

## **Impact of river discharge on distribution of zooplankton biomass, community structure and food web dynamics in the Western coastal Bay of Bengal**

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### **Abstract**

Observations were carried out along the western coastal Bay of Bengal, to examine the physical, chemical and biological parameters during the summer monsoon particularly when the rivers of India are in flood condition and discharge large quantities of fresh water into the Bay of Bengal. River discharge has a significant impact on plankton biomass in the coastal Bay of Bengal. High concentrations of nutrients were observed at the Southern coastal Bay of Bengal (SCB), which were associated with high suspended matter (SPM) that limits the phytoplankton biomass (Chl-*a*). In contrast, the Northern coastal Bay of Bengal (NCB) was characterized by low nutrients and SPM coupled with higher phytoplankton biomass and zooplankton abundance. Therefore primary production in the coastal Bay of Bengal appears to be controlled by light availability in the water column more so than by nutrients, particularly during the peak river discharge. Relatively higher zooplankton biomass and abundance have been found in NCB than in SCB. Zooplankton biomass showed a strong linear relationship with phytoplankton biomass in NCB. On the other hand, a strong linear relationship was observed with particulate organic carbon (POC) in the SCB.

*Key words:* River discharge; Nutrients; Chl-*a*; Zooplankton; Bay of Bengal.

## 1. Introduction

The Bay of Bengal (Northeastern Indian Ocean) is one of the best regions in the world to study land ocean interaction, because this region receives ample riverine inflow from major rivers such as the Ganges, Brahmaputra, Godavari, Mahanadi, Cauvery, Irrawaddy and Krishna ( $1.62 \times 10^{12} \text{ m}^3 \text{ yr}^{-1}$ , UNESCO, 1979) compared to its adjacent basin, the Arabian Sea ( $0.3 \times 10^{12} \text{ m}^3 \text{ yr}^{-1}$ , Subramanian, 1993). During the fall inter-monsoon, the strong stratification in the top 50m of the sea that results sea surface salinity as low as 28 and sea surface temperature  $\geq 28^\circ\text{C}$  (Prasanna Kumar et al., 2007). These conditions cannot be eroded by the low speed winds ( $5\text{-}7 \text{ m.s}^{-1}$ ) (Narvekar and Prasanna Kumar, 2006). Therefore, in the absence of any open ocean upwelling, nutrient supply from the subsurface to the mixed layer is greatly restricted. Further, the river system also delivers major parts of its annual average sediment load ( $1.1 \times 10^9$  tonnes) during June to September (Milliman and Meade, 1983; Milliman and Syvitski, 1992). The fluvial inputs are major sources of nutrients to the Bay of Bengal. Annually, the Ganges and Brahmaputra rivers supply  $133 \times 10^9 \text{ mol yr}^{-1}$  of dissolved silicate, which is  $\sim 2\%$  of the riverine input to the world ocean (Sarin et al., 1989). Most of the nutrients brought to the coastal area are lost in the deep because of its narrow shelf (Qasim, 1977; Sen Gupta et al., 1977; Radhakrishna et al., 1978). Despite nutrients being brought down by rivers, the Bay of Bengal is conventionally referred to as an oligotrophic system where nitrate depletion in the surface waters and shortage of solar radiation due to persistent cloud cover, which in turn restricts the phytoplankton growth (Gomes et al., 2000; Prasannakumaret al., 2002; Madhupratap et al., 2003; Madhu et al., 2006). Due to limited light penetration through water column during monsoon periods, the phytoplankton community could not efficiently utilize the high amount of nutrients present in the inshore regions (Sengupta et al., 1977; Madhupratap et al., 2003).

The chemical characteristics of Indian rivers are significantly different due to large spatial variations in precipitation patterns over the Indian subcontinent, population density and terrain characteristics that lead to variable magnitudes of discharge and concentrations of material brought to the coastal ocean. The specific conditions may have impact on the coastal biogeochemical processes and food web dynamics along the East Coast of India. Temperature, salinity and food supply are some of the important factors that are known to cause spatial changes in zooplankton population (Lawrence et al., 2004). All these factors, such as salinity, nutrients, and terrestrial organic matter, are significantly modified by the river discharge which has direct influence on the abundance and diversity (Siokou-Frangou et al., 1998) as well as the distribution (Nasser et al., 1998) of zooplankton. Therefore river discharge modified not only water column characteristics but also food web dynamics in the coastal

Bay of Bengal. Planktonic copepods are the major members of zooplankton in the marine pelagic ecosystems (de Puellès et al., 2003; Leandro et al., 2007). They graze on phytoplankton and microzooplankton (Sherr and Sherr, 2009) and at the same time they are preyed by higher trophic levels, such as fishes. Therefore copepods play a pivotal role in the transfer of energy from primary producers and microbial food web to the traditional food chain (diatom-copepod-fish) (Sherr and Sherr, 2009). Studies on the zooplankton distributions in the western Bay of Bengal during and after the International Indian Ocean Expedition (1960-1965) are scarce. Our aim is to examine how the freshwater discharge can influence spatial distribution of zooplankton biomass and its abundance and community structure and also to know whether all these are controlled by either Chl-*a* or POC in the western Bay of Bengal.

## **2. Materials and Methods**

Sampling was carried out during cruise SN42 of ORV *Sagar Nidhi* in the Western coastal Bay of Bengal during the peak monsoon season. Nine transects were occupied, established Krishna South (KS), Krishna North (KN), Godavari South (GS), Godavari North (GN), Visakhapatnam (V), Vamsadhara (VD), Hyadri (HD), Mahanadi South (MS) and Mahanadi North (MN). Dissolved Oxygen (DO) was measured using Winkler's titrimetric method of Carritt and Carpenter (1966). The analytical precision, expressed as standard deviation, was 0.07% for DO. Nutrients were measured using standard spectrophotometric procedures (Grasshoff et al., 1983). SPM was measured as weight difference of material retained on 0.2  $\mu\text{m}$  polycarbonate filter (Millipore) after filtering 200-500 ml of water. About 1 liter of water samples was filtered through pre-combusted GF/F filter (0.7  $\mu\text{m}$  pore size; 47mm diameter; Whatman) at 300°C for 6 h, at low vacuum and dried at 60°C for at least 24 h. Filters were acid fumigated for 12 h in the desiccator to remove inorganic carbon, and POC on the filter was measured using an elemental analyser coupled with an isotope ratio mass spectrometer (EA-IRMS-Delva V, Finnigan, Germany). Water samples for Chl-*a*, collected from the surface, were analyzed fluorometrically (Turner Designs, USA) following Suzuki and Ishimaru (1990). Zooplankton samples were collected from the surface by horizontal towing of a Bongo net mouth area 0.25 m<sup>2</sup>, mesh size 200- $\mu\text{m}$ . The volume of water filtered by the net was measured with a calibrated flow meter (General Oceanics) mounted at the mouth of the net. Upon recovery of the samples, catch was immediately preserved in a 5% buffer formaldehyde/seawater solution, for the species counts and identifications. Zooplankton biomass was estimated by the standard displacement volume method (UNESCO, 1968; ICES, 2000) and expressed in ml m<sup>-3</sup> of water filtered. Prior to analysis, zooplankton abundance levels were converted to individual.m<sup>-3</sup>. When the sample size was

large, usually in the first and second strata, it was split into several subsamples by using a Folsom's plankton splitter and, in general, 25% aliquots were used for enumeration of zooplankton abundance and identification of taxa. All zooplankton samples were sorted from the original samples and identification was to species level wherever possible for most taxonomic groups. Copepods were identified using the standard identification keys of the marine species identification portal (<http://copepods.obs-banyuls.fr>), the world register of marine species (<http://marinespecies.org>), a key for the identification of the more common planktonic Copepoda of Indian coastal waters (Kasturirangan, 1963) and marine planktology (Zheng et al., 1990) were used to aid in the identification of copepod species.

