

## Role of eddies in structuring the mesozooplankton composition in coastal waters of the western Bay of Bengal.

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### Abstract

The mesozooplankton community structure of a cold core eddy, moving through a coastal location (Bheemunipatnam) in the western Bay of Bengal (BoB), was studied continuously for 17 days (21<sup>st</sup> February to 8<sup>th</sup> March 2016) during Spring Intermonsoon. Vertical profiles of temperature, salinity and Chlorophyll *a* were measured in 1hr interval. Nutrients and dissolved oxygen were measured in every 3 hrs from 8 discrete depths. Mesozooplankton samples were collected through vertical haul (100 m depth to the surface) in 6 hrs intervals. Cluster analysis delineated the entire sampling days into 3 clusters based on temperature, salinity, anomaly of temperature and salinity in various depth layers Viz., phase I (Pre-eddy: 21<sup>st</sup> to 24<sup>th</sup> February), phase II (Core eddy: 28<sup>th</sup> February to 6<sup>th</sup> March) and phase III (Transition: 25<sup>th</sup> to 27<sup>th</sup> February and 7<sup>th</sup> to 8<sup>th</sup> March). The phase I was characterised as a comparatively warm, low saline, less nutrient and oxygenated subsurface water. During phase II, cool, nutrient-rich and oxygen deficient waters in the study location indicating the presence of a cold core eddy. Phase III is an intermediate condition between the phases I and II. Deep chlorophyll maxima (DCM) were shoaled to 23m in Phase II from a depth of 38m in Phase I. Mesozooplankton abundance was high during phase II (62320 No. m<sup>-2</sup>) compared to phase III (41633 No. m<sup>-2</sup>) and phase I (39510 No. m<sup>-2</sup>). Altogether 64 copepod species were identified of which, seven were dominant throughout the observation. Twelve species found as the indicator species in the core eddy condition. The high abundance of the *Temora turbinata* (upwelling indicator), *Pleuromamma indica* (low oxygen tolerant and highly central BoB reported) and occurrence of oceanic, oxygen minimum zone (OMZ) reported forms as indicator species in phase II is indicative of their entrainment from offshore by eddies. Eddy genesis and their movement tracking appear that this northeastern offshore formed cold core eddy advected to western coastal Bay of Bengal and traversing through the study site during the sampling period. Copepod species composition indicates the eddy trapped biological communities were sustained and retained in the core over a long period, and it advected over a long distance. This study is the first kind of information about northeastern offshore formed cold core eddy carries the plankton community in coastal waters of western BoB on their path and explains copepods community structure can be used as the indicator of eddy water masses.

**Keywords:** Cold-core eddy; Physicochemical parameters; Chlorophyll *a*; Mesozooplankton composition; Copepods; Indicator species; Eddy retention.

## 1. Introduction

Eddies are the mesoscale physical processes commonly occurring in the vicinity of coastal currents and oceanic circulation in the Bay of Bengal (BoB) (Prasanna Kumar et al., 2002; Prasanna Kumar et al., 2004; Jyothibabu et al., 2008a; Fernandes and Ramaiah, 2009; Patnaik et al., 2014; Jyothibabu et al., 2015). Eddies classified as cyclonic or anticyclonic (hereafter CE = Cyclonic Eddy; ACE = AntiCyclonic Eddy), based on their circulation (anticlockwise or clockwise). Eddy dimensions are varied from 10 to 200 km in diameter and persist for a period of days to months (Muraleedharan et al., 2007; Prasanna Kumar et al., 2007; Prasanna Kumar et al., 2010). In a year, almost ten eddies formation found in the BOB, in that ACE areas were relatively high compared to CE (Chen et al., 2012; Dandapath and Chakraborty, 2016). Monsoonal winds showed the seasonal reversal, southwesterly during the Southwest Monsoon (June-September) and northeasterly during the Northeast Monsoon (November to February), which causes a semi-annual reversal of the surface circulation as well (Shetye et al., 1993; Shetye et al., 1996; Shankar et al., 2002). Mesoscale physical processes alter the hydrography, productivity and biogeochemistry of an environment (Chelton et al., 2011; Mahadevan, 2014). Generally, CE's considered rich in phytoplankton production than the ACE's (Prasanna Kumar et al., 2004). CE pumping the nutrients in the euphotic layer and enhances the primary and export production in the BoB (Prasanna Kumar et al., 2004). Cyclonic eddies have concerned the hotspots of the biological productivity and found 2-3 folds an enhancement of the primary production compared to the non-eddy regions; this eddy-induced biological productivity can transfer higher trophical levels even to predators (Kai and Marsac, 2010; Mahadevan et al., 2012; Condie and Condie, 2016).

