

Waning of plankton food web in the upstream region of the Cochin backwaters during the Southwest Monsoon

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Heterotrophic bacteria (0.2-2 μm), pico-phytoplankton (0.2-2 μm), nano-phytoplankton (2-20 μm), micro-phytoplankton (>20 μm), heterotrophic nanoflagellates (2-20 μm), and micro-zooplankton (20 – 200 μm) present in the Cochin backwaters were quantified during the Southwest Monsoon. High fresh water influx during the period transformed the Cochin backwaters into an extensive fresh water zone with high levels of nutrients (nitrate av. 20 μM ; phosphate av. 3 μM), which favoured high phytoplankton abundance (av. $31 \pm 9 \times 10^4$ No. L^{-1}) and chlorophyll *a* (av. 5.2 ± 3.2 mg m^{-3}). Autotrophic pico-plankton and nano-plankton contributed the majority (av. $69 \pm 16\%$) of the total chlorophyll *a* while heterotrophic bacteria was found to be high throughout the study area (av. $3 \pm 0.6 \times 10^8$ No. L^{-1}). Abundance of heterotrophic nano-flagellates and micro-zooplankton were markedly lower in the freshwater dominant region (av. $0.5 \pm 0.3 \times 10^6$ No. L^{-1} and av. 3 ± 1 No. L^{-1}) as compared to the downstream region (av. $6 \pm 3 \times 10^6$ No. L^{-1} and av. 3222 ± 3619 No. L^{-1}). This clearly indicated a weak microbial food web in a major part of the Cochin backwaters during the Southwest Monsoon. The ecological implication is that it leads to inefficient transfer of bacterial and pico/nano-phytoplankton biomass to higher trophic levels. This study provides further evidences to our earlier observation that most of the heterotrophic bacteria and phytoplankton carbon in monsoonal estuaries gets transported to the coastal regions during the Southwest Monsoon.

[**Keywords:** Plankton food web, microzooplankton, mesozooplankton, Cochin backwaters, Arabian Sea.]

Introduction

Microbial food web refers to the combined trophic interactions among microbes in aquatic environments. It consists of autotrophic pico-plankton (0.2 - 2 μm), heterotrophic bacteria (0.2 - 2 μm), autotrophic nano-plankton (2 - 20 μm), heterotrophic nano-flagellates (2 - 20 μm) and micro-zooplankton (20- 200 μm)¹. It is fairly well-understood that ‘microbial loop’, the ‘heterotrophic pathway’ of microbial food web, is responsible for shunting a considerable part of the organic carbon produced by phytoplankton to higher trophic levels^{2,3}. The other component of microbial food web, the ‘herbivorous pathway’, channels organic carbon produced by autotrophic picoplankton and nano-phytoplankton to higher trophic levels¹.

Among various components of microbial plankton food web, heterotrophic bacteria and micro-zooplankton inhabiting the Zuary and Cochin backwaters (two major estuaries along the west coast of India) have received scientific attention⁴⁻⁸. In these estuaries, phytoplankton

production exceeds heterotrophic bacteria production during the Pre-monsoon (March – May), whereas it is vice versa during the Southwest Monsoon (June – September). The former condition is called ‘net autotrophy’ while the latter is referred to as ‘net heterotrophy’⁵⁻⁸. The prominent decline in phytoplankton production in these estuaries during the Southwest Monsoon plays a major role in causing ‘net heterotrophy’^{5,8}.

Cochin backwaters, the largest estuarine system along the west coast of India, is influenced by intense rain and fresh water influx during the Southwest Monsoon. As a result, salinity in a vast area of the Cochin backwaters reaches near zero values⁷. During the Southwest Monsoon, the high levels of allochthonous organic carbon mainly support the heterotrophic bacteria production ($1-2 \times 10^7$ and $1-4 \times 10^8$, respectively)⁸. The high heterotrophic bacteria biomass present during the Southwest Monsoon is expected to provide significant nutritional support to higher trophic levels through microbial loop^{5,8}. However, a number of studies showed a prominent decline in

the abundance of micro-zooplankton and meso-zooplankton communities in the Cochin backwaters during the Southwest Monsoon due to high freshwater influx^{7,9,10-12}. Therefore, it is important to know how various components of the microbial food web (heterotrophic bacteria, autotrophic pico-plankton, autotrophic nano-plankton and heterotrophic nano-flagellates) in the Cochin backwaters respond to heavy freshwater influx during the Southwest Monsoon. In order to analyze this, we measured different components of the microbial plankton food web in August 2007 in the Cochin backwaters in relation to heavy fresh water influx. Present study was primarily targeted at drawing information on the ecological significance of the microbial food web in a monsoonal estuary during the Southwest Monsoon. Results of the present study may be applicable to several similar estuarine systems in the tropical region where heavy seasonal rain and freshwater influx occurs.

Materials and Methods

Cochin backwaters extends from 9° 30' to 10° 10'N and 76° 15' to 76° 25 'E (Azhikode to Alappuzha). It forms a complex system of shallow estuarine network running parallel to the coastline of Kerala with two permanent openings into the Arabian Sea – one at Cochin and the other at Azhikode, six rivers debouches into this estuary. Periyar and Muvattupuzha discharge into the northern part of the backwater and hence have an active influence on the prevailing salinity in the estuarine regions of the Cochin backwaters. Tidal incursion from the adjacent Arabian Sea (tidal range ~1m) contributes a regular flow of salt water into the Cochin backwaters, which diminishes considerably towards the head of the estuary⁹. During the peak Southwest Monsoon (July/August) heavy rain and freshwater influx cause near zero values of salinity over a large portion of the Cochin backwaters¹¹.