### **3. Study area**

The Northern Indian Ocean is a unique region in terms of its geographical setting, as it is semi-enclosed and connected to the Indian Ocean and its circulation pattern in the south. Winds and circulation in the study region are largely influenced by seasonal variations and change direction twice a year. During the southwest monsoon season (summer) winds blow from the southwest direction and during northeast (winter) monsoon the winds are from the northeast direction. The East Indian coastal current which flows from the southwest during February to September with a peak in March–April reverses its direction and flows from the northeast direction during October - January with a strong flow in November (Schott and McCreary, 2001). Besides the precipitation ( $\sim 2 \text{ m yr}^{-1}$ , Prasad, 1997) and monsoonal winds, the land driven discharge leads to changes in the coastal current patterns and brings noticeable alteration in the physicochemical and biological characteristics of the coastal waters. Rains over the Bay of Bengal show strong seasonality. The southeast coast of India has a winter rainfall maximum whereas the rest of the east coast of India has a summer rainfall maximum (Ramage, 1984). Over the Bay of Bengal, storms and depressions are observed mostly from June to November (Rao, 1981). Tropical cyclones in the Bay of Bengal during the post monsoon transition period are associated with very heavy rain and stormy winds, especially in the coastal area (Rao, 1981).

The northern coastal Bay of Bengal, north of transect VD, receives discharge from the Ganges whereas monsoonal rivers such as Godavari and Krishna, discharge in the south. Hence the data were divided into two zones. They are (1) SCB, comprising the transects of KS, KN, GS and GN, which are influenced by the monsoonal rivers, Godavari and Krishna, (2) NCB, comprising transects VD,

HD, MS and MN, which are more influenced by discharge from river Ganges and (3) Transect V, which was not influenced by any river discharges (Fig. 1).

## **4. Results and discussion**

### ***4.1 River discharge influences spatial distribution of zooplankton***

The coastal Bay of Bengal receives discharge from various rivers, and the volume of discharge is higher in the NCB, where discharge by the Ganges ( $>14000 \text{ m}^3 \text{ S}^{-1}$ ) dominates the peninsular rivers (Mahanadi and Vamsadhara;  $<600 \text{ m}^3 \text{ S}^{-1}$ ). On the other hand, SCB receives discharge from the peninsular rivers (Godavari and Krishna;  $<1000 \text{ m}^3 \text{ S}^{-1}$ ) (Fig. 2). Zooplankton biomass and abundance varied from 0.02 to 0.21  $\text{ml m}^{-3}$  and 52 to 1745 numbers (N)  $\text{m}^{-3}$  in the SCB, respectively, whereas it was 0.06 to 0.98  $\text{ml m}^{-3}$  and 216 to 2889  $\text{N m}^{-3}$  in the NCB, respectively (Fig. 3). Biomass showed a decreasing trend towards the offshore, all along the transect sampled. The highest zooplankton biomass and abundance in the NCB was associated with low discharge station along the MN transect  $0.66\pm 0.31 \text{ ml m}^{-3}$  and  $1756\pm 893 \text{ N m}^{-3}$  (Fig. 4b). On the other hand low biomass and abundance found at KS transect  $0.03\pm 0.02 \text{ ml m}^{-3}$  and  $104\pm 63 \text{ N m}^{-3}$  (Fig. 4a) is associated with high discharge in the SCB. The zooplankton biomass and abundance were  $0.22 \text{ ml m}^{-3}$  and  $1475 \text{ N m}^{-3}$  respectively along transect V (Fig. 3 and 4c) where no direct discharge occurs, however this region receives significant domestic and industrial effluents as a major city is situated close to this transect. Zooplankton biomass was mostly contributed by copepods in the entire study region. Two major peaks belonging to copepods were noticed in the low discharge stations found along the MN-5 and VD-1 transects, while the lowest copepod density was observed particularly in the high discharge station in the KS-3 transect (Fig. 4a,b). Subsequently, highest copepod species diversity index ranged from 0.60 to 1.18 is associated with low discharge in the NCB, whereas the index of 0.55 to 1.03 range is associated with high discharge stations in the SCB (Fig. 5).

### ***4.2. Chl-*a* and POC controls zooplankton abundance and community structure***

The surface Chl-*a* in the study region varied from 0.5 to 6.1  $\text{mg m}^{-3}$  (Fig. 6a) and gradually decreased from the low saline NCB region ( $2.8\pm 1.7 \text{ mg m}^{-3}$ ) towards the high saline region of SCB ( $1.53\pm 1.15 \text{ mg m}^{-3}$ ) (Table 1). The observed concentration of Chl-*a* is consistent with the other reports (Radhakrishna et al., 1978; Bhattathiri et al., 1980; Devassy et al., 1983). POC concentration ranged from 2 to 17.5  $\mu\text{MC}$  (Fig. 6b) and it was relatively higher in SCB with a concentration of  $12.4\pm 4 \mu\text{MC}$  than in NCB with  $8.1\pm 3.5 \mu\text{MC}$  (Table 1). Sarma et al. (2013a) noticed that high POC

concentration in the SCB contributed by higher terrestrial organic matter whereas *in situ* production contributes in the NCB. No significant correlation has been found between Chl-*a* and POC at either SCB ( $r^2=0.28$ ;  $p=0.51$ ) or NCB ( $r^2=0.02$ ;  $p=0.54$ ) regions, suggesting a strong influence of river discharge driven allochthonous organic matter on POC concentration in the Western coastal Bay of Bengal during the study period. Sreepada et al. (1993) also found a lack of correlation between POC and Chl-*a* in the coastal Bay of Bengal and attributed this to detrital material input through river discharge during Southwest monsoon. POC concentrations found in this study are very close to those reported earlier in the Bay of Bengal during Southwest monsoon (4.3-11.1  $\mu\text{M}$ ; Fernandes et al., 2009). The highest POC concentrations were noticed at GN ( $14.5\pm 5.4 \mu\text{M}$ ) and MS ( $14\pm 3.1 \mu\text{M}$ ) in the SCB and NCB (Fig. 6b) respectively, and were associated with high river discharge stations. SPM in the surface waters varied from 4.3 to 42.7  $\text{mg l}^{-1}$  (Fig. 7d) and higher concentrations were noticed in the SCB which was  $23.1\pm 8.5 \text{ mg l}^{-1}$  whereas it was  $11.6\pm 5.8 \text{ mg l}^{-1}$  in the NCB. (Table 1). Higher zooplankton biomass and abundance have been found in NCB than in SCB and displayed a strong linear relation with Chl-*a* ( $r^2=0.8$ ;  $p<0.001$ ) and a weak linear relation with POC ( $r^2=0.33$ ;  $p<0.05$ ) in NCB. On the other hand, the zooplankton biomass and abundance has a strong linear relation with POC ( $r^2=0.58$ ;  $p<0.001$ ) and weak linear relation with Chl-*a* ( $r^2=0.36$ ;  $p<0.01$ ) in SCB (Table 2). Nair et al. (1981) found high zooplankton biomass associated with cold-core eddies in the Western Bay. The cold-core eddies inject nutrient rich waters into the photic zone that promotes phytoplankton biomass and it is one of the major sources of nutrients to fuel phytoplankton blooms in the Bay of Bengal (Prasanna Kumar et al., 2002). Calanoids were most predominant during the study period, displayed linear relation with Chl-*a* at both NCB and SCB (Table 2). Cyclopoids displayed linear relationship with Chl-*a* ( $r^2=0.5$ ;  $p<0.05$ ) in the SCB, on the other hand inverse relationship showed with Chl-*a* ( $r^2=0.6$ ;  $p<0.05$ ) in the NCB (Table 2). Poecilostomatoids and harpacticoids displayed a strong linear relation with POC at both NCB and SCB (Table 2). Turner (1986) considered poecilostomatoids to be omnivores while Yamaguchi et al. (2002) considered them to be detritivores. Sautour and Castel (1993; 1995) reported that *Euterpina acutifrons* (harpacticoid) grazes on detritus and algae. For the non-copepod community, decapods and *Lucifer* sp. showed a linear relation with POC at both NCB and SCB (Table 2). Cladocerans displayed a linear relationship with Chl-*a* at both NCB ( $r^2=0.3$ ;  $p<0.001$ ) and SCB ( $r^2=0.4$ ;  $p<0.05$ ) (Table 2). Furthermore, ostracods showed a linear relationship with POC at both NCB and SCB, while chaetognaths only had a linear relationship with POC ( $r^2=0.3$ ;  $p<0.05$ ) in the SCB and with Chl-*a* ( $r^2=0.46$ ;  $p<0.001$ ) in the NCB respectively (Table 2).