Warmer, low salinity (28–32 PSU) and weaker winds ( $10 \text{ ms}^{-1}$ ) compared to Arabian sea results the strong stratification in the Bay of Bengal (Prasanna Kumar et al., 2004). Stratification prevents mixing of subsurface nutrients with the surface (Prasanna Kumar et al. 2002), and upwelling is weak, narrow and sporadic (Shetye et al., 1991) in the western bay results the BoB to low productive compared to the Eastern Arabian sea (Madhupratap et al., 2003; Prasanna Kumar et al. 2002; Gauns et al., 2005; Jyothibabu et al., 2008b). Cyclonic eddies are increased the biological productivity of the Bay of Bengal (Prasanna Kumar et al., 2004; Madhu et al., 2006; Prasanna Kumar et al., 2007; Jyothibabu et al., 2008a; Prasanna Kumar et al., 2010). During the Spring Intermonsoon (March-May), Bay of Bengal was characterised as relatively high saline, warmer and nutrient depleted conditions resulting the overall less productivity compared to Southwest and Northeast Monsoon conditions (Gauns et al., 2005; Madhu et al., 2006; Jyothibabu et al., 2008a). The strong stratification and less nutrients during Spring Intermonsoon (SIM) biologically evidenced by intense

blooms of marine cyanobacterium *Trichodesmium erythraeum* in the surface waters of the BoB (Madhu et al., 2006; Jyothibabu et al., 2008a; Paul et al., 2008). *Trichodesmium* fix the atmospheric nitrogen and play a significant role in the ocean nitrogen cycle in the Bay of Bengal.

