



Implications of stratification on the heterotrophic plankton community (micro- & meso zooplankton) in the South Eastern Arabian Sea

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ABSTRACT

The response of the plankton community (micro- herein after MZP and mesozooplankton) to the seasonal intrusion of Bay of Bengal (BoB) water into the Arabian Sea from November (Initial Phase-IP) to January (Peak Phase-PP) and resultant stratification was tracked in the present study. During the winter monsoon (November – February) as part of seasonally reversing monsoonal circulation, low saline BoB waters intrude into the Arabian Sea which initiates stratification. The peak phase of salinity stratification in the Eastern Arabian Sea is in January during which a thick barrier layer develops in the region. The study showed that during the initial phase of the BoB water intrusion, fluctuation was observed in the MZP and mesozooplankton community with noticeable coast-oceanic variations while such variation was not found during the peak phase when the entire SEAS was influenced by the intruded low saline BoB waters. This variation in the interaction between MZP and mesozooplankton during the initial phase can be attributed to the seasonal transition which was more pronounced in the offshore during the initial phase. A statistically significant correlation was observed between barrier layer thickness (BLT), an indicator of stratification with plankton diversity. The insignificant coast-oceanic variations (homogeneity) in planktonic components during the peak phase can be attributed to higher abundance of grazers. Among the MZP community, the ciliates (CTS) formed the predominant group and its contribution varied between 50% & 59% during the initial and peak phase respectively with the highest dissimilarity observed along the Trivandrum transect. The study points to the fact that interactions between trophic levels during the seasonal transition phase when stratification sets in, is subtle which is evident as coast-oceanic variation, while in established stratification the interaction between plankton at different trophic level, gets stabilized due to balance between the *Bottom-up* and *Top-down* controls.

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1. Introduction

The structure and functioning of ecosystem is chiefly governed by the environmental variability and are discernible as changes in the abundance, distribution pattern and community structure of marine organisms. However, in marine ecosystem the biological communities are organized in terms of size which strongly influences the partitioning of carbon and accordingly two pathways have been distinguished, the classical food web and the microbial food web (Azam et al., 1983; Sommaruga, 1995; Calbet, 2008). The plankton being the drifters of the ocean, the translation of physical processes in the water column is expressed biologically as variation in patterns of planktonic standing stock (Cullen et al., 2002). Furthermore, amongst these array of organisms, MZP (20–200 μ M), the phagotrophic protists acts as the top grazer within

the microbial food web and forms the nexus between the microbial food web and classical food web (Sherr et al., 1986). The mesozooplankton (200 μ M–20 mm) placed at the secondary trophic level distribute the organic matter synthesized by the autotrophs to higher trophic levels. However, the interactions between planktonic components at different trophic levels would decipher the relative contributions of each component and thereby pathways of energy transfer in food web. Moreover, studies have shown that the relationship between physical processes and food web structure appear to vary on spatial and temporal scales (Kiorboe et al., 1990).

The South Eastern Arabian Sea (SEAS) is a highly dynamic region which exhibit distinct seasonality in physical forcings leading to cycles of high (Summer monsoon-Upwelling) and low production (Spring intermonsoon and Winter monsoon-Stratification). Theories suggest that the hydrography of SEAS is seemed to be governed by local as well as remote forcing especially from the Bay of Bengal. Studies have shown that Sea Surface Temperature (SST) and Sea Surface Salinity (SSS) of the Eastern Arabian Sea are influenced

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by the seasonally reversing monsoons which is characteristics of the northern Indian Ocean (Maresh and Banakar, 2014). During winter monsoon (November to February) cooler low saline waters are brought into the SEAS by the East India Coastal Current (EICC) and Winter Monsoon Current (WMC) resulting in enhanced near surface stratification and deepening of the isothermal layer resulting to the formation of barrier layer (Shenoi et al., 1999). The intrusion of low saline BoB water begin during the month of November and gradually spreads over the entire SEAS by January and these hydrographic settings seem to modulate the biological characteristics and food web structure of the region.

The understanding on biological characteristics of the SEAS has brought out the fact that apart from high biological production observed during the coastal upwelling in the summer monsoon the SEAS remains oligotrophic for most part of the year due to stratification. Moreover, studies on the planktonic components in the pelagic food web also indicates the fact the MZP is ecologically significant in stratified systems as they transfer majority of the primary carbon to the higher trophic levels (Calbet, 2001). Therefore the ecological role of MZP seems to be significant in the Arabian Sea Ecosystem as most of the primary carbon may be channeled via MZP. It is generally believed that phytoplankton which forms the base of the food web and that small sized phytoplankton (pico/nano) dominate the oligotrophic and stratified waters whereas larger fraction characterize the nutrient rich environments (Malone, 1980; Legendre, 1981; Harris et al., 1987). Therefore it is suggested that in stratified systems the longer microbial food web predominates whereas short classical food web operates in nutrient enriched systems which seem to vary on spatial and temporal scales across oceanic regimes (Cushing, 1989). It is also known that food web and species diversity are highly linked concepts (Worm et al., 2002). Furthermore, the species specific tolerance to physical parameters determine the species potential to sustain in that environment, and usually stable environment like stratified system harbors less diversity (Thorpe, 1986). Also, the Flow analysis model by McManus (1991) shows that in the microbial food web the flux of carbon to the zooplankton is greatly influenced by the protozoan efficiency through consumption of picoplankton. Therefore in less productive systems, the protozoan efficiency forms the potential link between pico/nano and the metazoans (Legendre and Rassoulzadegan, 1995). Taking into consideration of the fact, the relative importance of microbial food web in stratified systems which is hitherto unknown understanding these inter-relationships could provide insight into planktonic food web during stratified condition in a comprehensive manner.

Studies pertaining to the ecological interactions between the MZP and mesozooplankton are few in the SEAS and are mostly limited to the seasonal variations, upwelling system and summer stratification (Gauns et al., 1996; Jyothibabu et al., 2008; Asha Devi et al., 2010). Moreover in the estuarine system off Kochi, the variability in the planktonic standing stock is seemed to be influenced by fresh water influx (Jyothibabu et al., 2006). Although most of these studies have explained the role of MZP and planktonic interactions on a seasonal scale and which mostly explains the bottom-up controls on MZP the importance of top-down controls remains inconclusive. Given the understanding on the close coupling between the physical processes and the resultant variability of the plankton on a spatial and temporal scale the implications can be best studied by assessing the changes in the community structure and trophic interactions from the initial to the peak phase of any physical forcing (intra-seasonal), like upwelling or the stratified system. On this backdrop the present study focuses on the following objectives (i) community structure of micro- and mesozooplankton and its variations in response to stratification resulting from intrusion of low saline BoB water (ii) spatio-temporal variations in the community structure

of CTS during the initial and peak phase of stratification (iii) interactions between MZP and mesozooplankton to explain the Bottom-up vs. Top-down controls during initial and peak phase of stratification.

2. Sampling and methods

2.1. Study area

The Arabian Sea is a unique geographic area being one of the most productive regions of the World Oceans (Qasim, 1982) and also exhibits complex pattern of ecological interactions which vary both spatially and temporally. Some of the strongest atmospheric forcing of oceanic properties is observed in the Arabian Sea where seasonally reversing monsoon winds drive fast-flowing, vertically extensive currents, complex eddy-fields, coastal upwelling, broad scale Open Ocean upwelling, pronounced mixed layer deepening and stratification. Annually the Arabian Sea loses fresh water through intense evaporation ($\sim 1 \text{ m yr}^{-1}$) while Bay of Bengal receives large quantities of fresh water through precipitation ($\sim 2 \text{ m yr}^{-1}$) and also through run off from rivers thereby creating a hydrological imbalance. The climatological surface currents for the winter monsoon shows that the westward-flowing North-east Monsoon Current (NMC, also called North Equatorial Current (Tomczak and Godfrey, 1994) south of India/Sri Lanka which carries water from the Bay of Bengal towards the Arabian Sea. In addition, the fact that in spite of weak equator ward wind stress, the meridional salinity gradient occurring in the eastern Arabian Sea after southwest monsoon is capable of forcing a northward current along west coast of India. During the winter monsoon remote forcing especially from the Bay of Bengal (BoB), play a major role in the dynamics of the SEAS (McCreary et al., 1993; Shankar et al., 2002; Nageswara Rao et al., 2014).

2.2. Data and methods

2.2.1. Hydrographical parameters

Sampling for the present study was conducted during the winter monsoon period in the SEAS, spanning from November to February on board FORV Sagar Sampada. For the initial phase sampling was carried during the month of November, 2010 (Cr.282 13–26th November) and the peak phase was sampled during the month of January, 2012 (Cr. 293, 4–17th January). During each phase, two transects namely, Trivandrum (Tvm) and Kochi were sampled for coastal (50 m), shelf (200 m) and oceanic stations ($> 1000 \text{ m}$) (Fig. 1). Even though the sampling for the initial and peak phase was carried out during different years 2010 and 2012, the hydrographic settings of the study area was comparable, as evident from the more or less similar current pattern during these months for both years. This similarity is obvious from the monthly geostrophy current pattern from the Aviso/Nillar climatology (<http://oceanwatch.pifsc.noaa.gov/las>) along SEAS between November and January during 2010/11 & 2011/12, shows the general flow features of the region associated with the intrusion of Winter Monsoon Current during November and subsequent, strengthening of current and development of LH during January. So the hydrography data during November 2010 and January 2012 were considered to study the characteristics of the initial and peak phase of winter monsoon respectively.

The vertical profiles of temperature and salinity were recorded using CTD profiler (SBE 911 plus, Seabird Electronics, USA). CTD salinities were calibrated against water collected simultaneously and analyzed with a Guildline 8400 Autosol onboard. Isothermal layer depth (ILD) was considered as depth at which the temperature decreased by 1°C from the surface values. The mixed layer depth (MLD) was taken as the depth at which 0.2 increase in

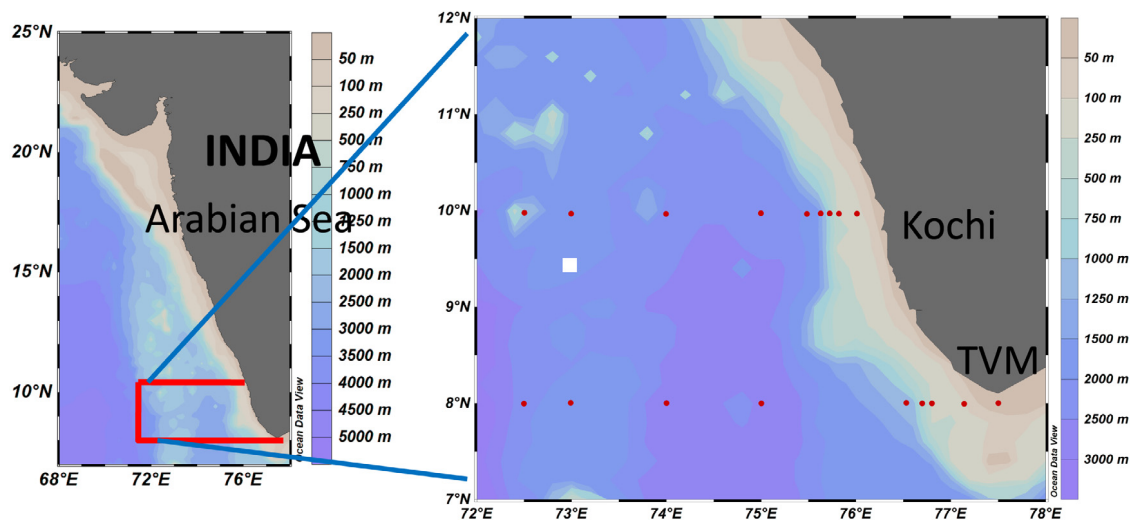


Fig. 1. Study area and red dot indicates station locations.

density (Sigma t) was observed (Shetye et al., 1996). The Barrier Layer Thickness (BLT) was considered as the intermediate layer between bottom of surface mixed layer and top of thermocline (Lukas and Lindstrom, 1991).