In August 2007 (Southwest Monsoon), field sampling was carried out at 8 locations in the Cochin backwaters; two in the barmouth area and remaining in the interior of the backwaters (Fig. 1). A speed boat was used to conduct the field works, and water samples were collected from the

surface (0.5m) and bottom (2m) using a 5 liter Niskin sampler. Water samples were used for measuring different physicochemical parameters. Salinity was measured using a digital salinometer (DIGI – AUTO, 3G Tsurumi Seiki, Japan, accuracy ± 0.001). Dissolved oxygen (DO) was measured by the Winkler method and nitrate (NO_3) using a spectrophotometer.

Water samples (500ml) were filtered through Millipore membrane filters (0.2 μm) for total chlorophyll *a*. Fractionation of phytoplankton biomass in terms of chlorophyll *a* was carried out by processing 2.5 L water samples from each sampling depth. Samples were fractionated to account for chlorophyll *a* contribution of each size classes of

phytoplankton such as pico-phytoplankton (0.2-2 μm), nano-phytoplankton (2-20 μm) and micro-phytoplankton (>20 μm). The fractionation was carried out by serial filtration procedure. The water samples were mixed well before each set of filtration. In the first step, 500ml of water samples were filtered through 3 μm glass fiber filter to collect phytoplankton >3 μm on the filter. In the second step, 500 ml water samples that had been pre-filtered through 20 μm bolting silk were filtered through 3 μm glass fiber filter to collect the nano-phytoplankton. The resultant filtrate (free of phytoplankton >3 μm) was then filtered through 0.2 μm Millipore membrane filters to collect the pico-phytoplankton. The chlorophyll *a* content of the phytoplankton collected on various filters was extracted in 90% acetone and analyzed using a Turner 10 - AU fluorometer¹³. Micro-phytoplankton (>20 μm) contribution to the total chlorophyll *a* was calculated by subtracting the nano-phytoplankton chlorophyll *a* from the amount of total chlorophyll *a* collected on 3 μm filters by direct filtration of samples.

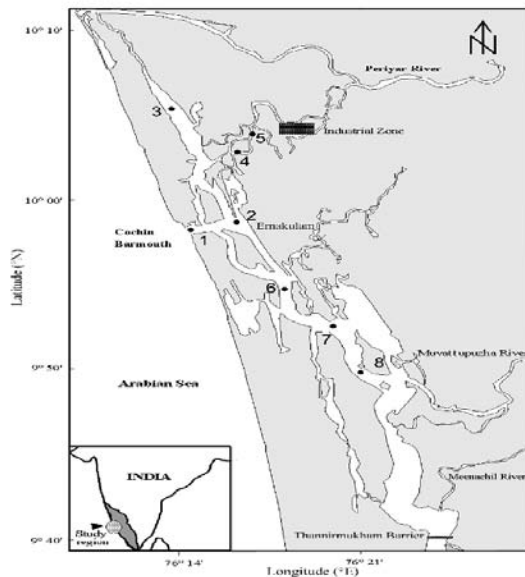


Fig. 1 - Station locations

Water samples (5 ml) were preserved in 3% glutaraldehyde and used for estimating the heterotrophic bacteria abundance and biomass. Heterotrophic bacteria abundance was estimated following direct count method¹³. Samples stained with DAPI (0.01%) were passed through 0.22 μm black polycarbonate membrane filter placed on top of a backing filter. The samples on the filter paper were mounted on a glass slide using a small drop of immersion oil and cover-slip. Heterotrophic bacteria was enumerated under an epifluorescence microscope (Olympus BX 41, Japan) with a blue filter set. The counting of heterotrophic bacteria was conducted in triplicates considering 20 fields per sample and expressed as L^{-1} .

Water samples (20 ml) fixed in 0.3% final concentration of glutaraldehyde were used for measuring heterotrophic nano-flagellates. Samples were processed using proflavine to distinguish the autotrophic and heterotrophic nanoflagellates in a single preparation¹⁴. Water samples were stained with 20 $\mu\text{g ml}^{-1}$ of proflavine for five minutes and then concentrated on a 0.8 μm black polycarbonate filter placed on top of a backing filter. Samples on the filter paper were mounted on a glass slide using a small drop of immersion oil and cover slip. Samples processed on slides

were analyzed using an epifluorescence microscope with blue light excitation.

Micro-zooplankton was collected by gently pre-filtering 1 L water samples through a 200 μm bolting silk to remove meso-zooplankton. These prefiltered samples were then collected into another set of polythene bottles. Acid Lugol's iodine (3%) was added to all samples and kept for settling under gravity. After 48 hours, supernatants were decanted by siphoning till ~ 100 ml volume remained in the bottles. The end of the tubing, which was immersed in the sample, was tied with a 20 μm Nitex screen as a safeguard for retaining all organisms of ≥ 20 μm size in the bottom of the carboy. Two days before the analysis by microscope, initial sample concentrates (ca. 100 ml) were allowed to settle down again for 48 hours in a settling chamber and observed under an inverted microscope (100 – 400X). Micro-zooplankton in the samples was categorized broadly into ciliates, heterotrophic dinoflagellates and crustacean larvae. Ciliates and heterotrophic dinoflagellates were identified up to the species level based on literature¹⁵⁻¹⁷. Conversion of bio-volumes into carbon was carried out using a factor of 0.19 $\text{pgC } \mu\text{m}^{-3}$ for ciliates and 0.14 $\text{pgC } \mu\text{m}^{-3}$ for dinoflagellates¹³. Crustacean larval forms were identified and enumerated and the biomass was estimated based on standard literature¹⁸.