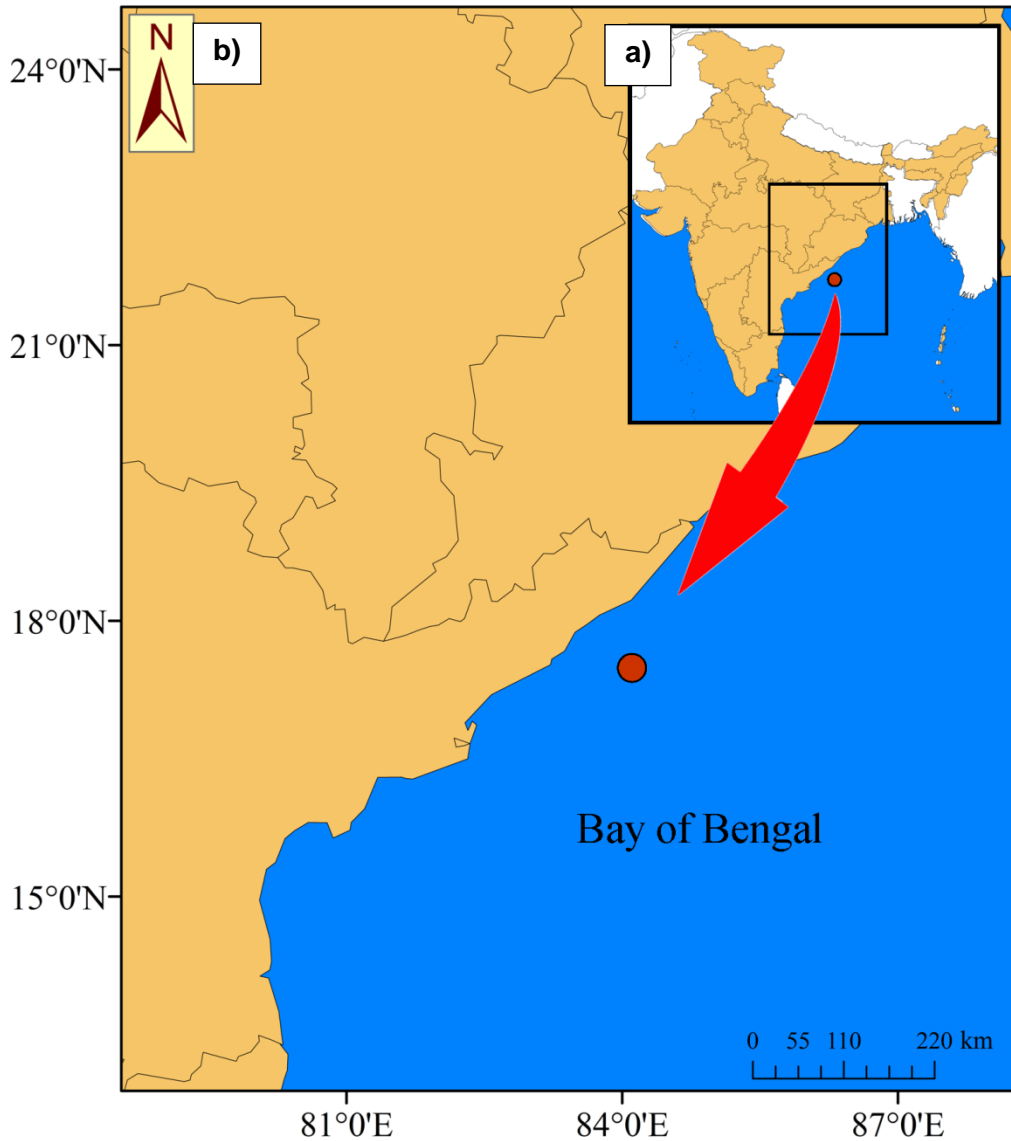
Eddies are partially isolated environments with distinct physical and chemical conditions, capable of support plankton productivity and transport the whole plankton communities in their path (Heywood and Priddle, 1987; Huang et al., 2010; Condie and Condie, 2016). CE and ACE formations in the BoB was reported by several authors (Gomes et al., 2000; Prasanna Kumar et al., 2004; Madhu et al., 2006; Jyothibabu et al., 2008a) in throughout of the year. During the Southwest Monsoon and Northeast Monsoon periods, fluvial flux was high and it alters the nutrients load and enhances the productivity of the coastal waters (Sarma et al., 2016), however, to delineate the actual role of eddies on the phytoplankton production in the coastal waters of the western BoB is more intricate. During the SIM, rainfall was less and runoff interferences is minimum (Sarma et al., 2016), so SIM could be the suitable period to quantify the actual role of eddy-induced changes in the hydrography and biological productivity in the coastal waters of Bay of Bengal on their path.

Eddies can retain the planktonic organism from a few days to months in their path (Condie and Condie, 2016). Mesozooplankton act as the connecting link between the primary producers to higher trophic levels and plays a significant role in the biogeochemistry of an environment (Jagadeesan et al., 2013). Zooplankton are the major regulatory factor of phytoplankton productivity, however the available mesoscale eddy studies in Indian waters are focused only about the phytoplankton (Prasanna Kumar et al., 2002; Madhupratap et al., 2003; Parasanna kumar et al., 2004; Madhu et al., 2006; Jyothibabau et al., 2008a; Sarma et al., 2016). Zooplankton abundance and their community structure differed even minor changes in their surroundings (Madhupratap et al., 1996; Rakesh et al., 2006; Rakesh et al., 2008; Jagadeesan et al., 2013; Jagadeesan et al., 2017a). Recent days, zooplankton quantification studies from Indian waters get attention about the role of physical processes (Coastal currents, upwelling) in structuring the copepod community structure (Jagadeesan et al., 2013; Jagadeesan et al., 2017a). However, eddy influences on the zooplankton community structure studies were meager in Indian waters (Fernandes, 2008; Fernandes and Ramaiah, 2009).