2.2.2. Satellite data

For the present study, Chlorophyll data (Chl a) was taken from the Moderate Resolution Imaging Spectroradiometer (MODIS)-Aqua. Eight day composite of Level-3 data (9 km resolution) for the corresponding locations and dates of the study period were downloaded and processed using SeaDAS. The chlorophyll distribution during the corresponding months of November 2010 and January 2012 were used to represent the initial and peak phase of winter monsoon.

2.2.3. Microzooplankton abundance & community

Qualitative and quantitative estimates of MZP, was done by collecting water samples from discrete depths (0.5, 10, 20, 50, 75, 100 and 120 m). For this, 5–8 L of seawater was filtered through a 200 μ m bolting silk (Hydro-Bios), to eliminate the mesozooplankton and the filtrate was carefully collected into black polythene bottles and fixed in 3%–8% of acid Lugol's iodine and concentrated by gravity settling prior to microscopic analysis. Several subsamples (3–5) were analyzed in Sedgwick rafter counting chamber under an Inverted Microscope with Phase Contrast optics (100–400x) magnifications. The organisms present in the samples were identified and categorized into four groups viz., heterotrophic dinoflagellates (HDS), ciliates (CTS), radiolarians (RAD), foraminifera (FORM) and crustacean nauplii (CNP). The heterotrophic dinoflagellates (HDS) and (CTS) were identified by standard protocols (Corliss, 1979; Jorgensen, 1924; Kofoed and Campbell, 1939; Lynn et al., 1988; Marshall, 1969; Maeda and Carey, 1985; Maeda, 1986; Steidinger and Williams, 1970; Subrahmanyam, 1971; Taylor, 1976a, b, 1987). RAD, FORM and CNP were categorized to the group level. The abundance of MZP at the sampled depths was integrated to calculate the column values.

2.2.4. Mesozooplankton abundance & community

Mesozooplankton samples were collected using Multi Plankton Net – Hydro Bios (mouth area-0.25 m^2 , mesh size- 200 μ) from stratified depths such as Mixed layer, Thermocline, Bottom of Thermocline to 300 m, 300–500 m and 500–1000 m. Mesozooplankton biovolume ($ml\ m^{-3}$) was estimated by displacement volume method (Postel et al., 2000). The aliquot or whole sample based on

displacement volume was sorted into various taxonomic groups based on published reference and expressed as $ind\ m^{-3}$ (ICES, 1947; Newell and Newell, 1973; Todd and Laverack, 1991). For the present study the biovolume and composition from the mixed layer was only considered since it gives a good representation of the secondary standing stock.

2.2.5. Statistical analyses

2.2.5.1. Diversity measures. Diversity measures are used to assess the distribution of proportional abundances of species and usually referred to as relative abundances. It also helps to analyze mathematically and compare changes in communities in response to environmental factors. The diversity indices used to analyze changes in community structure are (i) Species richness, a measure of total number of different species in a community in a particular area (Margalef, 1968) (ii) Species evenness – the relative abundance with which each species are represented in an area (Pielou, 1969) and (iii) Species diversity (H') – this index takes into account the number and the evenness of the species. The index is increased either by having more unique species, or by having greater species evenness (Shannon and Weaver, 1963).

2.2.5.2. Multivariate analysis (MDS/SIMPER/BEST). Multivariate methods were followed for distinguishing the changes in biological communities with respect to the environmental conditions. Non parametric multivariate methods were used to analyze the community structure. Prior to analysis the data was square-root transformed to normalize the difference between the most abundant species as well as the species with nominal representation. Multivariate procedures include classification (cluster analysis) and species ordination through multidimensional scaling (MDS), implemented in PRIMER v6 (Clarke and Warwick, 1994; Clarke and Gorley, 2001). The Bray–Curtis similarity matrix, which reflects changes in relative abundance as well as species composition, was used to obtain multidimensional scaling (MDS) ordinations, so as to reproduce the observed similarities/dissimilarities. To determine the species contributing most to dissimilarities among groups, we used the program SIMPER (Warwick and Clarke, 1991). Organisms with a high average contribution and large ratio of average contribution to standard deviation were considered as good discriminating organisms (Clarke, 1993). BEST Analysis is an explanatory tool and was done for selecting the environmental variables which best explains the community pattern through BIOENV.

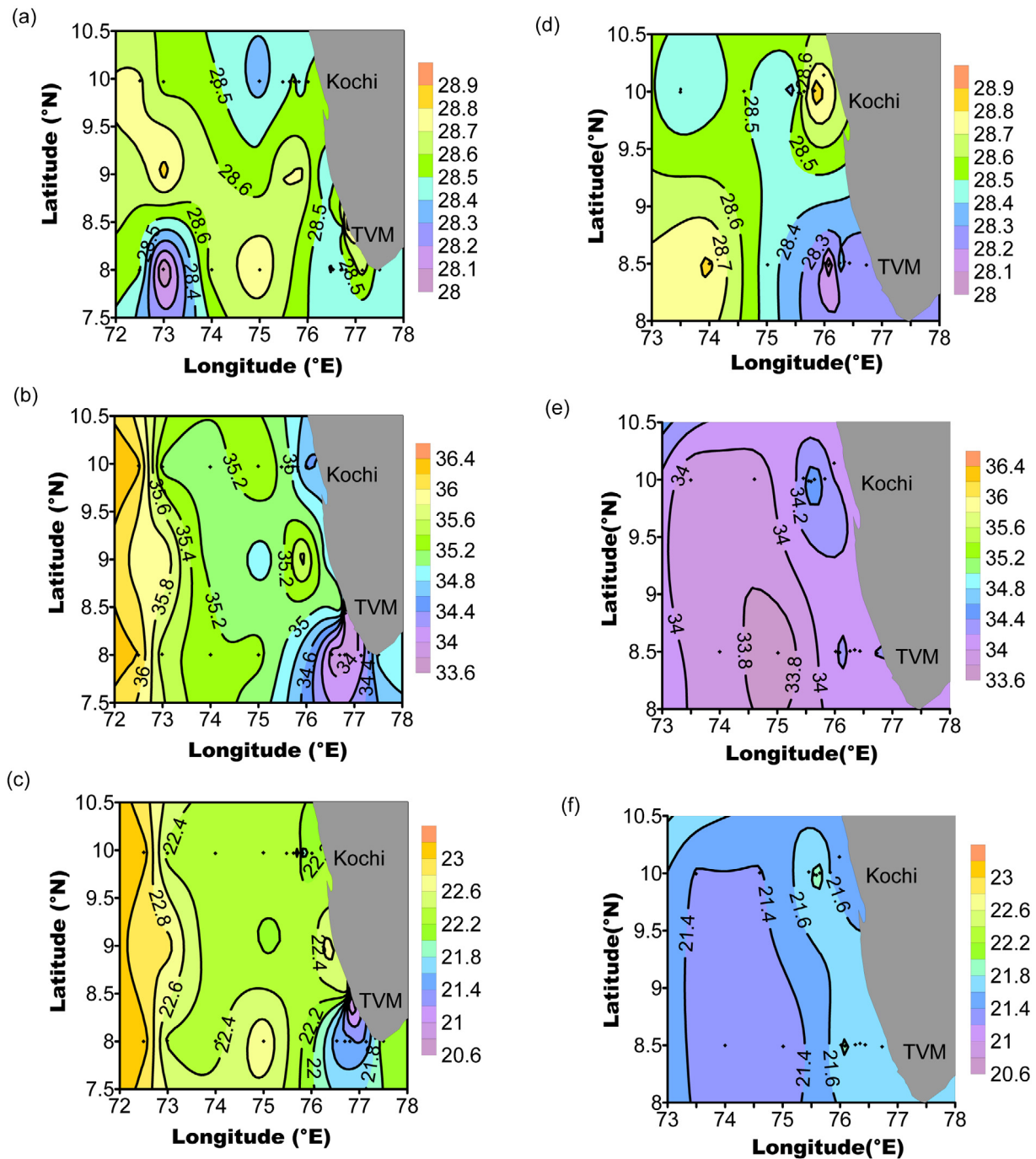


Fig. 2. Spatial distribution of SST (°C), SSS and SSD during the initial phase (a, b & c) and peak phase (d, e & f) of winter monsoon in the South Eastern Arabian Sea. Black dot indicates station locations.

3. Results

3.1. Hydrography

The hydrographic characteristics showed distinct features along the two transects Trivandrum (Tvm- 8°N) and Kochi (10°N), in response to the intrusion and spread of low saline BoB water during the initial (November) and peak phase (January) of winter monsoon respectively. During initial phase of winter Monsoon, the presence of low saline BoB water was restricted to the shelf of Tvm transect. The spatial distribution of surface hydrographic parameters showed the presence of warm (28.6 °C), low saline

(34–34.9) and less dense water ($\sim 22 \sigma_t$) only in the shelf whereas relatively warm (28.1–28.6 °C), high saline (35.1–35.5) and dense water ($> 22.2 \sigma_t$) occupied the offshore region off Tvm (Fig. 2 a, b & c). Moreover, the Isothermal Layer Depth (ILD) was deep in the shelf (70–95 m) and was shallow in the oceanic region (30–50 m) which indicates the existence of barrier layer. Relatively deeper ILD and shallow mixed Layer Depth [(MLD) (10–20 m)] resulted in thick barrier layer (50–75 m) along the shelf/slope region of Tvm (Fig. 3 a, b & c). However, the presence of low saline water (34.1–35.3) in the upper 30 m seems to be responsible for the formation of barrier layer along this transect indicating that stratification has set in along the shelf of Tvm transect.