Results

Variation in water temperature between locations was only marginal; surface temperature was higher (av. 31.03 ± 0.76 $^{\circ}\text{C}$) compared to the bottom (av. 29.77 ± 0.774 $^{\circ}\text{C}$) (Fig. 2). Salinity was remarkably high in locations close to the barmouth. Surface salinity varied markedly in the study area (av. 1.87 ± 3.64) with the highest at location 1 followed by location 2. In the interior of the backwaters, relatively high salinity (~ 0.7) was also found at location 3 compared to other locations. Salinity distribution in the bottom water was similar to the surface, but the variation between locations was more prominent (av. 5.06 ± 11.98) (Fig. 2). However, DO concentration was in saturated level in the surface (av. 4.94 ± 0.39

mg L⁻¹) and bottom waters (av. 4.9 ± 0.78 mg L⁻¹) and no specific pattern was evident in its overall distribution (Fig. 2). The NO₃ concentration was exceptionally high in all locations (av. 21.84 ± 6.46 μM in the surface and av. 21.9 ± 8.18 μM in the bottom, respectively) with the highest in the bottom waters of location 5 (Fig. 2). The NO₃ and PO₄ levels were generally high in locations 4 and 5, which were in the industrial area. Phosphate level was the lowest in the barmouth area (Fig. 2).

High concentration of chlorophyll *a* with large variation between locations (av. 5.2 ± 3.2 mg m⁻³) was evident in the study area. High chlorophyll *a* level was found both in the barmouth region (locations 1 & 2) and fresh water zones (location 6) (Fig. 3a & b). Correlation between chlorophyll

a and salinity showed a weak positive relation ($r = 0.28$, $n = 16$, $p > 0.01$) indicating that freshwater influx during the Southwest Monsoon had an insignificant impact on the chlorophyll *a* levels in the Cochin backwaters. Results of size fractionation of phytoplankton clearly showed that a majority of the chlorophyll *a* concentration in the Cochin backwaters (av. $69 \pm 16\%$) was contributed by pico and nano fractions (Fig. 3c). Among small fractions, contribution of nano-phytoplankton was relatively high (av. $45 \pm 18\%$) compared to the pico-phytoplankton (av. $24 \pm 12\%$). Similar to the total chlorophyll *a*, the pico-phytoplankton and nano-phytoplankton chlorophyll *a* levels showed insignificant correlation with salinity ($r = 0.192$, $n = 16$ and $r = 0.42$, $n = 16$, respectively)

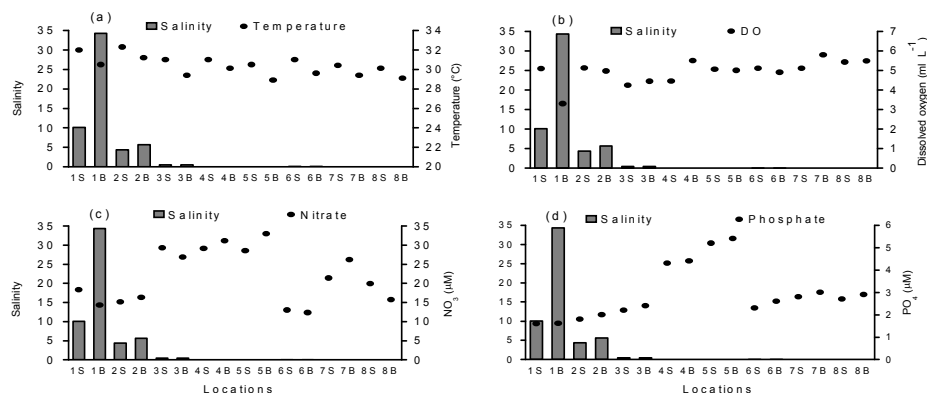


Fig. 2 - Distribution of (a) temperature (b) dissolved oxygen (c) nitrate and (d) phosphate with respect to salinity. Abbreviations: (s) surface and (b) bottom.

indicating that their abundance in the Cochin backwaters was not inhibited by fresh water conditions. The relative contribution of micro-phytoplankton to the total chlorophyll *a* has varied between locations (av. $25.6 \pm 16\%$). The micro-phytoplankton chlorophyll *a* and abundance were higher in the estuarine areas (av. 2 ± 1.7 mg m⁻³ and av. $38.8 \pm 7.94 \times 10^4$ No. L⁻¹, respectively) compared to the freshwater zones (av. 1 ± 0.9 mg m⁻³ and av. $38.8 \pm 7.8 \times 10^4$ No. L⁻¹) (Fig. 3c & 4a). This feature was clear in the correlation analysis between micro-phytoplankton abundance and salinity ($r = 0.78$, $n = 16$, $p < 0.05$).