Copepods are the most dominant zooplankton group, and it contributes 50 - 95% to the total zooplankton abundance. Copepod community structure changed with the subtle changes in their surroundings hydrography and productivity, so they are used as an indicator of an environment (Jagadeesan et al., 2017a; Jyothibabu et al., 2018). Copepods community structure and species composition differed between the coastal, shelf and offshore water masses (Madhupratap et al., 1996; Rakesh et al., 2006; Rakesh et al., 2008). Eastern offshore BoB formed eddies moves over several

hundreds of kilometres and reach into western side BoB, and coastal eddies are moves in the direction vice versa south to north or north to south along with the coastal currents. Moving eddy retain and transfer the water properties including the planktonic communities in their path, but this differed from the actual surrounding water masses (Heywood and Priddle, 1987; Condie and Condie, 2016). The intensity of eddy pumping differed between the core and outer rings; this alters the nutrient availability and phytoplankton productivity (Madhu et al., 2006; Fernandes, 2008; Jyothibabu et al., 2008a; Fernandes and Ramaiah, 2009; Jyothibabu et al., 2015). Differences in phytoplankton productivity between the various phases of eddy cause differences in zooplankton composition within the eddy. However, most of the available eddy studies are in spot measurements (Fernandes, 2008; Fernandes and Ramaiah, 2009) from BoB and without a comparison of immediate neighbouring waters.

We are hypothesised that 1) Mesozooplankton composition and copepod community structure is different between cold core eddy and adjacent local coastal conditions in the Bay of Bengal during Spring Intermonsoon period and 2.) Eddy carries the water masses from their origin, and the copepods community structure in core eddy has a link with the eddy origin water masses. For explaining the hypothesis mentioned above, time series study is required in a moving eddy to cover the various eddy phases and delineate the actual role of eddies in mesozooplankton composition and copepods community structure alterations in the coastal waters of the western BoB. In the present study, seventeen days (21<sup>st</sup> February to 8<sup>th</sup> March) time series study was conducted in off Bheemunipatnam (Figure 1) to explain the following objectives, 1) to measure differences in hydrography and phytoplankton biomass between various phases of cold core eddy and adjacent coastal waters during the Spring Intermonsoon period; 2) to quantify the Mesozooplankton composition and copepods community structure differences between the eddy phases and adjacent coastal waters 3) to identify eddy movement have any link in the copepods community structure differences.



**Figure – 1** - (a) India with the boundaries of the states (insertion) and the present study area (red dot), and (b) an enlargement of the study area (Square area).

## 2. Materials and methods

### 2.1 Study area, sampling, and methods

Seventeen days' time series study was conducted in off Bheemunipatnam (Lat 18°N; Long 84°E) to capture the various eddy phases. The depth of the location was 105m and ~ 80 kilometres away from the shore (Figure 1). This study area is located 50 km north from the Off Visakhapatnam and it didn't have any connection to major rivers and rainfall was less during the spring intermonsoon period. Time series study was carried out onboard *RV Sindhu Sankalp* (SSK 88) from 21st February to 8<sup>th</sup> March 2016 as the part of the Bay of Bengal biogeochemistry studies. Sea Surface Height Anomalies (SSHA) and geostrophic current velocity in the sampling periods were

retrieved (<http://marine.copernicus.eu/>) to show the eddies and their movements. Vertical distribution of the temperature and salinity measured through the rosette CTD (Conductivity, Temperature, Depth) at every 1 hr intervals. Chl - *a* fluorescence sensor is additionally attached with the rosette CTD. We retrieved the details of the depth, temperature, density, salinity and Chl - *a* fluorescence in every 0.2m depth interval in every CTD cast.

In this time series studies, temperature and salinity anomaly (differences from the mean) between the observations were calculated in various depth layers to visualise the temperature and salinity changes in the sampling days.