### ***4.3. The influences of nutrients***

River discharge brings a significant amount of nutrients to the coastal Bay of Bengal. The concentration of dissolved inorganic nutrients (DIN) along the coastal Bay of Bengal varied between 0.1 and 14  $\mu\text{M}$  in the surface waters (Fig. 7a) during the study period, with higher concentrations in the SCB and decreased towards the NCB region. The mean concentration of nitrate in the surface waters in the SCB region was  $4.4 \pm 3 \mu\text{M}$  while it was  $0.5 \pm 0.7 \mu\text{M}$  in the NCB region (Table 1). D'Sousa et al. (1981) reported nitrate to be the limiting nutrient for phytoplankton biomass in the Bay of Bengal. The spatial variations in the nutrient concentrations and ratios are mainly driven by the concentration of the discharge waters. Low nutrients concentrations in the NCB were probably due to rapid utilization by phytoplankton biomass coupled with low SPM resulting high Chl-*a* content, which lead to substantial enhancement of the zooplankton biomass and abundance in the NCB. Madhupratap et al. (2003) stated that phytoplankton growth in the Bay of Bengal was controlled by the availability of light, especially during the southwest monsoon. N: P ratios varied between 0.3 and 23.3 in the coastal Bay of Bengal with relatively higher ratios in the SCB  $13 \pm 5.5$  and decreased to  $5.4 \pm 4.1$  in the NCB (Table 1). The dissolved inorganic phosphate (DIP) concentrations were ranged from 0.1 to 6  $\mu\text{M}$  (Fig. 7b) with the mean value of  $0.4 \pm 0.4 \mu\text{M}$  and  $0.3 \pm 0.4 \mu\text{M}$  SCB and NCB respectively (Table 1). The dissolved silicate (DSi) concentrations ranged from 0.9 to 17.5  $\mu\text{M}$  (Fig. 7c), while it was higher in NCB ( $8.9 \pm 6.2 \mu\text{M}$ ) than in SCB ( $4.5 \pm 3.3 \mu\text{M}$ ) (Table 1). The low N:P ratios in the NCB were driven by low DIN. Furthermore, Si:P varied between 2.3 and 77.9 and was lower in SCB ( $13.3 \pm 8.1$ ) than in NCB ( $34.8 \pm 21.6$ ). Similarly, N:Si varied between 0.03 and 14.1 with higher ratios in the SCB ( $2.5 \pm 3$ ) than in the NCB ( $0.17 \pm 0.1$ ) (Table 1). The nutrient ratios suggest that nitrogen and silicate are limiting nutrients in the NCB and SCB respectively. The concentrations of nutrients during the study period were significantly higher than those of the non-monsoon period when under detection limits were recorded (Kumar et al., 2004).

### ***4.4. The influences of other physico-chemical factors***

The surface water temperature was  $\sim 27^\circ \text{C}$  in the SCB region, which is  $\sim 3^\circ \text{C}$  cooler than that in the NCB region (Fig. 8a). The up sloping of isotherms from the depth of  $\sim 50 \text{ m}$  can be noticed in the SCB region. Throughout the study period, surface salinity ranged from 21 to 34.8 over the western coastal Bay of Bengal (Fig. 8b) and it was much lower than that of the winter season (Suryanarayana et al., 1991). The occurrence of low saline water over a large area of the northern Bay was reported earlier by Gopalkrishna and Sastry (1985) and Conkright et al. (1994). Nyandwai and Dubi (2001)

found a significant decrease in salinity and temperature of inshore waters due to freshwater runoff during the 1998 El-Nino rains on the East African coast. The highest salinity was noticed along transect V, where no direct river discharge occurs (Fig. 8b). The surface DO concentrations were relatively higher in NCB than in SCB (Table 1). The lower DO concentrations in the SCB is resulted from upwelling of oxygen minimum waters to surface, whereas higher DO concentrations in the NCB was caused by strong stratification and high primary production which is evident from higher Chl-*a* concentration from the NCB (Table 1). During the present study zooplankton biomass displayed a linear relation with temperature ( $r^2=0.46$ ;  $p<0.001$ ) and DO ( $r^2=0.53$ ;  $p<0.05$ ) in the NCB. In contrast, zooplankton biomass inversely correlated with temperature ( $r^2=0.68$ ;  $p<0.001$ ), salinity ( $r^2=0.55$ ;  $p<0.05$ ) and DO ( $r^2=0.46$ ;  $p<0.05$ ) in the SCB (Table 2). Recently Vidjak et al. (2012) noticed that the zooplankton biomass primarily responded to physical parameters, such as temperature and salinity coastal waters of eastern Adriatic (Mediterranean Sea). In the NCB calanoids showed strong linear relation with temperature ( $r^2=0.52$ ;  $p<0.001$ ) and DO ( $r^2=0.49$ ;  $p<0.001$ ) and inverse relation with salinity ( $r^2=0.5$ ;  $p<0.001$ ). Furthermore, cyclopoids showed a linear relation with salinity ( $r^2=0.42$ ;  $p<0.05$ ) and DO ( $r^2=0.48$ ;  $p<0.05$ ), subsequently harpacticoids displayed linear relation with temperature and DO (Table 2). Decapods and *Lucifer* sp. showed a linear relation with temperature and DO (Table 2). In SCB calanoids, cyclopoids, poecilostomatoids and harpacticoids showed an inverse relation with temperature and salinity, but a linear relation with POC (Table 2). Subsequently, calanoids and cyclopoids showed an inverse relation with DO (Table 2). In the non-copepod group, decapods and *Lucifer* sp. in the NCB showed a positive correlation with temperature, however *Lucifer* sp. in the SCB showed an inverse relation with temperature and DO (Table 2). Furthermore, cladocerans and ostracods displayed linear relation with temperature, where chaetognaths showed an inverse relation in both NCB and SCB (Table 2).

#### **4.5 Distribution of copepod groups**

During the study period, in the western coastal Bay of Bengal copepod group was dominant and contributed ~76% of the total zooplankton biomass. Recently Sabu et al. (2015) reported that the copepod group was dominant group within the mixed layer, contributing to 81% of the total abundance in the northern Bay of Bengal (16°-20° N) during early winter monsoon. Within the copepods, calanoids (39%) were predominant, followed by poecilostomatoids (30%), harpacticoids (4%) and cyclopoids (3%) (Table 3). Similarly, earlier reports also showed that Calanoida was the dominant order among the copepods followed by Poecilostomatoida (Deevey and Brooks, 1977;



Madhuratap and Haridas, 1990). The next important taxa in decreasing order of their abundance were chaetognaths (7.5%) ostracods (6.5%), cladocerans (3%), decapods (2.5%), lucifers (1.5%), appendicularians (1.5%) and polychaeta larvae (1.5%) (Table 3). Copepods normally contribute significantly to the zooplankton abundance followed by chaetognaths and have been reported earlier in the Indian Ocean (Madhuratap and Haridas, 1990; Padmavati et al., 1998; Koppelman and Weikert, 2000). Calanoida, belonging to the copepod community, had higher density in the study region, and it increased towards the NCB from SCB (Fig. 9) while it decreased from inshore to offshore. The maximum peak found along MN transect (Fig. 9) that associated with high phytoplankton biomass (Chl-*a*). Among the calanoids, cyclopoids co-dominated and their density was higher at SCB ( $43 \pm 28 \text{ N m}^{-3}$ ) than in the NCB ( $13 \pm 6 \text{ N m}^{-3}$ ) (Table 3) and maximum peak was observed in the GN transect (Fig. 9). The possible reason for decreasing cyclopoid communities in the NCB region is probably the presence of teeming abundance of predatory zooplankton such as chaetognaths. Results showed that the density of chaetognaths at NCB was almost double than that at SCB (Table 3). Furthermore, due to the small body-length of cyclopoid, mainly *Oithona* sp., might be grazed by larger community. Our findings confirm previous investigations, with numerical dominance of the cyclopoid coastal form *O. similis*, which is considered as the most abundant copepod in the world's ocean (Begelow, 1926). The density of Poecilostomatoida was higher at NCB ( $956 \pm 389 \text{ N m}^{-3}$ ) than at SCB ( $816 \pm 566 \text{ N m}^{-3}$ ) (Table 3) and maximum abundance was noticed at GN transect of SCB and VD of NCB (Fig. 9). The abundant poecilostomatoids were *Oncaea venusta*, *Oncaea* sp., *Corycaeus* sp., *Saphrinina* sp. and *Copilia* sp. in the study region. Similarly the dominance of copepod species *O. venusta* was reported in the Japan Sea, further this species breed intensively at higher temperatures, especially in the range of 25 to 27.5°C in the Japan Sea (Hirakawa, 1995), during the study period the surface water temperature was 27°C in the Western coastal Bay of Bengal. Subsequently, *Corycaeus andrewsi* and *Farranula gibbula* have been reported to be indicator species of the warm-oceanic waters (Kang et al., 1990). Harpacticoid community was higher at NCB ( $258 \pm 148 \text{ N m}^{-3}$ ) than in SCB ( $88 \pm 57 \text{ N m}^{-3}$ ) (Table 3), furthermore the maximum density of harpacticoids has been found along transect MS (Fig. 9). Spatially, a marked increase in harpacticoids as observed towards offshore at transects V.