Heterotrophic bacteria density and biomass were high throughout the Cochin backwaters (> 2.3

$\times 10^8$ No.L⁻¹ and 2 mgC L⁻¹, respectively – Fig. 4b & c), and its variation between locations were only marginal (av. $3.04 \pm 0.62 \times 10^8$ No. L⁻¹ and 3.34 ± 0.69 mgC L⁻¹, respectively). Relatively high heterotrophic bacteria abundance was found both in the high saline (location 1; av. $4 \pm 0.1 \times 10^8$ No.L⁻¹) and low saline regions (location 5; av. $3.84 \pm 0.01 \times 10^8$ No. L⁻¹). This indicated that the heterotrophic bacteria abundance in the Cochin backwaters was not inhibited by extremely low saline conditions. This was also evidenced as a weak positive correlation between heterotrophic bacteria abundance and salinity ($r = 0.42$, $n = 16$, $p > 0.01$). In contrast with heterotrophic bacteria, heterotrophic nano-flagellate abundance in the

study area showed marked variations between locations (av. $2.6 \pm 3.2 \times 10^6 \text{ L}^{-1}$). It was prominently higher in the estuarine region (av. $6 \pm 2.9 \times 10^6 \text{ L}^{-1}$) compared to the freshwater zones (av. $0.5 \pm 0.3 \times 10^6 \text{ L}^{-1}$) (Fig. 4d). This was a clear evidence of inhibition of extreme low salinity on heterotrophic nano-flagellate abundance in the Cochin backwaters. This feature was also evident in the correlation between heterotrophic nano-flagellates abundance and salinity ($r = 0.85$, $n = 16$, $p < 0.01$).

Microzooplankton community in the Cochin backwaters was dominated by ciliates (av. 70 ± 25 %) followed by heterotrophic dinoflagellates (av. 21.5 ± 16.1 %). A total of 14 microzooplankton species, mostly belonging to loricate (tintinnid) ciliates, were found in the study area. The common tintinnids recorded in the study area were in the following order of abundance - *Tintinnopsis beroidea* > *Tintinnidium incertum* > *Tintinnopsis lohmanni* > *T. tubulosa* > *T. uruguayensis*. Aloricate ciliates were limited to only three species, one each belonging to the genera

Strombidium, *Strobilidium* and *Strombidinopsis*. The abundance of crustacean larvae was very low during the study period (av. 3 ± 5 %). The micro-zooplankton abundance and biomass distribution in the study area showed marked variations between locations (av. $1247 \pm 2668 \text{ No. L}^{-1}$ and av. $28.6 \pm 60.9 \text{ mg L}^{-1}$) (Fig. 4e & f). A sharp decline of micro-zooplankton abundance was found in the freshwater zones (av. $3 \pm 1 \text{ No. L}^{-1}$) compared to the estuarine region (av. $3222 \pm 3619 \text{ No. L}^{-1}$). Micro-zooplankton abundance and biomass showed significant positive correlation with salinity ($r = 0.8916$, $n = 16$, $p < 0.01$ and $r = 0.8916$, $n = 16$, $p < 0.01$, respectively).

Discussion

During the Southwest Monsoon, due to heavy rainfall and runoff (40 – 50 cm rainfall can occur in a few hours), freshwater occupies a major part of the Cochin backwaters^{7,11}. This feature was clear during the present study also, as freshwater zones were present in the Cochin backwaters except areas closer to the barmouth. As a result of high runoff, nutrient levels in the Cochin backwaters was remarkably high (nitrate >20 μM ; phosphate >10 μM). This high nutrient level in the Cochin backwaters is contributed by various sources such as industrial waste, domestic sewage and agricultural wastes^{11,19}. The high concentration of chlorophyll *a* encountered in the Cochin backwaters (av. $5.2 \pm 3.2 \text{ mg m}^{-3}$) signifies the presence of abundant primary producers. Several earlier studies have shown high chlorophyll levels in the Cochin backwaters during the Southwest Monsoon period as a result of high concentration of nutrients in the system^{10,12}. Phytoplankton species tolerant to low salinity conditions such as *Skeletonema*, *Nitzschia*, *Plectorina*, *Volvox*, *Pediastrum* and *Desmids* are abundant in the Cochin backwaters during the Southwest Monsoon. During the Pre- Monsoon, besides *Nitzschia* and *Skeletonema*, other diatoms adapted to mesohaline conditions such as *Chaetoceros*, *Coscinodiscus* and *Pleurosigma* also dominated in the Cochin backwaters. Correlation between

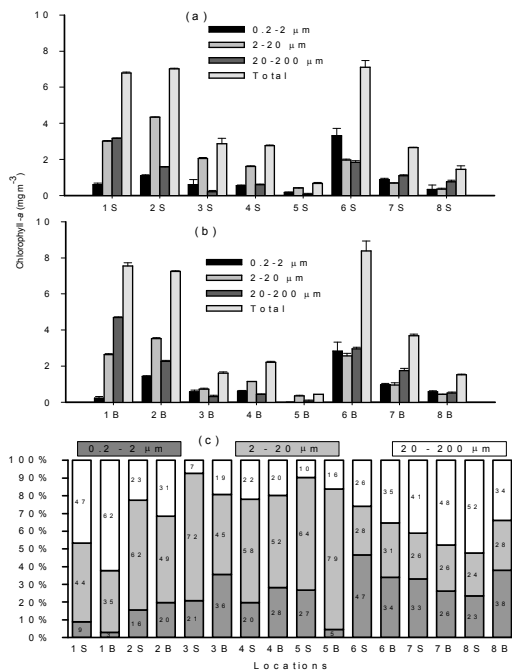


Fig. 3 - Contribution of different size groups of phytoplankton to the total chlorophyll *a*. Abbreviations: (s) surface and (b) bottom.

micro-phytoplankton abundance and salinity showed a positive relation ($r = 0.78$, $n = 16$, $p < 0.05$). This was due to the high abundance of estuarine/coastal diatoms *viz.*, *Nitzschia*, *Skeletonema*, *Chaetoceros*, *Coscinodiscus* and *Pleurosigma* in the barmouth region. On the other hand, limnohaline/estuarine forms *Nitzschia*, *Skeletonema*, *Pleodorina*, *Volvox*, *Pediastrum* and *Desmids* were the common ones in the low saline zones.