Temperature anomaly (TA) were calculated using the formula of

$$TA_{xj} = TM_{xi} - T_{xj}$$

$TA_{xj}$  – Temperature Anomaly at depth  $x$  in observation  $j$ ;  $TM_{xi}$ - Mean temperature of entire observations (Overall mean temperature of the entire observations, N=384) in depth  $x$ ;  $T_{xj}$ - Temperature in observation  $j$  at depth  $x$ . Positive TA indicates the water column is warmer and the negative anomaly indicates that its cooler than the mean values.

Salinity anomaly was calculated using

$$SA_{xj} = SM_{xi} - S_{xj}$$

$SA_{xj}$  – Salinity Anomaly at depth  $x$  in observation  $j$ ;  $SM_{xi}$ - Mean salinity of entire observations (Overall mean temperature of the entire observations, N=384) in depth  $x$ ;  $S_{xj}$  -Salinity in observation  $j$  at depth  $x$ . Positive SA indicates the saltier and the negative anomaly indicates the less saline than the mean values. TA and SA zero indicates no deviation from the mean.

Water samples were collected from 8 discrete depth layers like surface, 5, 10, 20, 30, 50, 75 and 100m through Niskin bottles mounted on a CTD (Conductivity, Temperature, Depth) rosette for measuring the dissolved oxygen (DO), nutrients, and pigments once in every 3 hrs intervals. Vertical distribution of the dissolved oxygen measured through the Winkler's method. Nutrients measured through the standard methods of Grasshoff et al. (1983). For measuring the pigments the 5- 10 L of the samples were filtered through G/F filter papers and the filters were stored in -20°C onboard and transported to the laboratory by the liquid nitrogen and later stored in -20°C till their analysis. Pigments were extracted with the 95% acetone in 3ml and analyzed using HPLC (Agilent Technology; Series 1200) using the methodology of Heukelem and Thomas (2001). The Chlorophyll *a* pigment concentration was quantified through the pigments standard calibration. CTD measured Chlorophyll *a* ( $\mu\text{g. L}^{-1}$ ) data is a proxy for in-situ phytoplankton biomass (Roesler et al., 2017). The

phytoplankton composition in the water column and default factory calibrations of Chlorophyll *a* sensors are different, so the extracted and in-situ Chl - *a* measurement exhibits differences. The regression analysis between two data sets showed a significant positive relation ( $Y=1.263X+0.075$ ;  $r=0.94$ ;  $P<0.001$ ;  $N=280$ ; HPLC Measured Chl - *a* =  $1.263 \cdot \text{CTD Chl - } a + 0.075$ ). CTD measured Chlorophyll *a* is corrected with HPLC measured Chlorophyll *a* using the regression analysis equation for an accurate representation of the vertical distribution of Chl - *a* and integrated Chl - *a* analysis.

Mesozooplankton samples were collected from vertical hauls from 100 meters to surface once in every 6 hrs using WP-2 net (mouth diameter 50 cm and mesh size 200 $\mu\text{m}$ ). The calibrated Hydrobios digital flow meter was attached across the mouth in net to measure the volume of the water filtration. Mesozooplankton biomass measured through the displacement method and zooplankton samples were preserved in the formalin for further analysis. In the laboratory, samples are split into two subsamples through Folsom's splitters in that one subsample 50% used for the analysis of the zooplankton composition and community structure. Initially, zooplankton samples are sorted into various groups under a stereozoom microscope, and their quantification carried out using the standard procedure of the Postel et al. (2000). Among the sorted zooplankton groups, copepods were further identified into species level using the standard literature (Kasturirangan, 1963; Sewell, 1999; Conway et al., 2003; <https://copepodes.obs-banyuls.fr/en/index.php>). Copepods species diversity was measured in each samplings using formula of Shannon and Wiener Index  $H' = -\sum (P_i * \ln (P_i))$  (Shannon and Weaver, 1963). Copepod species abundance (0-100m)  $\text{No.m}^{-2}$  data used for calculation of the copepods species diversity.  $P_i$  is  $n/N$ . Where  $n$  is the individual number of copepods species  $i$  and  $N$  is the total number of individuals of all copepods in a sample.