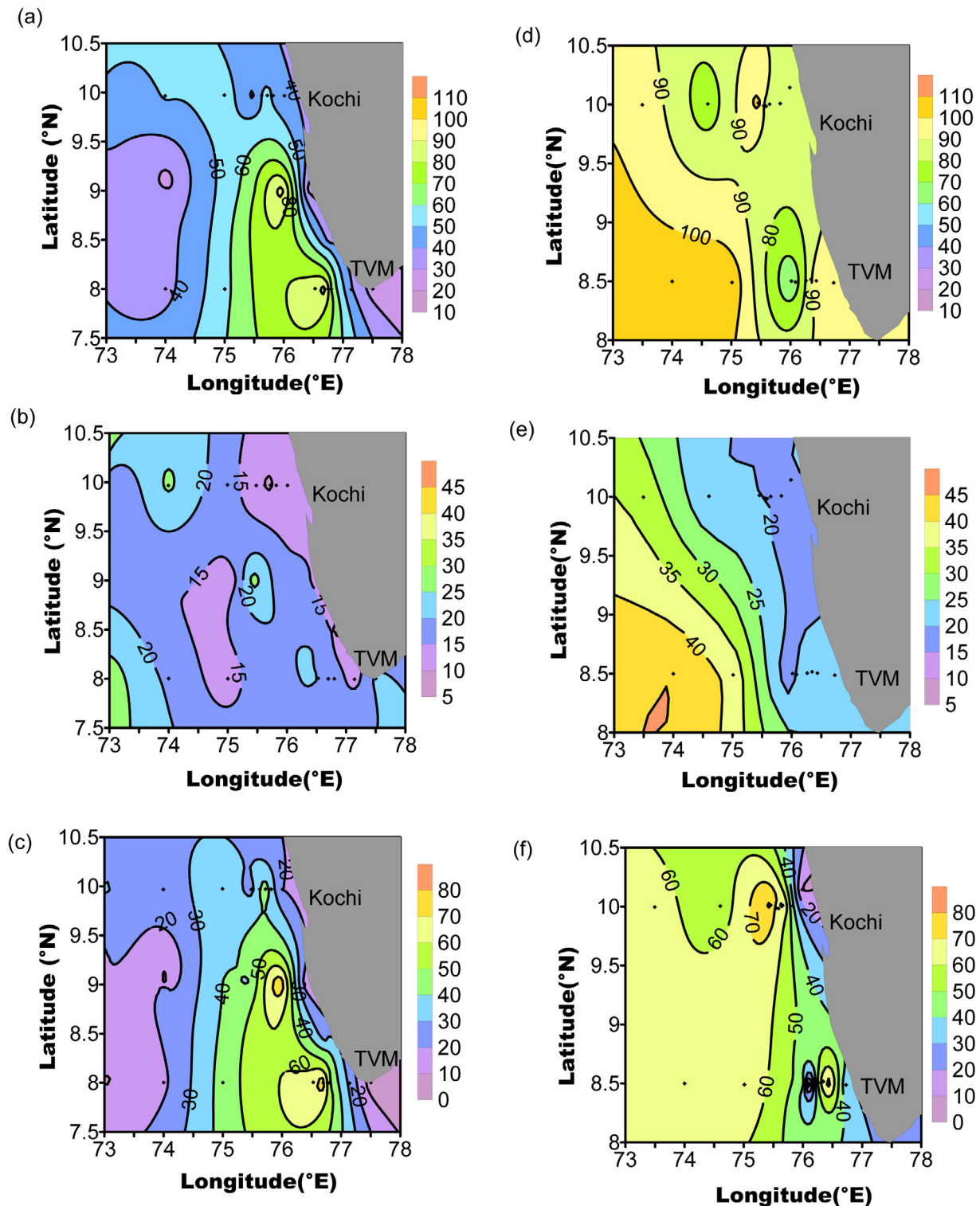


Fig. 3. Spatial distribution of ILLD (m), MLD (m) and BLT (m) during the initial phase (a, b & c) and peak phase (d, e & f) of winter monsoon in the South Eastern Arabian Sea. Black dot indicates station locations.

On the other hand, the surface hydrography off Kochi was different from that of the Tvm transect to certain extent. Relatively warmer ($28.3\text{--}28.5^\circ\text{C}$), low saline (SSS: $34.5\text{--}35.1$), and less dense ($\sim 22\sigma_t$) water was observed in the shelf/slope area off Kochi transect. In the offshore region although SST did not show variation high saline ($35.1\text{--}35.5$) and dense ($>22.2\sigma_t$) waters were observed when compared to that of Tvm transect. Contrary to

the Tvm transect, the ILLD and MLD was shallow. The ILLD varied between 40 to 60 m and MLD was between 10–20 m. Thermohaline structure indicates the prevalence of homogeneous water ($\sim 28.5^\circ\text{C}$) and sharp horizontal gradient of isohaline ($34.5\text{--}36.1$) in the upper 50 m. Due to this, relatively thin barrier layer (20–50 m) was observed along shelf and offshore waters, indicative of weak stratification, which was a localized feature.

Table 1

Chlorophyll *a* (mg m^{-3}) (3 day average) derived from MODIS showing distribution in the coast, shelf and oceanic waters in the Trivandrum and Kochi transects during the initial and peak phase of winter monsoon in the SEAS.

Transects	Initial phase Chlorophyll <i>a</i> (mg m^{-3})			Peak phase Chlorophyll <i>a</i> (mg m^{-3})		
	Coast	Shelf	Oceanic	Coast	Shelf	Oceanic
Trivandrum	2.25	1.90	0.466	0.932	1.04	0.256
Kochi	0.63	0.90	–	0.851	0.159	0.26

However, during the peak phase of winter monsoon (January) the intrusion and spread of low saline BoB water could be tracked up to the shelf and offshore regions of both Tvm and Kochi transects which implies the fact that stratification is established over this part of the SEAS. The SST showed an increasing trend from coast to offshore waters and ranged between 28.2 and 28.7 °C at off Tvm. Salinity and density pattern showed the area to be entirely under the influence of low saline (33.8–34.2) and less dense water (21.4–21.6) (Fig. 2 d, e & f). Relatively deeper ILD (80–110 m) and shallow MLD (20–40 m) observed during this period, resulted in thick barrier layer (50–70 m). The deepening of ILD resulted in thick BL which strengthened stratification when compared to that of November (Fig. 3 d, e & f). Moreover at off Kochi, the upper layers of shelf and offshore waters also seem to be occupied with relatively warm (>28.4 °C), low saline (<34.5) and less dense ($<22\sigma_t$) water. When compared to the Initial phase during the month of November, the isothermal layer also deepened (70 to 100 m) and MLD varied between 10 to 30 m during the period. Further thick barrier layer (50–80 m) observed along this transect in association with intrusion and spread of low saline water to the area was indicative of the fact that stratification has become established over the entire study area by the peak phase of winter monsoon.

3.2. Chlorophyll

Consistent with the hydrographic characteristics the average chlorophyll concentration also varied between the Tvm and Kochi transects during the initial and the peak phase of winter monsoon. The average chlorophyll concentration was lower during the peak phase ($0.584 \pm 0.39 \text{ mg m}^{-3}$) when compared to the initial phase ($1.23 \pm 0.79 \text{ mg m}^{-3}$). During the initial phase spatial variation was observed in the chlorophyll concentration between the coast, shelf and oceanic waters in the Tvm transect. High chlorophyll was noticed in the coastal and shelf waters off Tvm transect (2.25 mg m^{-3} and 1.95 mg m^{-3} respectively) than oceanic waters (0.46 mg m^{-3}). However, along the Kochi transect only the shelf waters recorded comparatively high chlorophyll (0.90 mg m^{-3}) than the coast (0.632 mg m^{-3}) and oceanic regions (0.256 mg m^{-3}). On the other hand, during the peak phase, even though stratification has been fully established the coast and shelf waters of Tvm transect sustained comparatively high chlorophyll (0.93 mg m^{-3}) whereas in the Kochi transect the shelf and oceanic waters recorded low chlorophyll concentration (0.25 mg m^{-3}). Interestingly, oceanic waters along both Tvm and Kochi recorded almost similar chlorophyll concentration during the peak phase (Table 1).

3.3. Microzooplankton

3.3.1. Abundance

The total MZP abundance showed considerable variation in response to the hydrographic changes due to the intrusion of low saline BoB waters along Tvm transect during the initial phase. While during the peak phase of winter monsoon the implication was evident in both Tvm and Kochi transects. However, irrespective of transects the overall average of MZP abundance was high

during the initial phase ($374 \pm 232 \times 10^3 \text{ ind m}^{-2}$) when compared to the peak phase ($175 \pm 81 \times 10^3 \text{ ind m}^{-2}$). During the initial phase the abundance of MZP was comparatively low in the Tvm transect (av. $303 \pm 289 \times 10^3 \text{ ind m}^{-2}$) where signatures of low saline water was apparent. Furthermore, during the initial phase, significant variation was observed between the coastal, shelf and oceanic waters in Tvm, showing an increasing trend towards the oceanic region ($635 \times 10^3 \text{ ind m}^{-2}$) from the coast and shelf waters ($100 \times 10^3 \text{ ind m}^{-2}$ and $175 \times 10^3 \text{ ind m}^{-2}$ respectively) whereas in the Kochi transect the abundance was almost similar in the coast ($525 \times 10^3 \text{ ind m}^{-2}$) and shelf waters ($437 \times 10^3 \text{ ind m}^{-2}$). During the peak phase, when the extent of low saline water could be tracked up to Kochi the MZP abundance decreased significantly in both Tvm ($112 \pm 32 \times 10^3 \text{ ind m}^{-2}$) and Kochi transects ($238 \pm 60 \times 10^3 \text{ ind m}^{-2}$). On the other hand during the peak phase, a uniform trend in the MZP abundance was observed in the coast ($132 \times 10^3 \text{ ind m}^{-2}$), shelf ($74 \times 10^3 \text{ ind m}^{-2}$) and oceanic ($129 \times 10^3 \text{ ind m}^{-2}$) waters of Tvm as well as Kochi transects (coast – $298 \times 10^3 \text{ ind m}^{-2}$, shelf ($239 \times 10^3 \text{ ind m}^{-2}$) and oceanic ($177 \times 10^3 \text{ ind m}^{-2}$) region when compared to the initial phase (Fig. 4a).

3.3.2. MZP composition

The ciliates (CTS) which formed the predominant group in the MZP community, although exhibited spatio-temporal variations, noticeable difference was observed only during initial phase between Tvm and Kochi transects. During the initial phase when the stratification sets in the contribution of CTS was found to be considerably low in the Tvm transect (31% - av. $94 \pm 38 \times 10^3 \text{ ind m}^{-2}$), whereas in the Kochi transect the contribution of CTS was as high as 76% ($368 \pm 33 \times 10^3 \text{ ind m}^{-2}$). Consistent with total MZP abundance, the coast-oceanic variation in the CTS was also observed during the initial phase along Tvm with higher contribution in the oceanic region ($137 \times 10^3 \text{ ind m}^{-2}$) than the shelf ($80 \times 10^3 \text{ ind m}^{-2}$) and coastal region ($68 \times 10^3 \text{ ind m}^{-2}$). However, such variations were not evident in the Kochi transect. Furthermore, during the peak phase when the stratification gets established over the entire southern part of the SEAS the contribution of CTS to the MZP community decreased in Kochi (58%; $141 \times 10^3 \text{ ind m}^{-2}$) and increased in Tvm transect (61%; $69 \times 10^3 \text{ ind m}^{-2}$). Moreover, the coast – oceanic variations were not pronounced during the peak phase in the Kochi transect (coast – $166 \times 10^3 \text{ ind m}^{-2}$; shelf – $153 \times 10^3 \text{ ind m}^{-2}$; oceanic – $101 \times 10^3 \text{ ind m}^{-2}$). Consistently, in the Tvm transect the abundance did not vary considerably between the coast ($102 \times 10^3 \text{ ind m}^{-2}$) and oceanic ($69 \times 10^3 \text{ ind m}^{-2}$) regions.