#### **4.6 Distribution of non-copepod density and influencing factors**

Among the copepod, other metazoan zooplankton compositions were also found subordinately. Decapod density was higher at NCB than at SCB (Table 3) and the highest density was found at HD

and lowest density was recorded at KS transect (Fig. 9), further a steep decreasing trend was observed towards offshore. However, in the western Bay of Bengal, the decapod community showed linear correlation with temperature ( $r^2=0.4$ ;  $p<0.05$ ) and DO ( $r^2=0.3$ ;  $p<0.05$ ) but there was no correlation with Chl-*a*, suggesting that these zooplankton groups probably depend on terrestrial organic matter, hence it showed positive correlation with POC. *Lucifer* sp. pertaining to the metazoan zooplankton had very poor density at SCB as compared to NCB (Table 3) and maximum density was noticed in the MS transect (Fig. 9). Cladocerans density was high at NCB where this community was observed only at GS transect in SCB (Table 3 and Fig. 9), displayed linear relations with temperature ( $r^2=0.45$ ;  $p<0.001$ ), and inverse correlation with POC ( $r^2=0.63$ ;  $p<0.001$ ) at SCB. A similar result has been observed in the coastal waters of Mediterranean Sea (Vidjak et al., 2012). *Evadne* sp. and *Podan* sp. were the dominant genera in the western Bay of Bengal during the monsoon periods, the positive feeding preference of *Evadne* sp. pertains to the cladocera which were associated with Chl-*a* ( $r^2=0.3$ ;  $p<0.001$ ) and negative relation was found with SPM ( $r^2=0.5$ ;  $p<0.001$ ). Similar results were found at the non-discharge station off Visakhapatnam. The feeding behaviour of marine cladocerans is not fully understood and the currently accepted view is that marine cladocerans usually thrive in coastal waters during periods when food is dominated by nano and picoplankton (Katechakis and Stibor, 2004). Wong et al. (2006) showed that *P. avirostris* was a key grazer on phytoplankton especially on cryptophytes in the eutrophic Tolo Harbor in eastern coastal waters of Hong Kong. The increase in population of cladocera following upwelling has been reported by others (Longhurst and Bainbridge, 1964; Naomi et al., 1990). In contrast the present study results show that cladocerans are ignorant at the upwelling region at SCB except the GS station.

Ostracods were found at almost all the stations in the western Bay of Bengal and a higher density was recorded at NCB than at SCB (Table 3) and the onshore community had a higher abundance than offshore. About 66% of the total Ostracoda communities were found in the NCB while ~19% and 15% at SCB transect V respectively. *Conchoecia* sp. was the dominant genera pertaining to Ostracoda, mainly consisting of ~59% particularly at one station along MN transect (Fig. 9). The occurrence of such high abundance at one station is rather obscure. The higher density of chaetognaths was observed at NCB ( $370\pm 152 \text{ N m}^{-3}$ ) than at SCB ( $100\pm 79 \text{ N m}^{-3}$ ) (Table 3), where maximum abundance showed at HD followed by MN, MS and VD transects respectively (Fig. 9). Sampatkumar et al. (2011) reported that chaetognath density was higher in the isothermal layer and

varied from 88 to 1010 ind.100 m<sup>-3</sup> in the Arabian Sea and 86 to 635 ind.100 m<sup>-3</sup> in the Bay of Bengal. They concluded that the maximum population density of chaetognaths was observed in the isothermal layer when compared to the other layers. Our present study reveals that the chaetognatha (*Sagitta* sp.) density was recorded as 2077 N m<sup>-3</sup> in the surface waters of the western Bay of Bengal during the monsoon season. In the waters of the Indian Ocean, Nair (1978) found the maximum density of chaetognaths at 0-125m water column.

#### ***4.7. Copepod species composition along the western coastal Bay of Bengal***

The zooplankton diversity and dominance were 0.83 and 0.21 respectively, along the transect V (Fig. 5), subsequently dominance index ranged from 0.12 to 1.13 and 0.07 to 0.37 in the SCB and NCB respectively. Diversity and dominance are mainly determined by several hydrographic properties as they control either indirectly or directly. Dominance showed a linear relation with salinity and DO in the NCB and SCB respectively furthermore displayed positive relation with Chl-*a* in NCB and with POC in SCB (Table 2). This suggests that zooplankton communities were opportunistic and preferred *in situ* production in the NCB and terrestrial organic matter in the SCB during the study period. For instance, calanoids mostly preferred Chl-*a* where poecielostomatoids and harpacticoids community depended on POC in both the regions (Table 2). The species occurrence and their feeding habitats also control their dominance in the coastal Bay of Bengal (Roman, 1984; Tackx et al., 1995). Diversity displayed inverse relation with temperature and DO in the NCB and SCB respectively (Table 2). This study suggested that zooplankton biomass, diversity and dominance in the western coastal Bay of Bengal was rather controlled by availability of food such as phytoplankton biomass (Chl-*a*) and POC.

A total of 53 genera/species was identified, with 24 species of Calanoida, 6 species of Cyclopoida, 3 species of Harpacticoida, 8 species of Poecilostomatoida belonging to copepod; besides, 3 Cladocera, 2 Ostracoda, 2 Malacostraca, 3 Chaetognatha and 2 species of Appendicularia were identified. Among the Calanoida, the abundance of dominant appearing family were Acartiidae, Paracalanidae, Clausocalanidae, Pseudodiaptomidae, Centropagidae, Candaciidae, Scolecitrichidae and Temoridae. Subsequently, in Cyclopoda, Oithonidae and in Poecilostomatoida, Oncaeidae, Corycaeidae and Sapphirinidae were abundant, furthermore, in Harpacticoida, Euterpinidae, Ectinosomatidae and Clytemnestridae were the dominant families from the copepod group. Within the Acartiidae family *Acartia danae*, *A. tonsa* and *A. southwelli* were by far the most abundant

species and dominated the zooplankton communities at all stations. The species *A. tonsa* was the most numerous and widely distributed from coastal to offshore (Fig.10) while *A. danae* was the most dominant with maximum abundance in the coastal waters (Fig. 10). The other species showed much lower abundance, such as *A. spinicauda* and *A. erythrea*. The next abundant species belonging to family Paracalanidae were *Paracalanus crassirostris*, *P. aculeatus* and *P. parvus* while *Clausocalanus minor*, *C. ingens* *Pseudodiaptomus bowmani*, *P. serricaudatus*, *Centropages elongatus*, *C. furcatus*, and *Candacia bradyi*, were dominant zooplankton species in the western coastal Bay of Bengal. Although, *C. minor* was predominant at coastal region whereas *C. furcatus* present at offshore region (Fig. 10) The dominance of *P. crassirostris*, *P. parvus* and *P. denudatus* from the Paracalanidae family has been reported from the coastal waters of Malaysia (Rezai et al., 2004). *Calanopia* sp. belonging to the family Pontellidae showed increasing trend towards offshore while *Labidocera bengalensis* was dominant at offshore region (Fig. 10). Further, *Oithona rigida* and *O. plumifera* were predominant species belonging to the family Oithonidae; however *Oncea venusta*, *O. clevei*, *O. ovalis*, *Corycaeus clause*, *C. longistylis* and *Sapphirina darwini* were dominant species from the Poecilostomatoidae. The species *O. clevei* was most dominant among poecilostomatoida in the South China Sea (Othman, 1990). Among the other species *S. darwini* was present less in number only at offshore waters (Fig. 10) *Euterpina acutifrons* and *Microsetella norvegica* were the predominant species from the harpacticoids, however *E. acutifrons* was most dominant in the coastal waters where *M. norvegica* predominant in the offshore waters (Fig. 10) in the western Bay of Bengal. Similarly the species *E. acutifrons* was found in greater abundance in coastal waters compared to open neritic waters (Johan et al., 2013). Although the species survive a wide range of salinities (Moreira, 1975; Moreira et al., 1982; Turner, 1994), it is more abundant in the coastal waters than in the offshore.