## **2.2 Data analysis**

### **2.2.1 Grouping of the sampling days**

Euclidean distance resemblance matrix based group average linkage method of Cluster and non-metric multidimensional scaling (NMDS) analysis was performed to grouping the sampling days into clusters based on their similarity in hydrographical parameters. Seven different depth layered (10m, 15m, 20m, 25m, 30m, 35m, 40m, and 50m) values of salinity, temperature, TA, and SA was used in this analysis to grouping the sampling days. The daily mean values of the hydrographical parameters were normalised (to avoid differences in units) before the cluster analysis. The observations within the cluster had a close resemblance to each other and dissimilar between the cluster members (Clarke and Warwick, 2001). Similarity Profiles (SIMPROF) permutation analysis

was performed with the cluster analysis to represent the statistically significant group separation of the sampling days at  $P < 0.05$  significance level (Clarke and Gorley, 2006). Cluster, NMDS and SIMPROF analysis were performed in the PRIMER V6.

### 2.2.2 Dominant species analysis

The dominant species (numerically abundant and frequently occurred species) of copepods in various phases of eddy was analysed using the dominance index analysis (Yang et al., 1999). Mean copepods species abundance (0-100m) of a sampling day ( $n=4$ ) was used in dominant species analysis. Dominance index depends upon the species numerical abundance and their occurrence frequency.

$$Y_i = (N_i / N) \times f_i$$

Where,  $Y_i$  is the dominance index of species  $i$ ,  $N_i$  is the number of individuals of species  $i$  in a cluster,  $N$  is the number of individuals of all species in a cluster, and  $f_i$  is the frequency of observations at which species  $i$  occurs. Copepods species with a  $Y_i \geq 0.02$  were considered dominant species (Yang et al., 1999).

### 2.2.3 Indicator or representative species analysis

Indicator value (INDVAL), is used to find out the characteristic or discriminating species in each group of observations (Dufrene and Legendre, 1997). Mean copepods species abundance (0-100m) of a sampling day ( $n=4$ ) was used in INDVAL calculation. In this study we used INDVAL index to find the indicator species in various of groups or phases of eddy. The IndVal analysis explains whether the species assemblages are symmetric or dissymmetric between groups of assemblages. This method takes into account combined measures of group specificity ( $A_{ij}$ ) and group fidelity ( $B_{ij}$ ). For each species  $i$  in each group  $j$ , we computed the product of  $A_{ij}$ - which is the mean abundance of species  $i$  in the sampling days of group  $j$  compared to all groups in the study, by  $B_{ij}$  which is the relative frequency of occurrence of species  $i$  in the sampling days of group  $j$ , as follows:

$$A_{ij} = N \text{ individuals } ij / N \text{ individuals } i \text{ -----(1)}$$

$$B_{ij} = N \text{ samples } ij / N \text{ samples } j \text{ ----- (2)}$$

Subsequently, the IndVal calculated as;

$$\text{INDVAL} = A_{ij} * B_{ij} * 100 \text{ ----- (3)}$$

Where INDVAL is the indicator value of the species  $i$  in cluster  $j$ . In the formula  $N \text{ individuals } ij$  is the mean number of individuals of species  $i$  in the samples of group  $j$ , while,  $N \text{ individuals } i$  is the



sum of the mean numbers of individuals of species  $i$  over all groups.  $N_{ij}$  is the number of samples in group  $j$  where species  $i$  is present, while  $N_j$  is the number of samples in group  $j$ .

The values of  $A$  and  $B$  represented independent information about species distribution and multiplied by 100 to get the percentages. INDVAL is maximum (100%) when all the individuals of a species found in a single group, which represents the asymmetric distribution of that species between the groups. On the other hand, the INDVAL becomes the minimum when the species is symmetrically distributed between the groups. The highest INDVAL for a particular species in one cluster represents the center of distribution of that species. According to Dufrêne and Legendre, (1997) at least a minimum of 25% can be considered as the threshold level to determine IndVal species. In the present study,  $\geq 50\%$  was used as the threshold level for determining the INDVAL copepods.