On the other hand the contribution of HDS to the community was substantial during the initial phase in the Tvm transect where its contribution ($133 \pm 188 \times 10^3 \text{ ind m}^{-2}$, 43%) outnumbered the CTS ($94 \pm 38 \times 10^3 \text{ ind m}^{-2}$, 31%). This higher contribution was chiefly due to the exceptional abundance observed in the oceanic region of Tvm transect. During the peak phase with established stratification, the contribution of HDS varied between 27% and 17% in Tvm and Kochi respectively. The contribution of sarcodines comprising the radiolarians and foraminifera to the MZP community was considerable only in the Kochi transect, during the peak phase (11%) (Fig. 4b). Moreover, the contribution of metazoan NAUP was substantial only in the Tvm transect ($70 \pm 55 \times 10^3 \text{ ind m}^{-2}$; 23%) during the initial phase, whereas during the peak phase the contribution was more or less similar in both Tvm and Kochi transects ($\sim 10\%$). From the above results it can be mentioned that consistent with the variation in the total abundance of MZP between the coast, shelf and oceanic regions in the Tvm transect during the initial phase, the community also exhibited a similar trend. Concurrently, the CTS, HDS and NAUP also showed higher abundance in the oceanic region of Tvm transect. However, during the peak phase of winter monsoon (January) when stratification gets established in the entire study area coast – oceanic variations were not observed in both Tvm and Kochi transects.

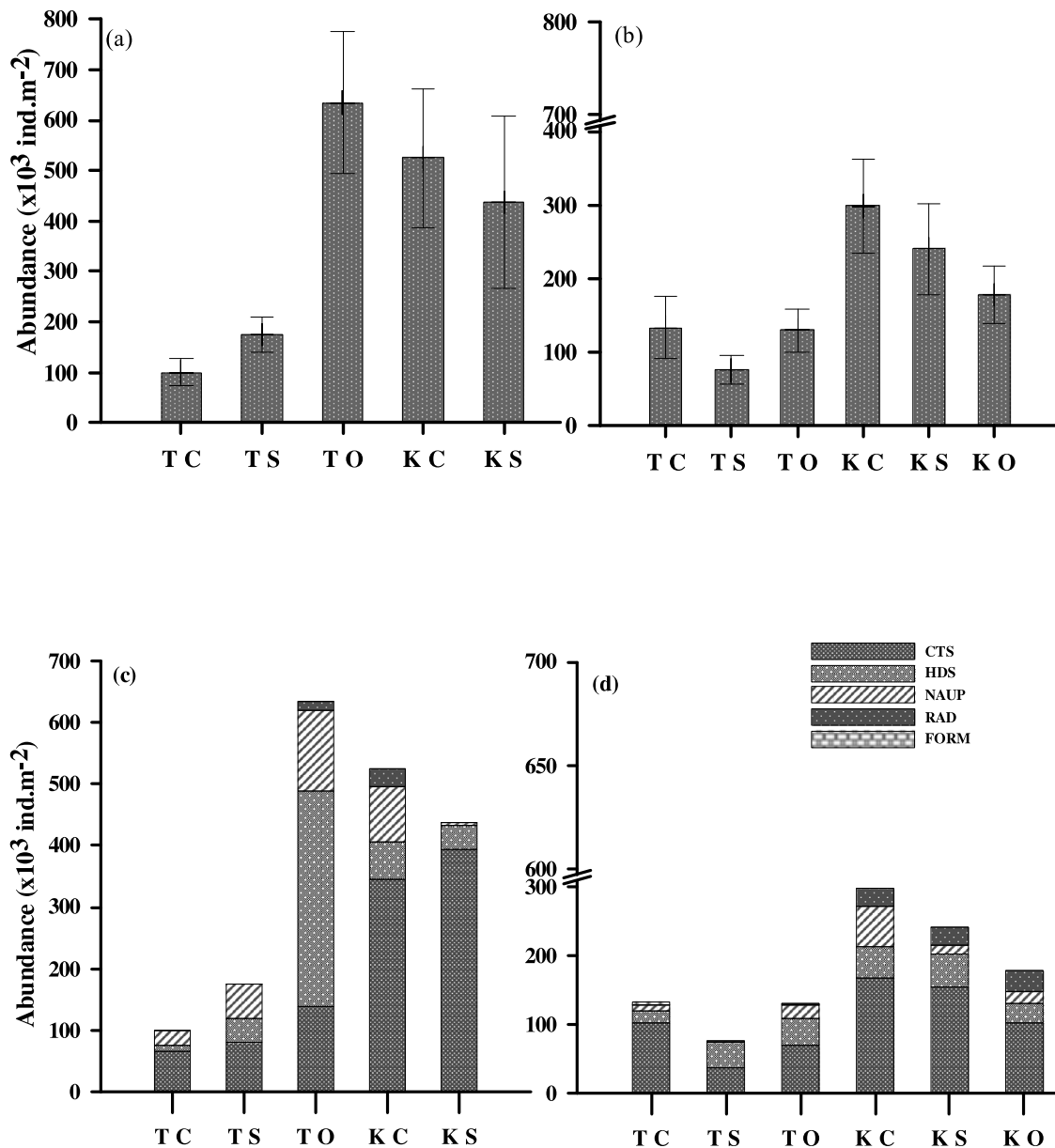


Fig. 4. Distribution pattern of total microzooplankton abundance (ind m⁻²) (a) initial phase (b) peak phase of winter monsoon in the SEAS and (c & d) relative contribution of ciliates (CTS), heterotrophic dinoflagellates (HDS), Nauplii (NAUP), Radiolarians (RAD) and foraminifera (FORM) in the coastal, shelf and oceanic waters in the Trivandrum and Kochi during the initial and peak phases of winter monsoon in the South Eastern Arabian Sea. (C, S and O represents the coastal, shelf and oceanic regions respectively in the T-Trivandrum and K-Kochi transects).

3.3.3. Community structure

The species composition of CTS, which formed the predominant group in the MZP community was studied to understand the variations in the community structure between the initial and peak phases of winter monsoon. CTS were comprised of mostly tintinnids, and only few aloricates were encountered during the study period. The numbers of species of CTS was almost similar during both initial and peak phase and varied between 5 to 16 species. The list of CTS species recorded during the study period is given in Table 2. It was observed that within the peak phase, considerable variation was noticed between Tvm and Kochi transects with more species in the Kochi transect. The most abundant species observed during the initial phase was *Dictyocysta lepida* followed by *Parundella caudata* in the Tvm transect while it was *Codonellopsis ostenfeldii* and *Dictyocysta magna* in the Kochi transect. On the other hand during the peak phase, *Epiplocylis reticulata* was

abundant along the Tvm transect, followed by *Steenosomella ventricosa* and *Eutintinnus elongatus*. In the Kochi transect the abundant species were *Rhabdonella spiralis*, *Epiplocylis reticulata* and *Amphorella quadralineata*. Only two species namely, *Eutintinnus lusus undae* and *Xystonella trefortii* showed uniform distribution during the peak phase in both Tvm and Kochi transects. The species diversity, richness and evenness are given in Table 3.

3.4. Mesozooplankton

3.4.1. Biovolume & numerical abundance

The mesozooplankton biovolume varied from 0.01 ml m⁻³ to 1.18 ml m⁻³ and was higher during the initial phase of stratification (0.68 ± 0.43 ml m⁻³) compared to the peak phase (0.39 ± 0.17 ml m⁻³). The numerical abundance also showed the same trend as that of biovolume being significantly high during the initial phase (1256 ± 762 ind m⁻³) and decreased significantly during the peak

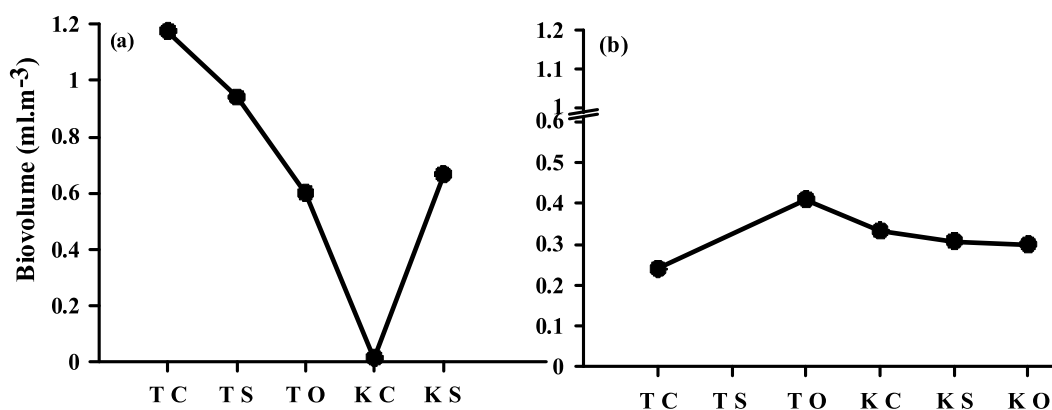


Fig. 5. Distribution pattern of mesozooplankton biovolume (ml m^{-3}) in the coastal, shelf and oceanic waters in the Tvm and Kochi transects during the initial and peak phases of winter monsoon in the South Eastern Arabian Sea (C, S and O represents the coastal, shelf and oceanic regions respectively in the T-Trivandrum and K-Kochi transects).

Table 2

The abundance of species of CTS represented as ind m^{-3} along the coastal, shelf and oceanic waters of Tvm and Kochi transects during the initial and peak phase of winter monsoon in the SEAS. (IP – represents the initial phase, PP – peak phase, T – represents the Tvm transect, K – Kochi transect, C – coastal, S – shelf and O – oceanic.)

