.69(14.48)
	2	1.36 (0.70)	5.44 (6.22)	2.72 (0.73)	9.57 (16.10)	1.68 (1.09)	10.81 (5.01)
	3	1.12 (0.99)	4.98 (6.55)	2.66 (0.64)	8.37 (5.09)	1.10 (0.66)	7.95 (5.01)
	4	0.70 (0.25)	4.53 (3.16)	2.11 (0.49)	7.64 (12.84)	0.50 (0.15)	4.46 (2.50)
DO (ml L <sup>-1</sup> )	1	5.89 (1.12)	3.71 (1.10)	8.07 (2.13)	2.99 (0.96)	9.14 (2.65)	6.66 (1.57)
	2	5.96 (0.63)	3.79 (1.73)	8.0 (2.36)	1.45 (0.65)	7.88 (1.65)	7.04 (1.25)
	3	5.57 (1.42)	3.44 (1.90)	8.37 (2.17)	1.32 (0.84)	8.09 (1.33)	7.62 (1.57)
	4	5.32(1.23)	4.06 (0.97)	7.07 (0.95)	1.49 (0.76)	8.64 (1.40)	6.48 (0.42)
Nitrate (µm)	1	1.5 (0.9)	0.9(0.3)	2.9(1.3)	5.6 (4.4)	0.7 (0.5)	0.8 (0.7)
	2	0.7(0.6)	0.7(0.4)	1.7(1.5)	6.9 (5.1)	0.3 (0.1)	0.6(0.1)
	3	0.5(0.4)	0.8(0.5)	1.5(0.3)	3.4(1.7)	0.5 (0.3)	0.7 (0.4)
	4	0.6(0.2)	0.5(0.1)	1.3(0.8)	3.1(3.5)	1 (0.7)	1.6 (0.8)

**Supplementary Table 1** - Seasonal variations of environmental and biological parameters during the Pre-Monsoon (PRW), Southwest Monsoon (SWM) & Northeast Monsoon (NEM) in the locations 1-4. Abbreviations S - Surface, SS – Subsurface/near-bottom. SD values in parenthesis.

	Species	Locations			
		1	2	3	4
	Hyaline				
	<i>Favella ehernbergii</i>	+	+	-	-
	<i>F. philippinensis</i>	+	-	-	-
	<i>Rhabonella spiralis</i>	-	-	+	-
	<i>Undella sp</i>	-	-	+	-
	<i>Amphorellopsis acuta</i>	-	-	+	+
	<i>Dadayiella ganymedes</i>	-	+	-	-
	<i>Eutintinnus lusus undae</i>	+	-	-	+
	Agglomerated				
	<i>Codonellopsis ostenfeldii</i>	+	-	+	-
	<i>Tintinnopsis bermudensis</i>	-	-	+	-
	<i>T. beroidea</i>	++	++	-	-
Loricata ciliates	<i>T. cylindrica</i>	+	-	-	-
	<i>T. lohmanni</i>	-	-	-	+
	<i>T. minuta</i>	-	-	-	+
	<i>T. tocaninensis</i>	++	+	-	-
	<i>T. uruguayensis</i>	+	-	-	-
	<i>Tintinnidium primitivum</i>	++	+	+	+
	<i>Stenosemellanivalis</i>	+	-	-	-
	<i>Lohmaniella oviformis</i>	+	+	-	-
	<i>L. spiralis</i>	++	+	+	++
	<i>Rimostrombidium conicum</i>	+	+	-	-
	<i>Strombidium acuminatum</i>	+	+	-	-
	<i>Strombidium acutum</i>	-	-	+	-
	<i>S. bilobum</i>	+	+	-	-
	<i>S. conicum</i>	++	-	+	+
Aloricate ciliates	<i>S. minimum</i>	++	++	-	+
	<i>S. sphericum</i>	+	+	+	-
	<i>S. wulffi</i>	+	-	+	-
	<i>Halteriachlorelligera</i>	+	++	+	-
	<i>Labeo strobila</i>	*	++	-	+
	<i>Protoperidinium conicum</i>	+	-	-	-
	<i>P. globulus</i>	+	-	-	-
	<i>P. oceanicum</i>	-	+	+	-
H. dinoflagellates	<i>P. divergens</i>	+	+	+	+
	<i>P. depressum</i>	-	-	+	-
	<i>Protoperidinium sp</i>	++	-	-	+
	<i>Ornithocirus sp</i>	-	+	-	-
	<i>Gyrodinium spiralis</i>	+	+	+	-
	<i>Noctiluca scintillans</i>	+	-	-	-

**Supplementary Table 2** - Microzooplankton composition during the Pre-Monsoon (PRM). + denotes presence and - denotes absence.