#### **2.3.4 Univariate analysis**

To compare the temporal variations of hydrographical and biological parameters between the various phases of eddy; initially, hydrographical and biological parameters tested for their distribution using the Shapiro-Wilk test. The results of the Shapiro-Wilk test ( $P > 0.05$ ) shows that hydrographical and biological parameters were distributed normally, based on the results Shapiro-Wilk test we used parametric ANOVA to compare the variance between the eddy phases (Zar, 1999). The Tukey's HSD post hoc test was used to compare the significance of pairwise variations obtained in parametric ANOVA. The tests of normality - Shapiro-Wilk test, parametric ANOVA were carried out in XL stat pro- software package.

#### **2.3.5 Multivariate Redundancy analysis**

Inter-relationships between zooplankton abundance, copepod community (Dominant and Indicators species) and Chl -  $a$  and depth of DCM layers with the physicochemical parameters (salinity, temperature, nutrients, dissolved oxygen, and SSHA) were analysed using linear multivariate RDA. Initially, detrended correspondence analysis (DCA) performed for selection of the ordination methods suitable for the present data sets. Based on the results of detrended correspondence analysis ( $< 2$  axis gradient length) we used Redundancy analysis (RDA). The biological variables were log transformed and centered before the analysis. The ordination significance was tested with Monte Carlo permutation tests (499 unrestricted permutations) ( $p < 0.05$ ). The results presented as in the 2D orientation of Triplot attributed with the overlay of dissolved oxygen (line contours). In RDA Triplot, sampling days are displayed by points, species and

quantitative environmental variables by dotted and lined arrows. The detailed Triplot interpretations were made following the RDA ordination explanation of Leps and Smilauer (2003).

### **3. Results**

#### **3.1 SSHA and geostrophic currents patterns**

SSHA and geostrophic current patterns show several cold core and warm core eddy occurrence found (Supplementary figure -1) in the Bay of Bengal during February. One cold core eddy was sighted  $\sim 1^\circ$  south from the study site, and its core was at  $83.37^\circ\text{E}$ ;  $16.88^\circ\text{N}$  during the first week of February and it moved slowly northward along with East India Coastal Current (EICC) (Figure 2). The eddy diameter was  $\sim 110$  kilometres and moving north at the average speed of  $\sim 7$  kilometres per day. In this moving eddy, we tracked the various phases of the eddy related hydrography and biological parameters through time series observations. Study location faced the positive SSHA during the 2<sup>nd</sup> week of February (12 -15 February) and became negative during the 3<sup>rd</sup> week of February (21- 23 February), and it decreased later. The distance between the study site and core eddy was gradually decreased from the 2<sup>nd</sup> week of February. The study site was in the core of eddy during the last week of February and the first week of March (01-06 March), however, from 2<sup>nd</sup> week of March onwards, the eddy is seen moving eastwards away site from the study site.