## Conclusions

The NCB region received fresh water discharge from the river Ganges which is higher by several orders of magnitude compared to the SCB region that received fresh water discharge from the peninsular rivers. In the present study, showed significant changes in the plankton biomass (Chl-*a*) affected by physicochemical variables in both the regions. Degree of nutrients determine the quality as well the quantity of plankton along the study region. Relatively higher nutrient concentrations found in the SCB than in the NCB are associated with SPM concentration leading to decrease in the

phytoplankton biomass (Chl-*a*) in the former than latter region. Consequently, zooplankton biomass was relatively low in SCB. In the SCB region, the phytoplankton biomass (Chl-*a*) was low in spite of high nutrient concentrations because of limited light penetration due to the high SPM load. In contrast, the NCB region was characterized by low nutrient and SPM coupled with high phytoplankton and zooplankton biomass as well, therefore light penetration seems to be the limiting factor for phytoplankton biomass in the coastal Bay of Bengal rather than the nutrients. Relatively higher zooplankton biomass and abundance have been found in NCB than in SCB, with biomass displaying a strong linear relation with Chl-*a* and weak linear relation with POC at NCB. On the other hand, a strong linear relation has been found with POC at SCB. Chl-*a* and POC play a major role at NCB where POC alone plays a key role for zooplankton biomass. The present study suggests that river discharge alters the hydrography in the SCB and NCB, subsequently either promoted *in situ* production or higher terrestrial organic matter. Further it is suggested that POC may serve as an alternative food source for the zooplankton when phytoplankton biomass (Chl-*a*) is low, thereby significantly influencing the food web dynamics in the western Bay of Bengal. The result of the present study would be important data for future monitoring studies because changes in concentrations of the nutrients and suspended matter influences the phytoplankton biomass (Chl-*a*) primarily, and it might affect the zooplankton biomass. It is feasible that the river discharge has a significant impact on the ecological functioning of the zooplankton community and in its food web dynamics in the study area.

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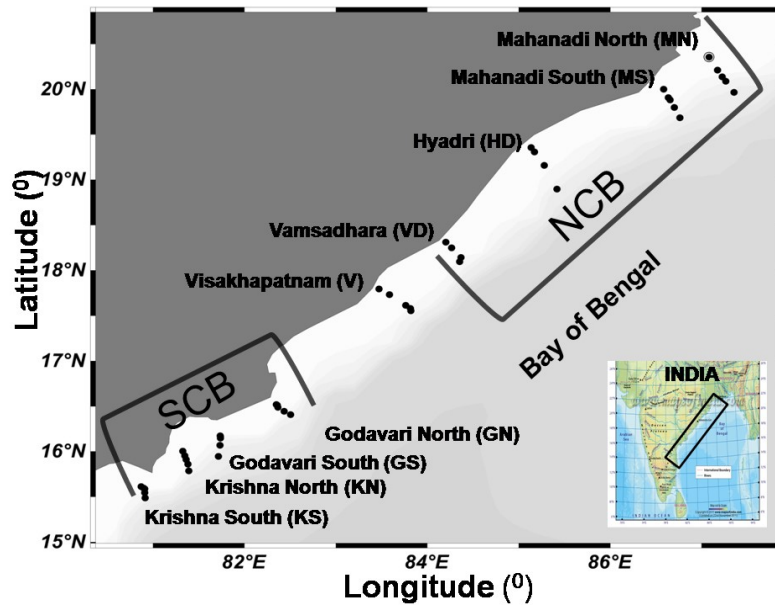


Fig. 1. Sampling location in the western coastal Bay of Bengal.

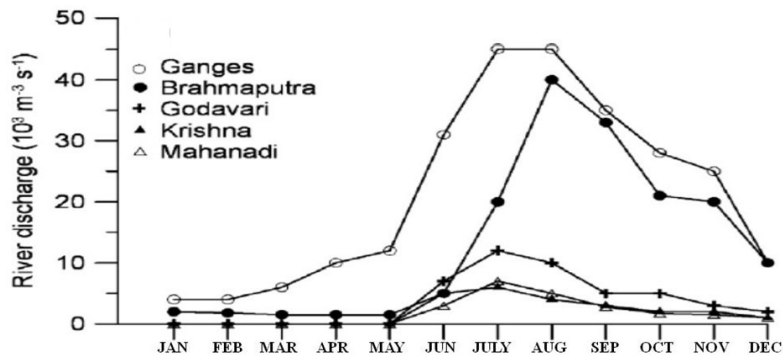
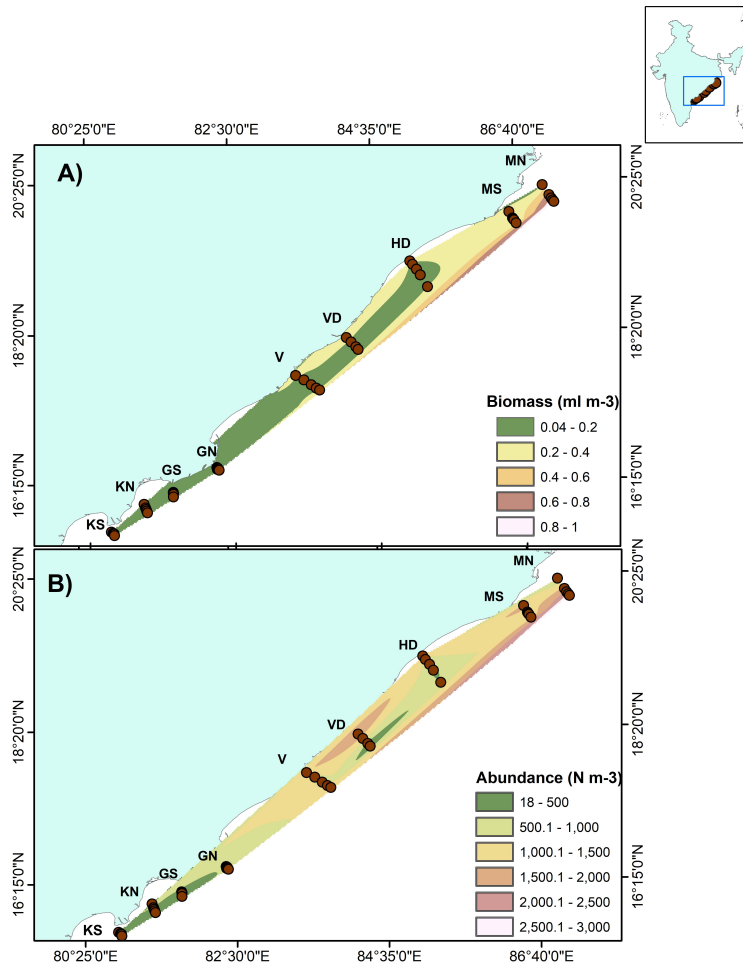
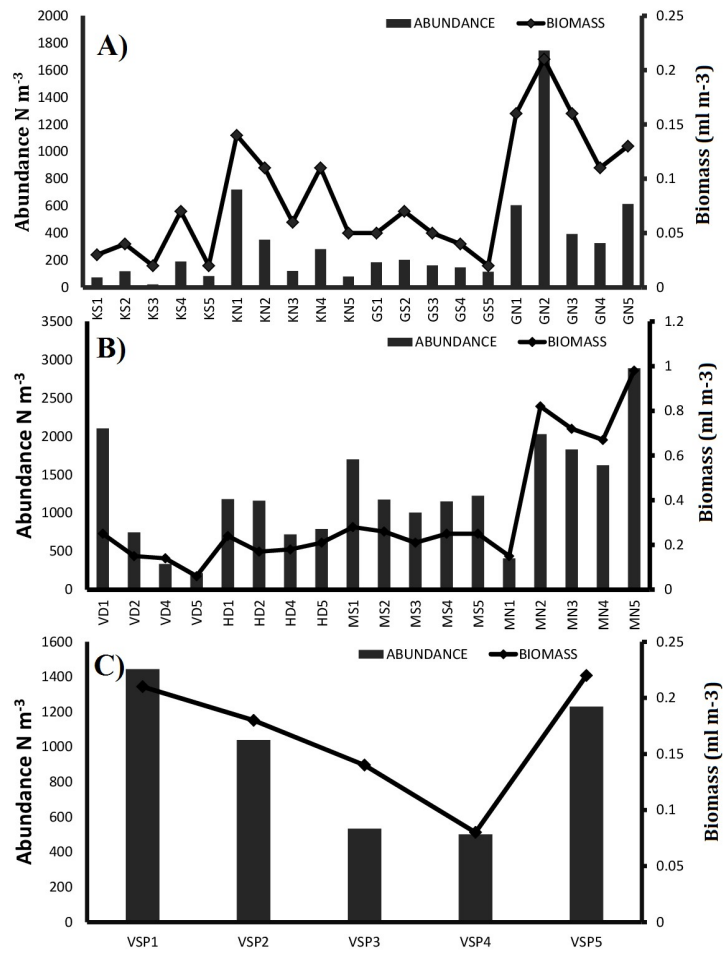