The meso-zooplankton community in the Cochin backwaters is markedly low during the Southwest Monsoon^{9,12}. A few earlier studies have linked this low abundance of mesozooplankton in the Cochin backwaters with the 'dilution effect' exerted by the heavy rain and flood waters^{9,20}. Heavy rain during the Southwest Monsoon causes the rivers to flood

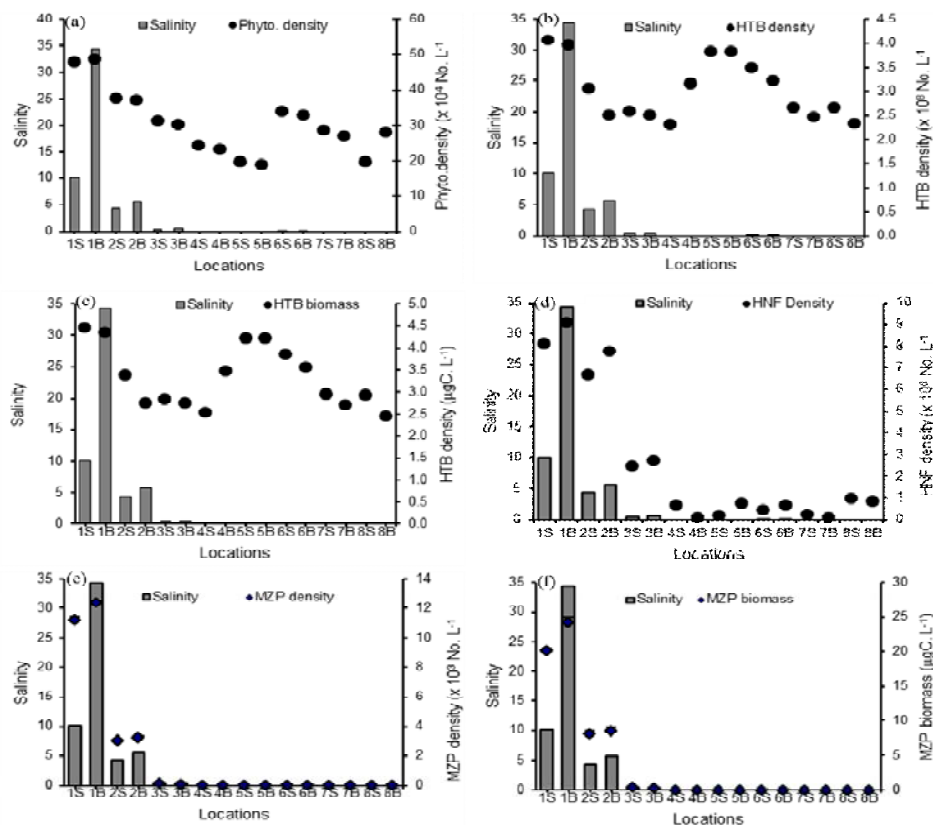


Fig. 4 - Distribution of (a) micro-phytoplankton density (b) heterotrophic bacteria density (c) heterotrophic bacteria biomass (d) heterotrophic nanoflagellate density (e) microzooplankton density and (f) microzooplankton biomass with respect to salinity. Abbreviations: (s) surface and (b) bottom.

and flush out the mesohaline waters from the upper and middle reaches of the Cochin backwaters. The meso-zooplankton community present in these mesohaline waters would also be rapidly washed down and widely dispersed (diluted) in the lower reaches²⁰. This condition lasts for some time, but it is too short a period for the development of a well-adapted low saline

zooplankton community in the middle and lower reaches^{9,20}. This ultimately causes sparse zooplankton community in most part of the Cochin backwaters during the Southwest Monsoon. These observations underscore the old hypothesis that the estuarine plankton community is more physically controlled than biologically accommodated^{9, 21}. Since the 'dilution effect' of

floodwater also influences other communities in the Cochin backwaters, it would be interesting to see the response of other plankton communities to floodwater conditions.

The ecological role of pico- and nano-phytoplankton in marine systems has been well established globally^{22,23}. However, quantitative information on these components from Indian waters is very sparse²⁴. Since most of our earlier information about pico- and nano-plankton is from the marine environments²⁵, there has been a general belief that these components may not be significant in estuarine and freshwater conditions. In the present study, it was clear that pico and nano-plankton are significant in the estuarine and freshwater conditions, as well. One possibility for the dominance of pico and nano-phytoplankton in the Cochin backwaters could be the low light levels available during the Southwest Monsoon period. Along with high freshwater influx, the suspended sediments in the system reach exceptional levels causing a significantly shallow euphotic column (~1m). Pico- and nano-plankton groups elicit greater advantages from the low light levels as compared to the other micro plankton groups²⁴. Another possible reason could be the fast generation time of pico-plankton that may enable them to reproduce faster and maintain high abundance within a short time period²⁵.