	Species	Locations					
		1	2	3	4		
	Hyaline						
	<i>Favella philippinensis</i>	+	-	-	-		
	<i>Helicostemella acuta</i>	-	-	+	-		
	<i>Metacylis sp</i>	-	+	-	-		
	<i>Petalotricha ampulla</i>	+	-	-	-		
	<i>Dadayiella ganymedes</i>	+	+	+	-		
Loricata ciliates	<i>Eutintinnus lusus undae</i>	+	+	-	-		
	<i>Amphorellaquadrilineata</i>	-	-	-	+		
	<i>Agglomerated</i>						
	<i>Codonellopsis ostenfeldii</i>	-	+	-	+++		
	<i>C. schabii</i>	+	-	-	-		
	<i>Dictyoscystaelelgans</i>	-	+	-	-		
	<i>Stenosemellanivalis</i>	-	+	+	-		
	<i>Tintinnopsis beroidea</i>	-	+	+	+		
	<i>T. cylindrica</i>	-	+	+	-		
	<i>T. minuta</i>	-	-	+	+		
	<i>T. tocaninensis</i>	+	+	-	-		
	<i>T. uruguayensis</i>	++	+	-	-		
	<i>Tintinnidium primitivum</i>	+++	++	++	++		
	<i>T. incertum</i>	-	+	-	-		
	<i>Leprotintinnus nordquistii</i>	+	+	+	-		
	<i>L.simplex</i>	-	+	-	-		
	<i>Lohmaniella oviformis</i>	+	+	+	++		
	<i>L. spiralis</i>	**	+	++	+++		
	<i>Rimostrombidium conicum</i>	-	+	-	-		
	<i>Strombidium acutum</i>	+	-	-	-		
	<i>S. bilobum</i>	+	+	+	+		
Aloricate ciliates	<i>S.conicum</i>	*	+	+	+++		
	<i>S.cornicopicum</i>	-	+	+	+		
	<i>S.minimum</i>	++	+	-	+		
	<i>S. sphericum</i>	+	-	-	+		
	<i>S. wulffi</i>	++	+	++	+		
	<i>Strombidium sp</i>	-	+	-	-		
	<i>Halteriachlorelligera</i>	-	-	++	+		
	<i>H. grandinella</i>	-	-	-	+		
	<i>Euplotesmoebusi</i>	++	+	-	-		
	<i>E.affinis</i>	-	+	-	-		
	<i>Didiniumgaragarantua</i>	-	+	-	-		
	<i>Myrionectarubrum</i>	**	+++	+	+		
	<i>Tetrahymneapyriformis</i>	-	+	-	-		
	<i>Protopteridinium conicum</i>	+	-	-	-		
	<i>P.globulus</i>	+	-	+	+		
	<i>P.oceanicum</i>	+	+	-	-		
	<i>P. steini</i>	-	+	-	++		
H. dinoflagellates	<i>P. divergens</i>	+++	++	++	+		
	<i>Protopteridinium sp</i>	+	-	-	+		
	<i>Ornithocirus sp</i>	-	+	-	-		
	<i>Gyrodinium spiralis</i>	++	++	+	+		
	<i>Noctiluca scintillans</i>	+	+	+	+		

**Supplementary Table 3 -** Microzooplankton composition during the Southwest Monsoon (SWM).  
+ denotes presence and - denotes absence.

	Species	Locations			
		1	2	3	4
	<b>Hyaline</b>				
	<i>Helicostemella acuta</i>	-	-	+	+
	<i>Metacylis sp</i>	-	-	-	+
	<i>Rhabonella spiralis</i>	-	-	+	-
	<i>Rhabdonella sp</i>	-	-	-	+
<b>Loricata ciliates</b>	<i>Undella sp</i>	-	-	-	+
	<i>Amphorellaquadrilineata</i>	-	-	+	+
	<i>Dadayiella ganymedes</i>	-	-	-	+
	<i>Eutintinnus lusus undae</i>	-	-	+	-
	<b>Agglomerated</b>				
	<i>Codonellopsis ostenfeldii</i>	++	-	+	-
	<i>C. schabii</i>	+	-	-	-
	<i>Leprotintinnus nordquistii</i>	+	+	-	-
	<i>Tintinnopsis beroidea</i>	+	++	+	-
	<i>T. cylindrica</i>	+	+	-	-
	<i>T. directa</i>	+	+	-	-
	<i>T.lohmanni</i>	+	+	-	-
	<i>T. minuta</i>	-	-	+	+
	<i>T.mortensenii</i>	+	+	-	-
	<i>T.tocantinensis</i>	+	+	++	-
	<i>T. uruguayensis</i>	+	-	-	-
	<i>Tintinnidium primitivum</i>	+	*	-	-
	<i>T. incertum</i>	+	-	-	-
	<i>Lohmaniella oviformis</i>	+	+	+	+
	<i>L.spiralis</i>	-	+	+	+
	<i>Strombidium acuminatum</i>	*	-	-	+
	<i>S. bilobum</i>	+	-	-	-
	<i>S. conicum</i>	++	+	+	-
	<i>S.cornicopicum</i>	+	-	-	-
<b>Aloricata Ciliates</b>	<i>S. minimum</i>	++	-	+	+
	<i>S. wulffi</i>	+	-	-	-
	<i>Strombidium sp</i>	-	+	-	+
	<i>Halteriachlorelligera</i>	+	-	-	-
	<i>H. grandinella</i>	+	-	-	+
	<i>Myrionectarubrum</i>	-	+	-	+
	<i>Protoperidinium conicum</i>	-	-	-	+
	<i>P.globulus</i>	+	-	-	-
<b>H. dinoflagellates</b>	<i>P.oceanicum</i>	++	++	-	+
	<i>P.divergens</i>	+	+	+	+
	<i>P. depressum</i>	++	-	-	+
	<i>Gyrodinium spiralis</i>	+	-	-	+

**Supplementary Table 4** - Species list of microzooplankton during the Northeast Monsoon (NEM). + denotes presence and – denotes absence.