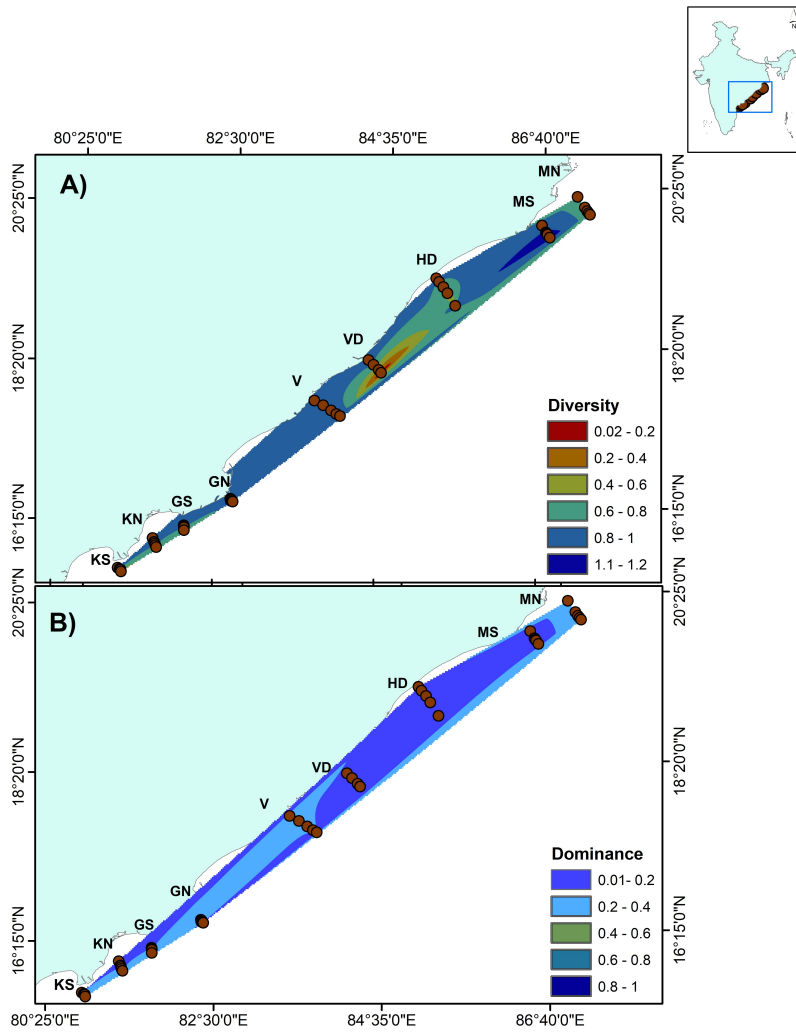
Fig. 2. Monthly variation in discharge by various major rivers into the Bay of Bengal (Source: Ittekkot et al., 1991).



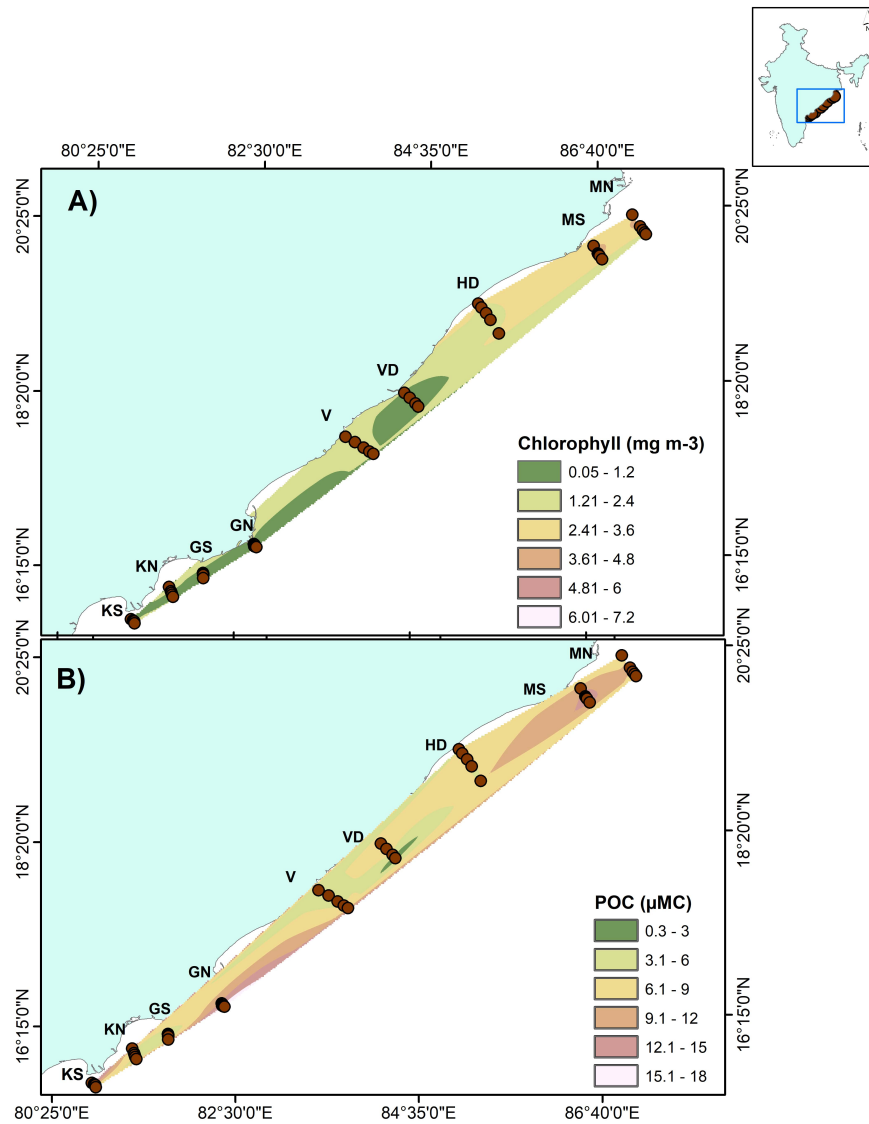
**Fig. 3.** Distributions of zooplankton biomass and abundance along each transect in the western coastal Bay of Bengal.



**Fig. 4.** Spatial distribution of zooplankton biomass and abundance (line graph indicate biomass and bar graph indicate abundance) along each sampling location (a) SCB (b) NCB and (c) No discharge station.