Species	IP_TC	IP_TS	IP_TO	IP_KC	IP_KS	PP_TC	PP_TS	PP_TO	PP_KC	PP_KS	PP_KO
<i>Amphorella gracilis</i>	0	0	0	0	0	0	0	8325	0	0	0
<i>Amphorella quadrilineata</i>	20 000	0	0	0	0	0	0	0	19995	0	0
<i>Brandtiella pallida</i>	0	10 000	0	0	5 000	5 700	0	0	6 660	0	0
<i>Codonella nipponica</i>	0	0	0	0	0	0	0	0	0	12 500	0
<i>Codonellopsis ecaudata</i>	0	0	10 000	0	0	0	0	0	0	0	4 000
<i>Codonellopsis ostensfeldii</i>	0	0	0	185 000	20 000	13 195	2 000	0	19 995	0	0
<i>Coxiella annulata</i>	0	0	0	10 000	10 000	0	0	0	0	12 500	0
<i>Dadyiella bulbosa</i>	0	0	0	20 000	10 000	0	0	0	4 995	0	0
<i>Dadyiella ganymedes</i>	20 000	0	0	0	0	0	0	8 325	6 660	9 157.5	0
<i>Dictyocysta lepidia</i>	60 000	40 000	20 000	0	40 000	0	0	0	1 665	36 643	0
<i>Dictyocysta magna</i>	10 000	0	20 000	55 000	40 000	0	0	0	4 995	0	0
<i>Epiplocylis reticulata</i>	0	0	0	0	0	15 690	0	0	21 660	8 000	0
<i>Epiplocylis undella</i>	0	0	0	0	0	0	0	9 157.5	0	0	0
<i>Eutimninus elongatus</i>	0	0	10 000	0	5 000	14 865	0	0	0	0	0
<i>Eutimninus frakonii</i>	0	0	0	0	0	0	0	0	4 995	0	0
<i>Eutimninus lusus undae</i>	10 000	0	20 000	0	15 000	13 195	6 660	8 325	6 660	3 330	11 000
<i>Eutimninus undella</i>	0	0	0	0	0	0	0	0	4 995	0	0
<i>Lohmaniella oviformes</i>	0	0	27 500	0	0	0	0	2 500	0	8 000	4 000
<i>Ormosella</i>	0	0	0	0	22 500	0	3 330	0	0	0	0
<i>Parundella caudata</i>	0	0	25 000	15 000	0	0	0	0	0	0	0
<i>Parundella lohmani</i>	0	0	0	0	27 500	0	0	0	0	0	0
<i>Proplectella globosa</i>	0	0	5 000	0	0	0	0	0	0	0	0
<i>Rhabdonella henseni</i>	0	0	0	0	0	10 695	0	0	9 990	0	1 665
<i>Rhabdonella poculum</i>	0	0	0	0	0	0	4 000	6 660	4 995	0	1 665
<i>Rhabdonella spiralis</i>	0	20 000	0	5 000	15 000	0	0	0	23 310	0	0
<i>Salpingacantha ampla</i>	0	0	0	0	22 500	0	0	0	0	0	11 000
<i>Salpingella acuminata</i>	0	0	0	20 000	10 000	0	0	0	0	21 658	0
<i>Salpingella decurtata</i>	0	0	0	0	0	0	0	0	0	0	32 000
<i>Steenostomella ventricosa</i>	0	0	0	0	0	15 690	0	0	0	0	0
<i>Strombidium</i>	0	0	0	0	47 500	0	0	17 598	0	13 000	32 500
<i>Strombidium lagenula</i>	0	0	0	0	0	0	0	0	0	0	1 665
<i>Tintinnopsis tocanensis</i>	0	0	0	0	10 000	10 695	9 000	0	0	0	0
<i>Undella globosa</i>	0	10 000	0	0	122 500	0	0	2 500	13 320	16 000	0
<i>Undella hyalina</i>	0	0	0	35 000	0	0	12 330	0	0	3 330	0
<i>Xystonella trefortii</i>	0	0	0	0	0	2 500	0	4 440	11 655	9 157.5	1 665

phase ($296 \pm 161 \text{ ind m}^{-3}$). Similarly, consistent with the variation in the extent of stratification during the initial phase when the inflow of low saline BoB water was traceable only up to the Tvm transect the biovolume also showed considerable variation between Tvm (0.91 ml m^{-3}) and Kochi (0.34 ml m^{-3}) (Fig. 5a). On the contrary, during the peak phase with established stratification, negligible variation in the biovolume was observed between Tvm (0.46 ml m^{-3}) and Kochi (0.31 ml m^{-3}) transects. Also during the initial phase the biovolume showed a decreasing trend from coast to oceanic waters (coast- 1.18 ml m^{-3} ; shelf- 0.98 ml m^{-3} and oceanic - 0.60 ml m^{-3}) in the Tvm transect. However, this inconsistency in biovolume was also evident in the Kochi transect during the initial phase as well (0.01 ml m^{-3} – coast & 0.67 ml

ml m^{-3} – shelf respectively) while such significant variation was not observed during the peak phase (Fig. 5b). On considering the initiation and extent of stratification between Tvm and Kochi transects during the initial phase the numerical abundance varied between transects while it was more or less similar during the peak phase when stratification was fully established. Concurrently, during the initial phase the numerical abundance also showed variation between the coastal, shelf and oceanic waters, with significantly high numbers in the coastal waters (1569 ind m^{-3}) followed by shelf (1043 ind m^{-3}) and oceanic (1043 ind m^{-3}) waters in the Tvm transect. While in the Kochi transect the biovolume and numerical abundance was comparatively high only in the shelf waters (0.67 ml m^{-3} ; 1047 ind m^{-3}). However, during the peak phase, except

Table 3

Variation in the diversity (H'), richness (d) and evenness (J') of CTS during the initial and peak phase of winter monsoon in the Trivandrum and Kochi transects (IP – Initial Phase & PP – Peak Phase).

Transects	Region	Richness (d)	Evenness (J')	Diversity (H')
Tvm_IP	Coast	0.60	0.96	1.54
	Shelf	0.47	0.96	1.34
	Oceanic	1.01	0.98	2.04
Kochi_IP	Coast	0.96	0.92	1.92
	Shelf	1.93	0.96	2.67
Tvm_PP	Coast	1.17	0.98	2.16
	Shelf	0.81	0.97	1.74
	Oceanic	1.20	0.98	2.15
Kochi_PP	Coast	2.04	0.97	2.75
	Shelf	1.53	0.97	2.43
	Oceanic	1.33	0.92	2.13

for high considerable standing stock in the shelf of Tvm transect (0.73 ml m^{-3} ; 543 ind m^{-3}), the biovolume was more or less similar in the coastal, shelf and oceanic waters of both Tvm and Kochi transects ($\sim 0.35 \text{ ml m}^{-3}$). The numerical abundance also showed the same trend as that of biovolume.

3.4.2. Mesozooplankton community

The mesozooplankton community was dominated by Copepods in general, and significant difference in the Copepod and non-Copepod taxa was evident between both phases of the season. Consistent with other biological variables, the mesozooplankton community also exhibited significant differences between the two periods. It was observed that the percentage contribution of Copepod and non-Copepod taxa varied between 83% & 16% during the initial phase while the contribution of Copepoda reduced to 68% and that of non-Copepod taxa increased to 31% during the peak phase. The spatial variation in the distribution pattern of Copepoda was also significant, with higher contribution in the Tvm transect. During the initial phase, the abundance of Copepoda varied from 257 ind m^{-3} to 1815 ind m^{-3} and the maximum was observed in the coastal station of Tvm transect. Concurrent to the variations in the biovolume pattern between the coast, shelf and oceanic waters in the Tvm transect the distribution pattern of Copepoda also followed a similar trend showing high abundance in the coast, followed by shelf and oceanic waters.

However, in the peak phase the abundance of Copepoda was considerably low and varied from 43 ind m^{-3} to 438 ind m^{-3} and the maximum abundance was observed in the shelf of Tvm transect (438 ind m^{-3}). Furthermore, during the peak phase, the coast, shelf and oceanic variation was also insignificant. Consistent with the distribution pattern exhibited by the Copepod taxa, the non-Copepod taxa also showed variations between the initial phase and peak phase, with variations between coast, shelf and oceanic waters evident only during the initial phase. Among the non-Copepod taxa high abundance was recorded from coastal station of Tvm transect (528 ind m^{-3}) during the initial phase while during the peak phase it was from the oceanic station of Tvm transect (231 ind m^{-3}). Crustaceans were the predominant non copepod taxa, and the contribution was significantly high during the initial phase (av. $227 \pm 192 \text{ ind m}^{-3}$) compared to the peak phase (av. $53 \pm 58 \text{ ind m}^{-3}$) (Fig. 6a). The high number of crustaceans during the initial phase was due to the exceptional high abundance of Ostracods in the coastal (318 ind m^{-3}) and oceanic stations (235 ind m^{-3}) of Tvm transect. In addition, the contribution of carnivorous group Chaetognatha was also found to be high, both in the coastal and shelf waters of Tvm transect (70 & 62 ind m^{-3}). The other dominant group during the initial phase was Appendicularians and its abundance was more in the shelf (93 ind m^{-3}) compared to the coastal station (49 ind m^{-3}). The Euphausiacea were also present

in large numbers in the Tvm transect ($\sim 51 \text{ ind m}^{-3}$). On the other hand in the Kochi transect Euphausiacea was the second dominant group after Copepods, and 38 ind m^{-3} were recorded from the shelf waters. Other groups such as Chaetognatha (28 ind m^{-3}) and Ostracods (15 ind m^{-3}) were also present in considerable numbers in this transect during the initial phase.

However during the peak phase of winter monsoon the non-Copepod mesozooplankton taxa was represented chiefly by Chaetognatha ($\sim 34 \text{ ind m}^{-3}$) and Appendicularians ($\sim 12 \text{ ind m}^{-3}$). It was observed that Chaetognatha was present in considerable numbers throughout the coastal, shelf and oceanic stations of both Tvm and Kochi transects, while the occurrence of Appendicularians was restricted to Tvm transect and only to the oceanic region of Kochi transect. Few Euphausiacea, Ostracoda and Amphipoda were recorded from the Tvm transect alone (~ 6 , 3 & 1 ind m^{-3} respectively). The contribution of jelly fish was limited to $\sim 5 \text{ ind m}^{-3}$ (Fig. 6b).

4. Discussion

The winter monsoon represents a quiescent period in the South Eastern Arabian Sea. It is well established fact that the Arabian Sea experiences seasonally reversing monsoon winds and during winter monsoon, the weak northeast trade winds bring cool and dry continental air which promote higher evaporation rate in the AS. In response to this, surface circulation undergoes seasonal changes. At south of Sri Lanka, equator ward flowing EICC, merge with westward flowing Winter Monsoon Current (WMC) which subsequently divides into two branches of which one branch flows pole ward as a coastal current (WICC) along west coast of India (Shetye et al., 1991) carrying low saline BoB water to the SEAS. These hydrographical changes due to the intrusion and gradual spreading of low saline BoB water into the SEAS results in stratification, leading to oligotrophic conditions. This distinct hydrographical regime in the SEAS seems to govern the biological characteristics and thereby the food web structure of SEAS during winter monsoon period.

During initial phase (November), though SST did not show much variation between shelf/slope waters of Tvm and Kochi transects, the SSS showed marked variation between the transects. Intrusion and spreading of Low saline water ($34 - 34.9$) was restricted to southern transect (TVM), which build thick barrier layer (50 to 75 m) along the shelf/slope region indicating the initiation of stratification. While on the other hand the thin BLT ($30 - 50 \text{ m}$) observed along the shelf/slope region of Kochi transect was due to the local relatively low saline water ($34.5 - 35.1$) implying that inflow of low saline BoB water was limited to the Tvm transect. However, during the peak phase of winter monsoon (January) the extent and spread of low saline ($33.8 - 34.2$) and less dense water ($21.4 - 21.6 \sigma_t$) was evident along the entire shelf/slope and offshore region of both transects which further deepened the BLT ($50 - 80 \text{ m}$) and strengthened the stratification during the peak phase. Hence during this phase, deepening of barrier layer was observed in the shelf/slope as well as offshore regions of Tvm and Kochi due to the intrusion and spreading of low saline BoB water. In addition, the inflow of low saline BoB water into SEAS could be tracked from the monthly climatology of Sea Surface Salinity (NIO Climatology, Chatterjee et al., 2012) from October to January, and was agreeing with the *in-situ* observation. Therefore, with substantial evidence using both *in-situ* and satellite data it could be depicted that during the month of November signatures of low saline water could be tracked only up to Tvm (~ 34) (Fig. 7 a & b). While during the subsequent months (January) this low saline water propagates northward and spread over the entire southern part of SEAS (Fig. 7c&d) strengthening stratification and resulting in oligotrophic conditions in the study area.