It is well-recognized that there is an abundant heterotrophic bacteria community (normally $> 2 \times 10^8$ No. L⁻¹) in Indian estuaries irrespective of seasons^{5,8,26}. High abundance of heterotrophic bacteria in these estuaries during the Southwest Monsoon is primarily governed by the high availability of allochthonous dissolved organic carbon. It has also been shown that the heterotrophic bacteria community at various salinity levels in the Cochin backwaters responds differently to same nutritional conditions²⁶. However, no published works are available so far on various phylogenetic categories of heterotrophic bacteria in these estuaries. Studies conducted elsewhere based on molecular and fluorescence microscope techniques (Fluorescence *In-situ* Hybridization) have evidenced that heterotrophic bacteria communities vary

phylogenetically from freshwater to marine conditions²⁷⁻²⁹. Evidences suggest that β -proteobacteria dominate in freshwater zones, Cytophage-Flavobacteria in the estuarine, and α -proteobacteria in marine conditions²⁷⁻²⁹. This phylogenetic change at various salinity levels possibly enables the heterotrophic bacteria community to maintain a high abundance and production rate. However, it is still unknown how and when this phylogenetic shift in heterotrophic bacteria community occurs along the salinity gradients in estuaries. The high division rate of heterotrophic bacteria could be one possible mechanism, which enables them to respond rapidly to the salinity changes and establish well-adapted, phylogenetically different communities in the Cochin backwaters with in short time duration.

Major heterotrophic nano-flagellates in estuarine ecosystems belong to the genera *Bodo*, *Rhyncomonas* and *Cafeteria*³⁰. Information on heterotrophic nano-flagellates inhabiting the Indian estuaries is limited to the work on the Zuary estuary, along the southwest coast of India⁴. This study has clearly shown that there is a prominent decrease of heterotrophic nano-flagellate density in the Zuary estuary during the Monsoon. Since the freshwater influx and formation of extended freshwater zones are of low magnitude in the Zuary estuary, it was unclear in the earlier study how the fresh water influx affects heterotrophic nano-flagellate community. Therefore, it is difficult at the moment to explain why heterotrophic nano-flagellate community drastically decreased in the freshwater zones in the Cochin backwaters. Possible reasons could be the low adaptability of heterotrophic nano-flagellate community to drastic changes in salinity or its low phylogenic diversity as compared to heterotrophic bacteria and other picoplankton. Certainly, these possibilities are subjects of scientific importance for future studies.

Our earlier study in the Cochin backwaters has shown that high fresh water influx during the Southwest Monsoon period adversely affects the micro-zooplankton community⁷. This feature was well-recorded during the present study also. Abundance and biomass of micro-zooplankton

were noticeably low in the fresh water zones compared to the barmouth region (Fig. 4). The number of micro-zooplankton species was also prominently less in the fresh water zones (4 species) compared to the estuarine regions (16 species). Recent studies elsewhere show that micro-zooplankton consume substantially more (6 to 7 times) phytoplankton production than heterotrophic bacteria³¹. This could be due to the consistent population growth rates for micro-zooplankton and phytoplankton under ambient conditions, which may be requisite for grazing interaction³¹. In our earlier study, we considered the likely low abundance of pico and nanophytoplankton during the Southwest Monsoon as one of the possible reasons for the low abundance of micro-zooplankton. However, the present measurements clearly evidence that pico and nanophytoplankton are abundant in the Cochin backwaters during the Southwest Monsoon. Therefore, the availability of pico and nanophytoplankton in the Cochin backwaters during Southwest Monsoon is not limiting the micro-zooplankton abundance.

Ciliates abundance, distribution and trophic behavior in various environments are governed mainly by temperature, availability of food (bottom-up control) and abundance of predator (top-down control)³⁰. The role of these factors in controlling the microzooplankton community in Cochin backwaters during the Southwest Monsoon seems to be irrelevant because of the (a) prevalence of high temperature (31.03 ± 0.76 °C) (b) high abundance of pico/nanoplankton/heterotrophic bacteria, and (c) considerably low abundance of mesozooplankton. Food preference of many ciliates towards pico and nanoplankton is well-established³². Dominance of agglomerated species of ciliates in the Cochin backwaters appears to be related to the availability of mineral particles to construct the lorica, in addition to the presence of, their preferred food. *Tintinnopsis beroidea*, the most common tintinnid in the Cochin backwaters, is a pico-planktivorous species³². Dinoflagellates were low in abundance in the Cochin backwaters and mostly restricted to the barmouth region. This could possibly be a consequence of their preference for the coastal and

oceanic conditions³³. The dinoflagellates abundance in the Cochin backwaters is low due to the competitive advantages of diatoms in utilizing nutrients in eutrophic waters^{34,35}. Very low abundance of crustacean nauplii can be directly linked to the low abundance of copepod and other plankton grazers in the study area.

The transfer efficiencies of plankton production from lower to higher trophic levels depend significantly on the number of predatory interactions among plankton grazers³¹. Based on this fact, the possible plankton interaction in the Cochin backwaters is shown in Fig. 5.

During the Pre- monsoon, every interaction between different trophic levels occurs effectively resulting in an efficient functioning of the traditional, as well as the microbial food web. This would cause high organic carbon substrate availability at higher trophic levels and, therefore, the tertiary production during this period is expected to be the highest. The high residence time and high plankton grazing activity in the Cochin backwaters during the Pre- Monsoon period could be the reason for the high detritus settling⁷. On the other hand, very low occurrence of heterotrophic nano-flagellates, micro-zooplankton and meso-zooplankton during the Southwest Monsoon causes weak transfer of primary and bacterial carbon to higher trophic levels, eventually leaving much

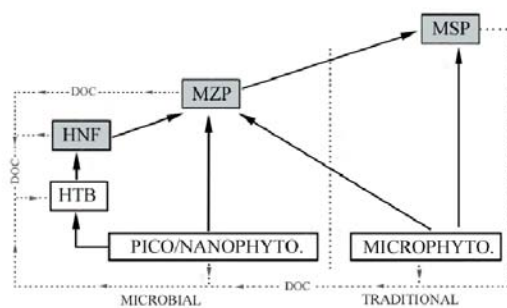


Fig. 5 - Possible plankton food web structure in the Cochin backwaters. Shaded components are weak during the Southwest Monsoon. Abbreviations: (HTB) Heterotrophic bacteria, (HNF) Heterotrophic nanoflagellates, (MZP) Microzooplankton, (MSP) Mesozooplankton and (DOC) Dissolved organic carbon.

unconsumed basic food in the environment.