**Fig. 5.** Spatial variations of zooplankton diversity and dominance in western Bay of Bengal.



**Fig. 6.** Spatial distribution of Chl-*a* and POC in the western coastal Bay of Bengal.

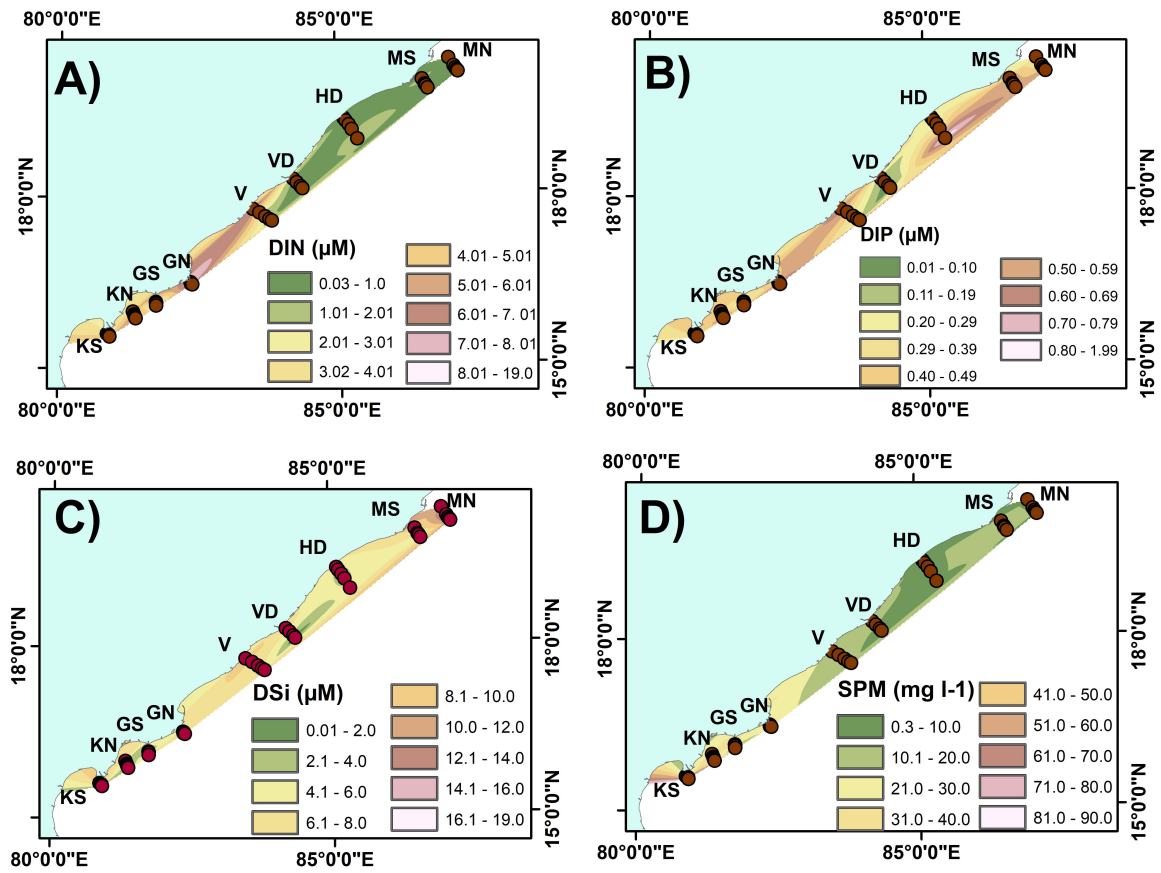
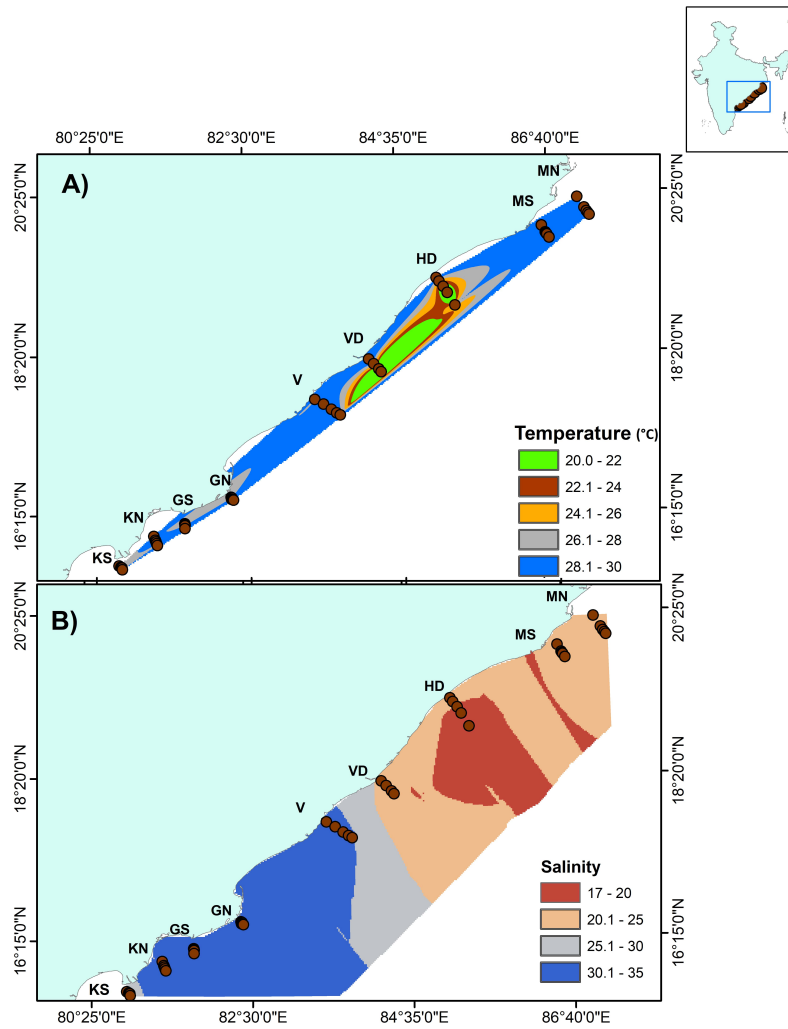


Fig. 7. Spatial measurements of DIN, DIP, DSi and SPM in the western coastal Bay of Bengal.





**Fig. 8.** Spatial measurements of temperature and salinity along the different transect in the western coastal Bay of Bengal.