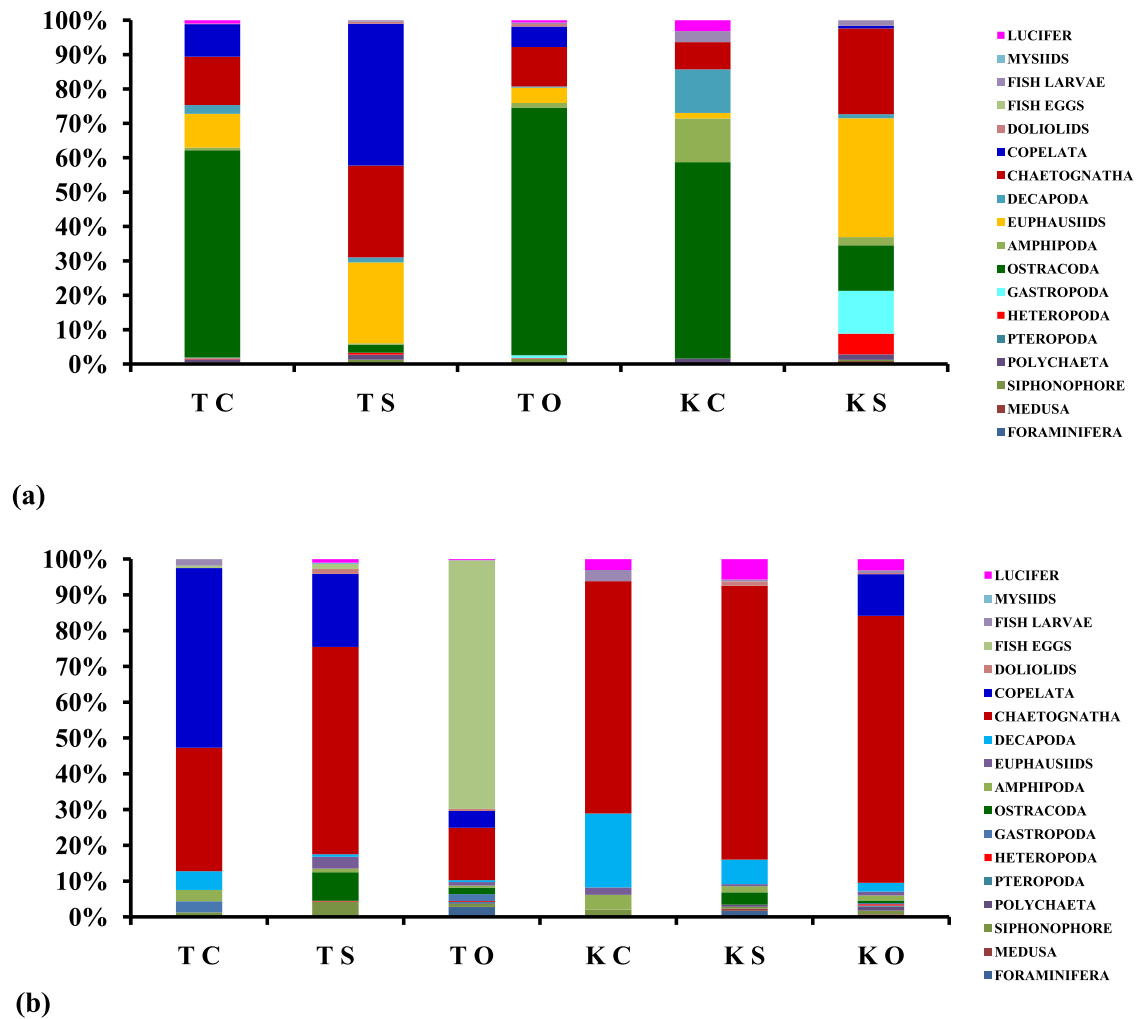


Fig. 6. Distribution pattern of major non-copepod mesozooplankton taxa in the coastal, shelf and oceanic waters of Trivandrum and Kochi transects during the (a) initial phase and (b) peak phase of winter monsoon in the SEAS (Trivandrum-T, Kochi-K, Coast-C, Shelf-S and Oceanic-O).

In addition the evidence for the intrusion of low saline BoB waters during the month of November could also be substantiated by the geostrophic current pattern from the Aviso/Nillar climatology during Nov. 2010 (Fig. 8a). The current pattern shows the equator ward flow of EICC which turns around Sri Lanka and continue to flow as WICC towards north in the Arabian Sea. This indicates that the EICC carrying low saline BoB water to the SEAS start in November, and the geostrophy pattern showed strong flow towards shelf waters of 8°N (Tvm) with a feeble current further northward. The current pattern from the Aviso/Nillar climatology is consistent with the *in-situ* hydrographic features as evident clearly from the presence of low saline water (34–34.9) along shelf/slope area of 8°N transect only. Concurrently, during the peak phase (January) the development of clockwise circulation around Lakshadweep High (LH) as documented by Shankar and Shetye (1997) supports further spreading and establishment of low saline water around east and west side of LH (Fig. 8f). This facilitates the spreading of low saline water along shelf/slope as well as open ocean waters along both Tvm and Kochi transects during the peak phase. The low saline BoB water further extends and spread over the entire area up to Kochi resulting in established oligotrophic conditions and deepening of the barrier layer. This indicates that the environmental settings get stabilized during the peak phase of winter monsoon in January. The deep thermocline and the low-salinity surface layer lead to stable near-surface stratification resulting in high SST's during January (Shenoi et al., 1999).

The presence of low saline BoB water only in the Tvm sector during November and its gradual spreading over the SEAS during January was obvious from the spatial distribution pattern of surface hydrography for these respective months (Fig. 2b). The prevalent weak winds in conjunction with the intrusion of low saline BoB waters during the winter monsoon period were found to be effective to build the surface layer stratification leading to oligotrophic conditions in the SEAS ($\text{NO}_3 < 0.5 \mu$, $\text{Chla} < 0.2 \text{ mg m}^{-3}$ - Prasannakumar et al., 2004, Jyothibabu et al., 2008). Moreover, with the gradual spreading of low saline BoB water over the entire area during January strengthened the stratification and thereby oligotrophy gets established. Nonetheless, the generally low concentration of chlorophyll depicts that SEAS is generally oligotrophic during the winter monsoon season. But, the satellite derived chlorophyll during the study period was in the range of $\sim 1 \text{ mg m}^{-3}$, which was supposed to be comparatively higher than *in situ* values. The reason stipulated for the comparatively high values may be that the satellite derived values during the study period showed fairly high concentration in the complex turbid coastal waters due to interferences from suspended sediment and sinking particles, as reported by Jyothibabu et al. (2014). Taking this into consideration, we assume that although the satellite derived chlorophyll values were comparatively high in general the chlorophyll concentration is low during winter monsoon in the SEAS ($< 0.5 \text{ mg m}^{-3}$).

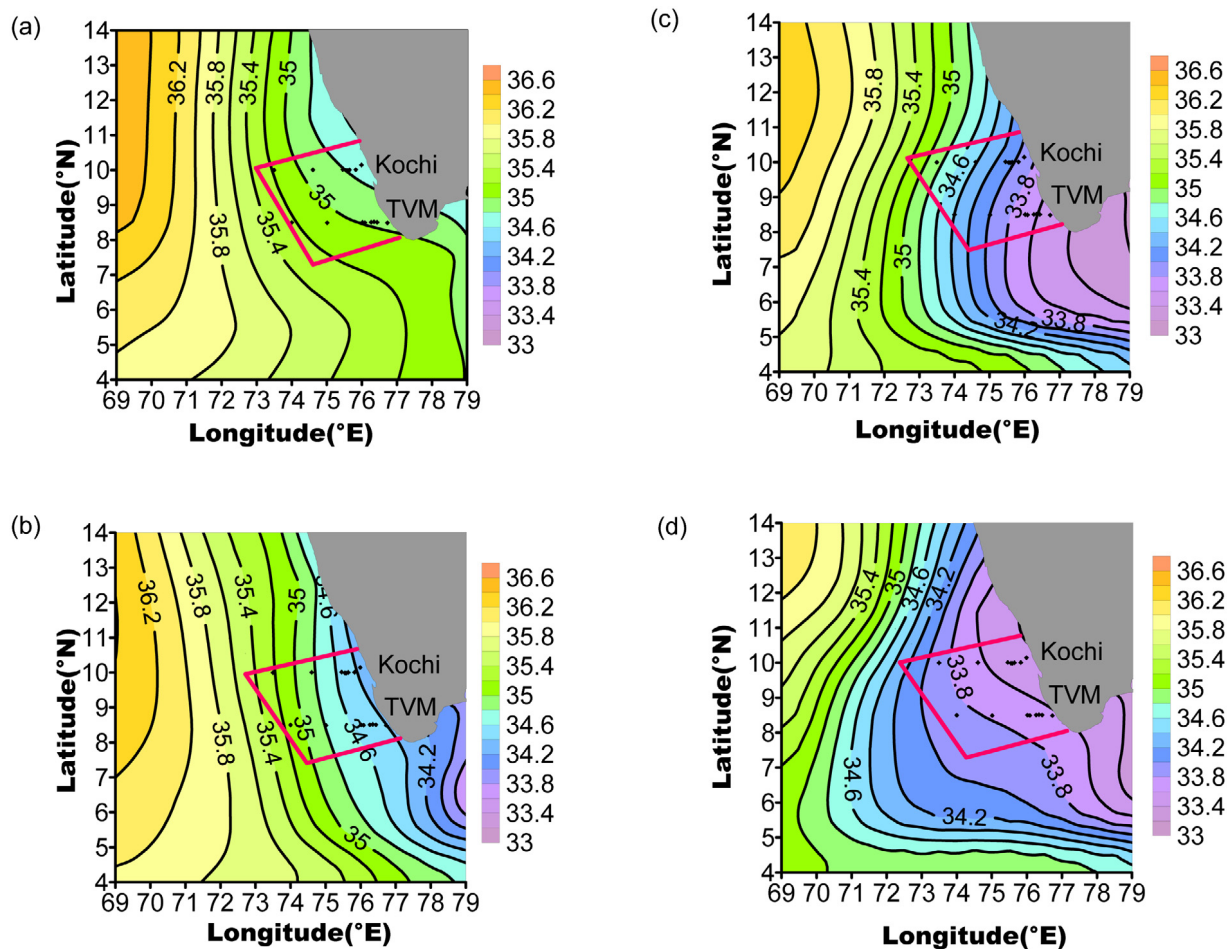


Fig. 7. Monthly climatology of Sea Surface Salinity along SEAS during (a) October (b) November (c) December and (d) January. Black dot within box indicates station location.

However, this environmental setting resulting from the intrusion of low saline water seems to influence the biological characteristics of the region. As a response to the hydrographic changes set in due to the intrusion of low saline BoB water up to the coast/shelf waters of Tvm transect and consequent stratification, the planktonic components (micro- and mesozooplankton) exhibited significant variations between the coast/shelf and oceanic regions. Studies have shown that the planktonic organisms respond rapidly to changes in temperature and oceanic current systems by expanding and contracting their ranges (Hays et al., 2005), and hence can be considered as good indicator to understand such changes. Since the signatures of low saline BoB water during the initial phase was restricted to coast and shelf of Tvm and the rest of the region was influenced by the high saline waters of the Arabian Sea (>35) it is presumed that this gradient in salinity and resultant environmental settings might be influential in structuring the MZP and mesozooplankton community. This coast-oceanic gradient in the mesozooplankton standing stock was more pronounced in the Tvm transect which was due to the higher secondary standing stock observed in the coast and shelf of Tvm. One of the possible reasons for sustaining the high mesozooplankton in the coast and shelf may be due to the high chlorophyll from the preceding winter monsoon in the Bay and is carried by the low saline BoB waters to the shelf during the month of November. However, in the Kochi transect such significant variations were not observed as the entire region is characterized by the local hydrographic regime with no gradients in salinity. The possible reason suggested for the coast-oceanic variation wherein stratification and oligotrophic conditions start to develop in the SEAS may be attributed to the

behavioral response to the seasonal transition phase because the assemblages may reinstate across the environmental gradients.