However, due to high flushing rate of the Cochin backwaters during the Southwest Monsoon, a major portion of this unconsumed carbon possibly gets transported to the coastal regions⁷. Present study provides supplementary evidences for the weak functioning of the microbial plankton food web in the Cochin backwaters during the Southwest Monsoon.

Conclusion

During the Southwest Monsoon, Cochin backwaters was characterized by extensive fresh water zones and high levels of nutrients (nitrate av. 20 μM ; phosphate av. 3 μM). Various components of the microbial food web in the Cochin backwaters showed distinct features with respect to high freshwater influx. Throughout the Cochin backwaters, pico and nano size classes contributed the majority (av. $69 \pm 16\%$) of the phytoplankton biomass (chlorophyll *a* av. $5.2 \pm 3.2 \text{ mg m}^{-3}$). Heterotrophic bacteria abundance was also high in the entire Cochin backwaters (av. $3 \pm 0.6 \times 10^8 \text{ No. L}^{-1}$). However, the density of heterotrophic nano-flagellates and microzooplankton was markedly low in the freshwater zones (av. $0.5 \pm 0.3 \times 10^6 \text{ No. L}^{-1}$ and av. $3 \pm 1 \text{ No. L}^{-1}$, respectively) compared to the downstream region (av. $6 \pm 3 \times 10^6 \text{ No. L}^{-1}$ and av. $3222 \pm 3619 \text{ No. L}^{-1}$, respectively). This clearly indicated a weak microbial food web in a major part of the Cochin backwaters during the Southwest Monsoon, possibly due to the less adaptability of heterotrophic nano-flagellates and microzooplankton to freshwater conditions. The ecological implication of this could be the inefficient transfer of bacterial, pico/nano-phytoplankton biomass to higher trophic levels. This eventually causes high levels of unutilized basic food in the Cochin backwaters during the Southwest Monsoon. High flushing of Cochin backwaters during the Southwest Monsoon period may possibly transport most of this unutilized carbon to the coastal regions.

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References

- 1 Azam, F. T., Fenchel, J. G., Field, J. S., Gray, L. A., Mayer, R., & Thingstad, F., The ecological role of water column microbes in the Sea, *Mar. Ecol. Prog. Ser.*, 10 (1983) 257 - 263.
- 2 Nival, P., & Nival, S., Particle retention efficiencies of herbivorous copepod *Acartia clausi* (adult and copepodite stages): effect of grazing, *Limnol. Oceanogr.*, 21(1976) 24-38.
- 3 Johnson, P. W., Sieburth, JMcN., & Xu, H. S., The utilization of crococcoid cyanobacteria by marine protozooplankters but not by calanoid copepods. *Annales de l'Institut Oceanographique*, 58 (1979) 297 - 305.
- 4 Gauns, M., Role of microzooplankton in the food chain dynamics of some tropical marine environments, Ph.D thesis, Goa University, (2000) pp. 189.
- 5 Ram, A. S P., Nair, S., & Chandramohan, D., Seasonal shift in net ecosystem production in a tropical estuary, *Limnol. Oceanogr.*, 48 (2003) 1601-1607.
- 6 Ram, A. S. P., Nair, S., & Chandramohan, D., Bacterial Growth Efficiency in a Tropical Estuary: Seasonal Variability Subsidized by Allochthonous Carbon, *Microbial Ecol.*, 53 (2007) 591-599.
- 7 Jyothibabu, R., Madhu, N. V., Jayalakshmi, K. V., Balachandran, K. K., Shiyas, C. A., Martin, G. D., & Nair, K. K. C., Impact of freshwater influx on microzooplankton mediated food web in a tropical estuary (Cochin backwaters e India), *Estuar. Coast. Shelf Sci.*, 69 (2006) 505-518.
- 8 Thottathil, S. D., Balachandran, K. K., Gupta, G. V. M., Madhu, N. V., & Nair, S., Influence of allochthonous input on autotrophic-heterotrophic switch-over in shallow waters of a tropical estuary (Cochin Estuary), India, *Estuar. Coast. Shelf Sci.*, 78 (2008a) 551-562.
- 9 Madhupratap, M., Status and strategy of zooplankton of tropical Indian estuaries: A review, *Bull. Plankton Soc. Japan*, 34 (1987) 65-81.
- 10 Menon, N. N., Balchand, A. N., & Menon, N. R., Hydrobiology of the Cochin backwater system – a review, *Hydrobio.*, 430 (2000) 149 - 183.
- 11 Qasim, S. Z., Indian Estuaries (Allied publication Pvt. Ltd. Ballard estate, Mumbai, (2003) pp.259.
- 12 Madhu, N. V., Jyothibabu, R., Balachandran, K. K., Honey, U. K., Martin, G. D., Vijay, J. G., Shiyas, C. A., Gupta, G. V. M., & Achuthankutty, C. T., Monsoonal impact on planktonic standing stock and abundance in a tropical estuary (Cochin backwaters e India), *Estuar. Coast. Shelf Sci.*, 73 (2007) 54-64.
- 13 UNESCO, Protocols for the Joint Global Ocean Flux