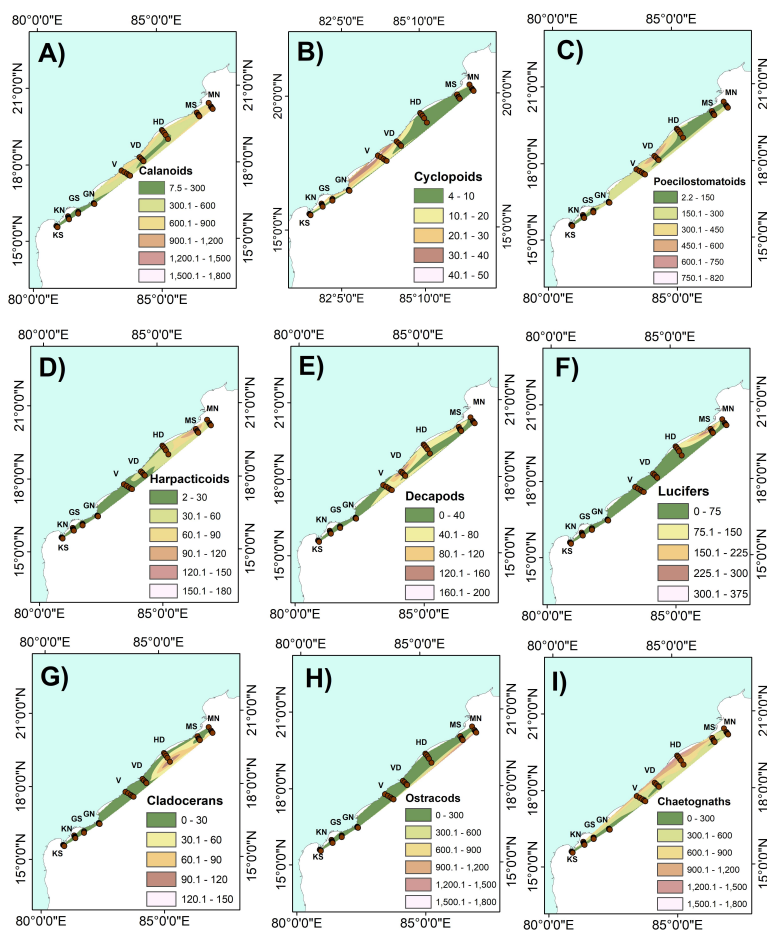
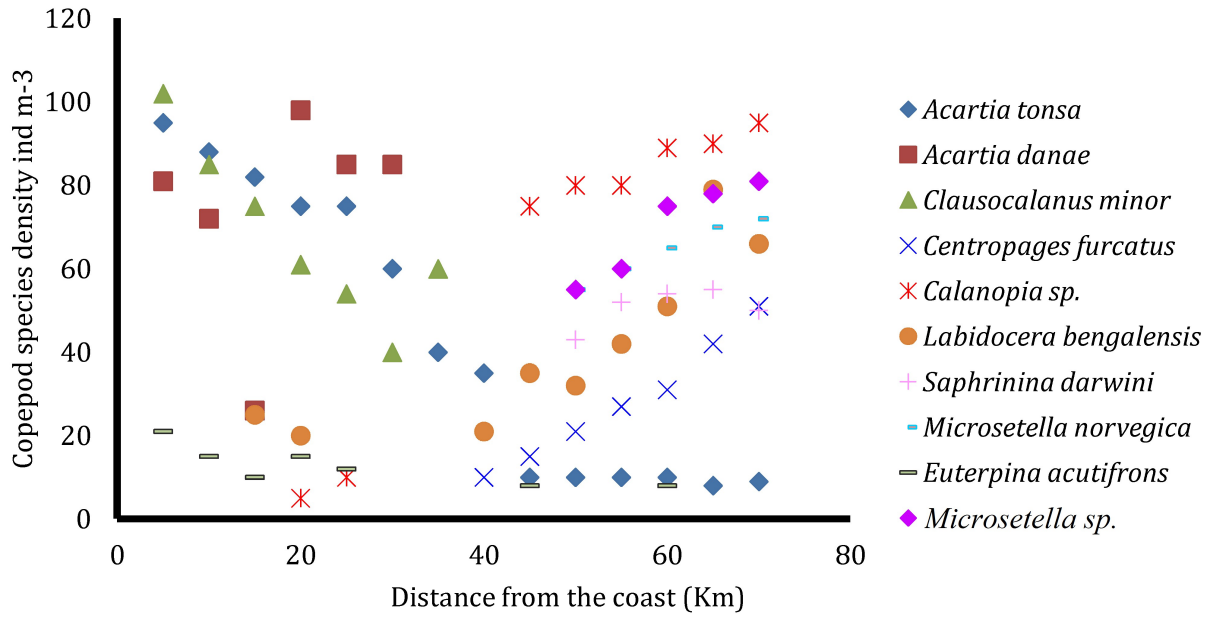


Fig. 9. Distribution of zooplankton group density ( $N m^{-3}$ ) along the western coastal Bay of Bengal.



**Fig. 10.** Distribution of dominant coastal and offshore copepod species in the western coastal Bay of Bengal.

**Table 1** Physicochemical and biological parameters along SCB and NCB region in western coastal Bay of Bengal.

Parameters	SCB region		NCB region	
	Range	Ave±Stdev	Range	Ave±Stdev
Temperature (°C)	26.8 – 28.7	27.9 ± 0.5	28.8 – 30	29.6 ± 0.4
Salinity	31.3 – 34.1	33.2 ± 1	21 – 31.5	25.1 ± 3.1
SPM (mg l <sup>-1</sup> )	10 – 42.7	23.1 ± 8.5	4.3 – 31.8	11.6 ± 5.8
NO <sub>3</sub> (μM)	1.5 – 12.8	4.4 ± 3	0 – 2.1	0.5 ± 0.7
NH <sub>4</sub> (μM)	0.3 – 14	2.1 ± 3.7	0.1 – 0.9	0.5 ± 0.2
PO <sub>4</sub> (μM)	0 – 2	0.4 ± 0.4	0.1 – 6	0.3 ± 0.4
SiO <sub>4</sub> (μM)	0.9 – 14.1	4.5 ± 3.3	3.4 – 17.5	8.9 ± 6.2
N:P	2.3-23.3	13±5.5	0.3-13.9	5.4±4.1
Si:P	2.3-37.1	13.3±8.1	3.6-77.9	34.8±21.6
N:Si	0.3-14.1	2.5±3	0-0.6	0.17±0.1
Chl- <i>a</i> (mg m <sup>-3</sup> )	0.5 – 3.5	1.53 ± 1.15	0.7 – 6.1	2.8 ± 1.7
POC (μMC)	2 – 17.5	12.4±4.0	4.8-14.5	8.1±3.5
DO saturation (%)	136.2 - 191.1	164.8 ± 15.7	179 – 208.9	194.1 ± 8.5

**Table 2** Correlation among the zooplankton biomass, community structure, diversity and dominance with physical, chemical and biological properties in the western coastal Bay of Bengal. \*\*= $p < 0.001$  and \*= $p < 0.01$ .

NCB	BIOMASS	DIVERSITY	DOMINANCE	POLYCHAETA LARVAE	CALANOIDA	CYCLOPOIDA	POECILOSTOMATOIDA	HARPACTICOIDA	DECAPODA	LUCIFERA	CLADOCERA	OSTROCODA	CHAETOGNATHS
TEMPERATURE	0.46**	-0.3*			0.52**			0.66**	0.32*	0.32*	0.4*	0.32*	-0.47*
SALINITY			0.46*		-0.5**	0.42*				-0.48**			
DO	0.53*	-0.4*	0.4*		0.49**	0.48*		0.45*	0.55*	0.35*			0.32*
CHL-a	0.8**	-0.3*	0.56**	0.3*	0.58**	-0.6*					0.3**		0.46**
POC	0.33*	0.41*	-0.54*		0.3*		0.42*	0.4*	0.4*	0.52*		0.3*	

SCB	BIOMASS	DIVERSITY	DOMINANCE	POLYCHAETA LARVAE	CALANOIDA	CYCLOPOIDA	POECILOSTOMATOIDA	HARPACTICOIDA	DECAPODA	LUCIFERA	CLADOCERA	OSTROCODA	CHAETOGNATHS
TEMPERATURE	-0.68**	-0.35*	0.33*		-0.64**	-0.61*	-0.33*	-0.66**		-0.47*	0.45*	0.35*	-0.41*
SALINITY	-0.55*	0.35*	0.41*		-0.63**	-0.42*		-0.73**	0.48*				-0.4*
DO	-0.46*	-0.55*	0.42*	0.5*	-0.55*	-0.73**				-0.41*			
CHL-a	0.36*	0.35*	-0.3**	0.44*	0.54*	0.5*					0.4*		
POC	0.58**	0.45*	0.46**		0.35*	0.4*	0.54*	0.5**	0.55*	0.37*	-0.63**	0.46*	0.3*

**Table 3** Zooplankton groups density and composition along the western coastal Bay of Bengal.

Zooplankton groups	Density (N m <sup>-3</sup> )		Group composition (%)		Western coastal Bay of Bengal (%)
	SCB (Avg±Sdv)	NCB (Avg±Sdv)	SCB	NCB	
Calanoida	476±326	2794±1959	28	50	39
Cyclopoida	43±28	13±6	4	2	3
Poecilostomatoida	816±566	956±389	46	14	30
Harpacticoida	88±57	258±148	3	5	4
Decoapoda	23±10	200±125	2	3	2.5
Lucifera	25±9	227±183	1	2	1.5
Claodocera	15±3	162±39	1	5	3
Ostracoda	132±83	828±453	6	7	6.5
Chaetognatha	100±79	370±152	7	8	7.5
Appendicularia	19±7	93±49	1	2	1.5
Polychaeta	10±3	12±9	1	2	1.5
Biomass (ml m <sup>-3</sup> )	0.08±0.05	0.33±0.26	-	-	-
Abundance (N m <sup>-3</sup> )	387±317	1239±692	-	-	-