Interestingly the distributional pattern in chlorophyll and mesozooplankton biovolume showed a comparable trend during the initial phase, both being high in the coastal and shelf waters when compared to the oceanic waters. However, it is a well-known fact that oligotrophic system support complex plankton community dominated by pico/nano fraction contributing mainly to the primary production, which are unavailable for direct utilization by the crustacean dominated mesozooplankton, because of size constraints on feeding mechanism (Rassoulzadegan and Etienne, 1981; Conover, 1982; Berggren et al., 1988; Hansen et al., 1994; Legendre and Rassoulzadegan, 1996). In the present study since the environment is switching over from the productive season (summer monsoon) to a quiescent period the contribution of pico/nano fraction to the phytoplankton seems to be dominant and the significance of MZP mediation could be envisaged. Studies have explained the intermediary role of MZP which are considered as the main grazers of small sized phytoplankton (pico/nano) which are dominant in such oligotrophic stratified system due to their capability to thrive in nutrients depleted environments (Cushing, 1989; Jyothibabu et al., 2008). This could also be corroborated from the opposite trend observed in the MZP distribution pattern to that of mesozooplankton which can be attributed to grazing by mesozooplankton and thus explains the intermediary role of MZP. Hence it is suggested that during the onset phase, which is a transition period, when oligotrophy starts to develop in the SEAS the microzooplankton mediated microbial food web gains significance.

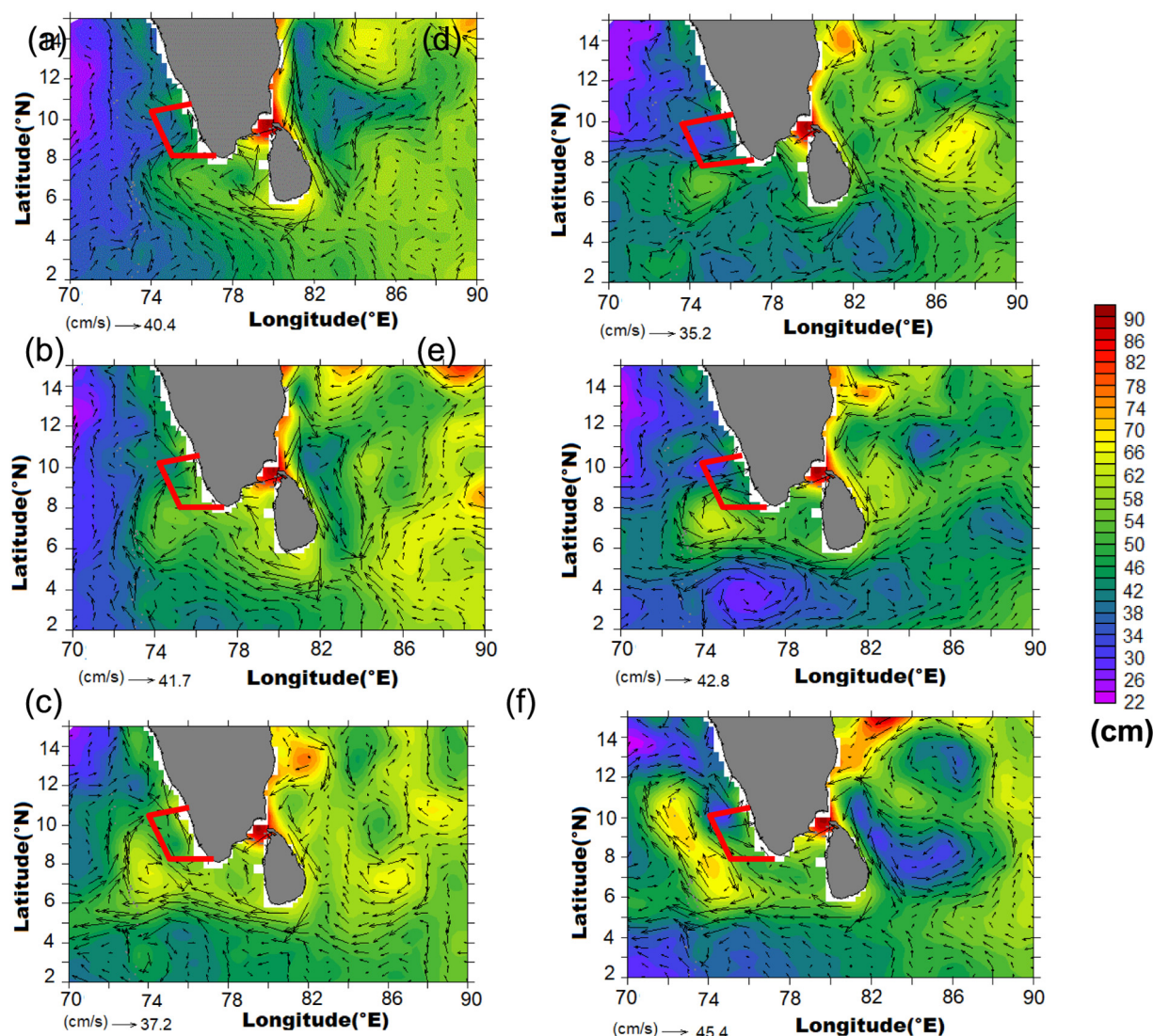


Fig. 8. Monthly sea surface height (cm) overlaid with geostrophic currents (cm/s) during Nov. 2010–Jan 2011 (a, b & c) and Nov. 2011–Jan. 2012. (d, e & f). Box indicates study area.

Furthermore, during the peak phase in January the spread of low saline BoB extends over the entire SEAS up to Kochi transect which results in the deepening of barrier layer and strengthening of stratification. As a result the concentration of chlorophyll decreased further during the peak phase (av. 0.584 mg m^{-3}) from that of the initial phase. Correspondingly, the planktonic components viz. MZP and mesozooplankton also exhibited a decreasing trend during the peak phase (av. $175 \times 10^3 \text{ ind m}^{-2}$, av. 0.39 ml m^{-3} respectively). Moreover, the influence of stratification on the planktonic community was remarkable in the Tvm transect since this transect endure the thrust of changes from the initial phase when signatures of low saline BoB water was evident from November to its spreading and strengthening of stratification over a period of time (January). This extended stratification resulted in a decrease in the planktonic standing stock compared to the initial phase and also did not show significant variation between the coastal, shelf and oceanic waters. That means a homogeneity was observed between the components at primary and secondary level ie. the concentration of chlorophyll, MZP and mesozooplankton did not exhibit variations between these regions in both transects. This is assumed to be attributed to the balance between production and grazing (*Bottom-up* and *Top-down* controls) usually observed in established stratified waters.

Considering the fact that MZP mediation attains significance in stratified oligotrophic waters, in the present study we have tried to understand the trophic role of MZP and also the disparity in the trophic level interactions during the onset and established phase of stratification. The planktonic components showed coast-oceanic variation during the initial phase of winter monsoon while during the peak phase it was uniform (did not vary). The possible reasons for this variation was that during the initial phase the system is in transition and adequate nutrients are available for the organisms to utilize and develop and showed variations in space and time. On the other hand when the system gets stabilized (established oligotrophy) during the peak phase, additional input of nutrients is being ruled out wherein the limited production is maintained mainly through the process of remineralization and the organisms seem to respond to the physical state of the system thus establishing equilibrium between production and grazing. Apart from this the community structure of mesozooplankton at the secondary level also seems to be influential in maintaining this uniformity by the *Top-Down* controls. The higher numbers of active predators like Chaetognatha was responsible in controlling the Copepod population through predation and sustained homogeneity during the peak phase of the winter monsoon. Chaetognaths are considered as primary carnivores and with abundant copepods during the

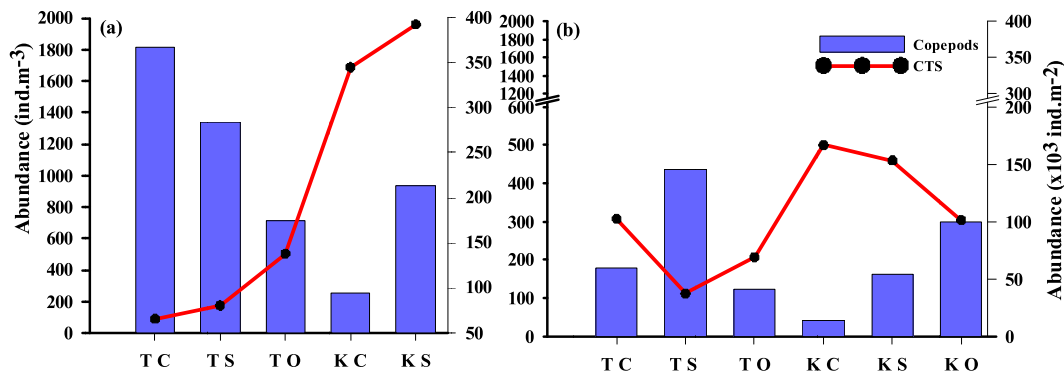


Fig. 9. Distribution pattern of abundance of Copepoda overlaid with the abundance of CTS in the coastal (C), shelf (S) and oceanic (O) waters in the Trivandrum (T) and Kochi (K) transects during the (a) initial and (b) peak phases of winter monsoon in the South Eastern Arabian Sea.

peak phase, effective grazing might govern the top-down controls. Recent study suggested that in a particular environment the trophic efficiency of planktonic food webs is controlled by the kind of zooplankton predator (Anjusha et al., 2013). Also food webs in oligotrophic systems are primarily recycling pathways, where little material is lost from the system through sinking (Landry et al., 1995) and is therefore capable to maintain the production through microbial loop signifying the importance of MZP. Although many studies have explained the trophic mediation of MZP which forms the nexus (heterotrophic link) between microbial food web and mesozooplankton (Calbet and Landry, 1999; Pomeroy, 2001; Calbet, 2008; Asha Devi et al., 2010; Anjusha et al., 2013) this study is novel since it documents changes in MZP species assemblage with respect to varying degrees of stratification.