- Study (JGOFS). Core Measurements, IOC Manuals and Guides 29, UNESCO, Paris, (1994) p. 170.
- 14 Sherr, E. B., Caron, D. A., & Sherr, B. F., Staining of heterotrophic protists for visualization via Epifluorescence microscopy. In: Handbook of methods in aquatic microbial ecology, (eds.) Kemp, P. F, Sherr, B. F, Sherr, B. E, Cole J J, Lewis Publishers, (1993) 213-227.
 - 15 Kofoid, C. A., & Campbell, A. S., 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(1939)1 - 403.
 - 16 Maeda, M., An illustrated guide to the species of the Family Halteridae and Strombilidae (Oligotrichida, Ciliophora), free swimming protozoa common in the aquatic environments.(eds. Asai T, Kobayashi K, Sakai H, Nemoto T, Kajihara T) Ocean Research Institute. University of Tokyo, 21(1986) pp.67 .
 - 17 Krishnamurthy, K., Naidu, D. W., Godhantaraman, N., Kannan, L., & Kathiresan, K., Microzooplankton with special reference to Tintinnida (Protozoa: Ciliata: Tintinnida). Plankton of Pangipettai (Porto Novo), India. New Series: Memoirs of the centre for advanced study in Marine Biology, (Annamalai University), Parangipettai, Tamilnadu, India, Fascicle No.1. 1995, pp 27.
 - 18 Berggreen, U., Hansen, B., & Kiorboe, T., Food size spectra, ingestion and growth of the *Acartia tonsa* during development: implication for determination for copepod production, *Mar.Biol.*, 99 (1988) 341 - 352.
 - 19 Sarala Devi, K., Venugopal, P., Remani, K. N., Zacharias, D., & Unnithan, R. V., Nutrients in some estuaries of Kerala. *Mahasagar -Bulletin of National Institute of Oceanography*, Goa, 16 (1983)161 - 173.
 - 20 Wellershaus, S., Seasonal changes in the zooplankton population in the Cochin backwater (a south Indian estuary), *Aquatic Ecol.*, 8 (1974)1-2.
 - 21 Sanders, H. L., Marine benthic diversity: a comparative study, *American Nature.*, 102 (1968) 243-282.
 - 22 Weisse, T., Dynamics of autotrophic picoplankton in marine and freshwater ecosystems. In: Advances in Microbial Ecology. JG Jones (Editor), Plenum Press, New York, 13(1993), pp. 327-370.
 - 23 Stockner, J. G., Phototrophic picoplankton: an overview from marine and freshwater ecosystems, *Limnol. Oceanogr.*, 33 (1988)765-775.
 - 24 Madhu, N. V., Jyothibabu, R., & Balachandran, K. K., Monsoon-induced changes in the size-fractionated phytoplankton biomass and production rate in the estuarine and coastal waters of southwest coast of India, *Environ. Monit. Assess.*, (2009). DOI 10.1007/ -009-1020-8.
 - 25 Platt, T., Rao, S. D., V & Irwin, B., Photosynthesis of picoplankton in the oligotrophic ocean, *Nature.*, 301(1983) 702-704.
 - 26 Thottathil, S. D., Balachandran, K. K., Jayalakshmy, K. V., Gupta, G. V. M., & Nair, S., Tidal switch on metabolic activity: Salinity induced responses on bacterioplankton metabolic capabilities in a tropical estuary, *Estuar. Coast. Shelf Sci.*, 78 (2008b), 665-673.
 - 27 Kirchman, D. L., The ecology of Cytophaga-Flavobacteria in aquatic environments, *FEMS Microbiol Ecol.*, 1317 (2002) 1-10.
 - 28 Giorgio, P. A., & Bouvier, T. C., Linking the physiologic and phylogenetic successions in free living bacterial communities along an estuarine salinity gradient, *Limnol. Oceanogr.*, 47 (2002) 471- 486.
 - 29 Bouvier, T. C., & Giorgio, P. A., Compositional changes in free living bacterial communities along a salinity gradient in two temperate estuaries, *Limnol. Oceanogr.*, 47 (2002) 453-470.
 - 30 Urrutxurtua, I., Orivea, E., & Sotab, A., Seasonal dynamics of ciliated protozoa and their potential food in an eutrophic estuary (Bay of Biscay), *Estuar. Coast. Shelf Sci.*, 57 (2003)1169-1182.
 - 31 Landry, M. R., & Carlbert, A., Microzooplankton production in the oceans, *ICES Journal of Marine Science.*, 61 (2004) 501- 507.
 - 32 Bernard, C., & Rassoulzadegan, F., The role of picoplankton (cyanobacteria and plastidic picoflagellates) in the diet of tintinnids, *J Plankton Res.*, 15 (1993) 361-373.
 - 33 Cushing, D. H., A difference in structure between ecosystems in strongly stratified waters and in those that are only weekly stratified, *J Plankton Res.*, 11 (1989) 1-13.
 - 34 Menzel, D. W., Hulbert, E. M., & Ryther, J. H., The effect of enriching the Sargasso Sea water on production and species composition of the phytoplankton, *Deep Sea Res.*, 10 (1963) 209 - 219.
 - 35 Qasim, S. Z., Bhattathiri P. M. A., & Devassy, V. P., Growth kinetics and nutrient requirements of two tropical marine phytoplankters, *Mar. Biol.*, 21 (1973) 299 - 304.