Also in the present study, the CTS-Copepod link was examined based on the relative abundance of both groups. The results showed that at locations where high Copepod abundance was observed in the Tvm transect the CTS were low in numbers indicating feeding preference and grazing by Copepods on CTS. Whereas in the Kochi transect, locations of high CTS abundance coincided with low Copepod abundance (Fig. 9). From the above mentioned facts we could confirm Copepod-CTS link to certain extent by direct evidence during both phases of winter monsoon during the present study. The trend of CTS-Copepod trophic interactions were also consistent with the pattern exhibited by other parameters viz. chlorophyll and mesozooplankton, observed as coast-oceanic variations in the initial phase and uniformity during the peak phase concurrent with the varying intensities of stratification. The preferential grazing of Copepods on CTS have been explained in many studies based on the fact that CTS usually fall in the range of optimal prey sizes for Copepods (Frost, 1972; Berggren et al., 1988), whereas many phytoplankton cells are either too small (picoplankton) or too large (e.g. chain-forming diatoms) which are not directly available for Copepod ingestion. The strength of Copepod-CTS link and the relative importance of CTS as carbon sources for Copepod were established based on comparative cross-ecosystem analysis by Calbet and Saiz (2005). In addition ambient concentration, food quality and encounter rates have also been suggested as the most likely reasons for CTS consumption by copepods (Jonsson and Tiselius, 1990; Stoecker and Capuzzo, 1990; Broglio et al., 2004). Even though the underlying mechanisms of the Copepod preference for MZP are not fully known, the relevant role of the CTS-Copepod trophic link is indisputable. This indicates that implication of intensity and extent of stratification during the initial and peak phase is manifested at all trophic levels. But it is a prerequisite to consider all the autotrophic as well as the heterotrophic planktonic components of different size spectra in future studies in order to strengthen the understanding on the pathways of interactions between trophic levels.

The variability in plankton community structure in response to stratification was perceptible at all trophic levels in the present study, viz. group levels in the mesozooplankton as well as at species level in the MZP community. At the mesozooplankton level more number of groups and among MZP more species of CTS were observed during the peak phase which may be attributed to stratification. However analysis of diversity indices of CTS species showed that although evenness (J') was more or less similar between the initial and peak phase of winter monsoon, the richness (d) and diversity (H') was high during the peak phase of the season (Table 3). It is well known fact that diversity is typically quantified by indices that account for the relative abundances of species (i.e. evenness) as well as the total species present (Washington, 1984). Hence such metrics would be strongly skewed by the pronounced dominance of particular genus/species and can be considered as a distinctive species. In a stable environment the organisms develop efficient reproductive and competitive strategies from the available resources and therefore stable environment harbor more number of species (Pierrot-Bults and Angel, 2012). Also in the present study MDS analysis with the species assemblage of CTS showed that the stations were significantly dissimilar and did not show any discrete grouping due to significant difference in the relative abundance of species assemblages during both initial and peak phase of the winter monsoon (Fig. 10). This can be attributed to the heterogeneity in the environment caused due to the varying degree of stratification from the initial to peak phase. In addition, the most influential factor in determining the diversity pattern between the initial and peak phase of stratification was understood from the correlation analysis using BIOENV. BIOENV analysis showed a coefficient of 0.44 between mesozooplankton, MZP and BLT. It is well known fact that the BLT indicates the degree of stratification and hence this correlation explains the fact that this environmental factor was most influential in determining the diversity pattern in the present study.

In order to further understand the contribution of species (discriminator species) causing this dissimilarity and also to account the percentage of dissimilarity between Tvm and Kochi as well as between the two phases (initial & peak) of the season SIMPER analysis was done. It was interesting to note that the dissimilarity in the percentage contribution of species of CTS was >70% in all the instances. However, the percentage of dissimilarity was the highest (87%) along the Tvm transect between the initial and peak phase followed by 79% in the initial phase between Tvm and Kochi transects (Table 4). The species causing 87% dissimilarity was chiefly due to the high abundance of *Dictyocysta lepidia* and *Dictyocysta magna* during the initial phase and *Tintinnopsis tocan-tinensis* during the peak phase. The other species accountable for causing the dissimilarity were *Rhabdonella spiralis* during the initial phase and *Rhabdonella poculum* and *Codonellopsis ostenfeldii* was

Table 4

Species of ciliates and the percentage of dissimilarity in their contribution during the initial and peak phase of winter monsoon along the Tvm and Kochi transects. (IP_T: Initial Phase Tvm, IP_K: Initial Phase, PP_T – Peak Phase Tvm and PK – Peak Phase Kochi).

Species	IP_T	IP_K	Species	IP_T	PP_T	Species	IP_K	PP_K	Species	PP_T	PP_K
	79%			87%			75.94%			72.17%	
<i>Codonellopsis ostenfeldii</i>	0	285.77	<i>Dictyocysta lepida</i>	195.46	0	<i>Codonellopsis ostenfeldii</i>	285.77	47.13	<i>Undella globosa</i>	16.67	80.63
<i>Dictyocysta magna</i>	80.47	217.26	<i>Dictyocysta magna</i>	80.47	0	<i>Dictyocysta magna</i>	217.26	23.56	<i>Dictyocysta lepida</i>	0	77.41
<i>Dictyocysta lepida</i>	195.46	100	<i>Tintinnopsis tocantinensis</i>	0	66.09	<i>Undella globosa</i>	175	80.63	<i>Salpingella decurtata</i>	0	59.63
<i>Dadayiella bulbosa</i>	0	120.71	<i>Rhabdonella spiralis</i>	47.14	0	<i>Salpingella acuminata</i>	120.71	49.05	<i>Tintinnopsis tocantinensis</i>	66.09	0
<i>Salpingella acuminata</i>	0	120.71	<i>Rhabdonella poculum</i>	0	48.28	<i>Dictyocysta lepida</i>	100	74.1	<i>Rhabdonella spiralis</i>	0	50.89
<i>Undella globosa</i>	33.33	175	<i>Codonellopsis sostenfeldii</i>	0	53.2	<i>Dadayiella bulbosa</i>	120.71	23.56	<i>Salpingacantha ampla</i>	0	34.96
<i>Eutintinnus lusus undae</i>	80.47	61.24	<i>Paundella caudata</i>	52.7	0	<i>Xystonella trefortii</i>	0	81.49	<i>Salpingella acuminata</i>	0	49.05
<i>Undella hyalina</i>	0	93.54	<i>Eutintinnus lusus undae</i>	80.47	95.91	<i>Undella hyalina</i>	93.54	19.24	<i>Amphorella quadrilineata</i>	0	47.31
<i>Coxiella annulata</i>	0	100	<i>Lohmaniella oviformes</i>	55.28	16.67	<i>Coxiella annulata</i>	100	37.27	<i>Dadayiella ganymedes</i>	30.41	59.1
<i>Strombidium sp.</i>	0	108.97	<i>Dadayiella ganymedes</i>	47.14	30.41	<i>Rhabdonella spiralis</i>	96.59	50.89	<i>Xystonella trefortii</i>	38.88	81.49

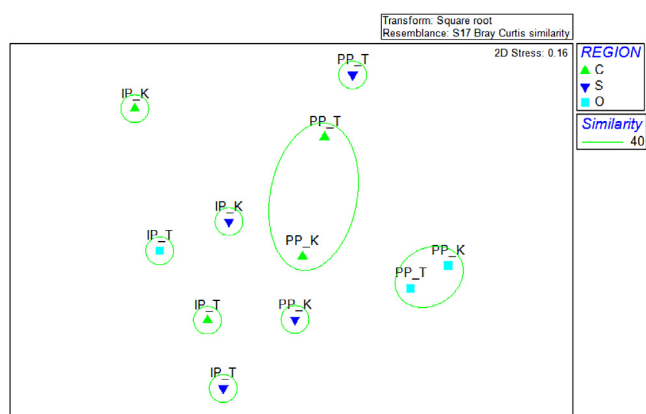


Fig. 10. MDS plot based on the species abundance data of ciliates species exhibiting the dissimilarity between the coastal, shelf and oceanic waters during the initial and peak phase of winter monsoon in the Tvm and Kochi transects.

observed only during the peak phase only. On the other hand the dissimilarity (79%) between initial phase of Tvm and Kochi transects were chiefly due to *Codonellopsis ostenfeldii*, followed by *Dictyocysta magna* present in considerable numbers only in the Kochi transect and *Dictyocysta lepida* in Tvm transect. Some of the other species which was influential in causing the dissimilarity were attributed to the occurrence of *Dadayiella bulbosa* and *Salpingella acuminata* only in Kochi transect. However, the dissimilarity of species between the initial and peak phase along the Kochi transect was comparatively low (75%) when compared to the dissimilarity between the initial and peak phase in the Tvm transect. Hence it is suggested that higher percentage of dissimilarity observed in the Tvm transect between the two phase of winter monsoon might be due to complete restructuring of the community from the initial to peak phase of established stratification. This restructuring may be attributed to the fact that Tvm transect is susceptible to the changes in the environment due to fact that the presence of Bay of Bengal low saline water was evident all through from the initial to the peak phase of winter monsoon. The comparatively lower percentage of dissimilarity (72%) between the Tvm and Kochi transects during the peak phase may be that the species with tolerance to salinity gradient and those which are able to withstand the intense stratification over a period of time continued to subsist.

The occurrence of more number of species in an established stratification during the peak phase of winter monsoon compared to initial phase results in a complex ciliate community in the SEAS. With the occurrence of more number of species more pathways of interactions seem to occur which may also be considered as one of the factors for the uniformity during the peak phase adding up to the balance between the *Bottom-up* and *Top-down* controls. This is found to be agreeing with the study by [Townsend et al. \(2003\)](#) which states that complex communities with more species and more interactions more possible pathways for energy transfer exist and may result in stability. It is also suggested that the synchronized effects of prey–predator interactions through *Bottom-up* and *Top-down* controls influence the community structure at each trophic level which in turn drive the planktonic response especially in stratified conditions when the system is oligotrophic ([Ward et al., 2014](#)). However, the strength of each of the two pathways may vary over space and time across each ecosystem ([Worm, 2000](#)).

Hence we suggest that interaction between the trophic levels (MZP and mesozooplankton) is subtle and expressed as coast-oceanic variation during the transition phase of a season (Initial Phase–November) which start with the intrusion of low saline BoB water into the SEAS. While on the other hand in an established stratified system (Peak Phase–January) the interactions achieve homogeneity due to balance between *Bottom-up* and *Top-down* controls. From the basis of this conventional understanding it is pertinent that intensity and extent of processes/mechanisms such as stratification drive the planktonic community and trophic level interactions viz. the MZP and mesozooplankton of SEAS ecosystem. Furthermore, the functional groups, i.e. all the autotrophic and heterotrophic components of different size class of plankton need to be considered in future studies to fully understand the planktonic food web during different phase of stratification which will be helpful in understanding the intricacies in the structuring of food web to varying environmental conditions. Such an understanding on the planktonic response to different physical processes is of great significance as the SEAS ecosystem is driven by monsoon reversals leading to cycles of high and low biological production and thereby variability in the response of plankton.

5. Summary

The present study attempts to explain the variations of MZP and mesozooplankton community with respect to the intensity of

stratification resulting from the intrusion of low saline BoB water into the SEAS. During the initial phase in November when stratification sets in with the signatures of low saline BoB waters being restricted to the Tvm transect both the MZP and mesozooplankton communities showed significant coast-oceanic variations, while during the peak phase when the BoB waters spread over the study area stratification gets established leading to homogeneity in the planktonic community. It is suggested that variations during the initial phase may be attributed to the behavioral response to the seasonal transition while the homogeneity during the peak phase is due to the balance between *Bottom-up* and *Top-down* controls resulting from the higher numbers of active predators like Chaetognatha at the secondary level. The study also showed that BLT was found to be the influential environmental variable in determining the diversity pattern indicating that stratification governs the community structure as evident from the complete restructuring of the community in Tvm transect during the peak phase. Therefore the study points to the fact that during the seasonal transition in the initial phase the planktonic response is subtle and perceptible as coast-oceanic variations, while in established stratification the planktonic response gets stabilized due to the balance between *Bottom-up* and *Top-down* controls.

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