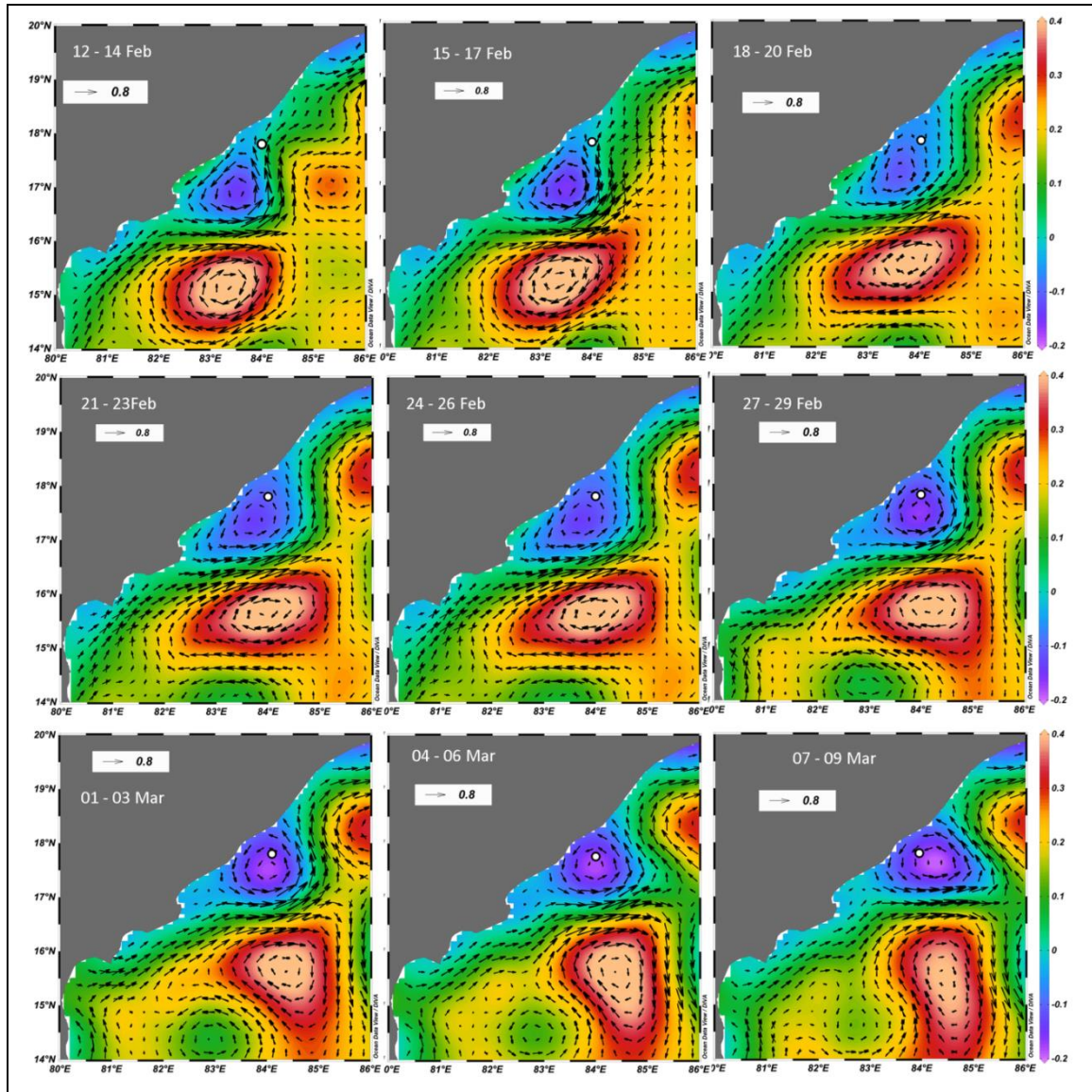


Figure 2. Dynamics of the eddy (Sea Surface Height Anomaly- SSHA, and geostrophic currents) during the study period from February 12 to March 09. The geostrophic current flow (small arrows) directions show that East India Coastal Current (EICC) was poleward. The arrows represent the direction of the current flow, and the length of the arrows represents the velocity currents. The current velocity of the geostrophic currents corresponds with reference arrow (0.8 arrows) and the velocity in m/s. Study location (white point) faced the positive SSHA during the 2<sup>nd</sup> week of February (12-15 February) and becomes negative during the 3<sup>rd</sup> week of February (21-23 February), and it decreased later (green to blue to violet). The distance between the study site and core eddy was gradually decreased from the 2<sup>nd</sup> week of February. The study site was in core of eddy during the last week of February and the first week of March (01-06 March), however, from 2<sup>nd</sup> week of March onwards, the eddy is seen moving eastwards away site (dark green and blue colour band expansion further east) from the study site (violet to blue). Vertical Color bars represent values of SSHA, positive colour values with the clockwise circulation of the geostrophic currents indicates the warm core eddy and negative SSHA and anticlockwise circulation of the currents represents cold core eddy.

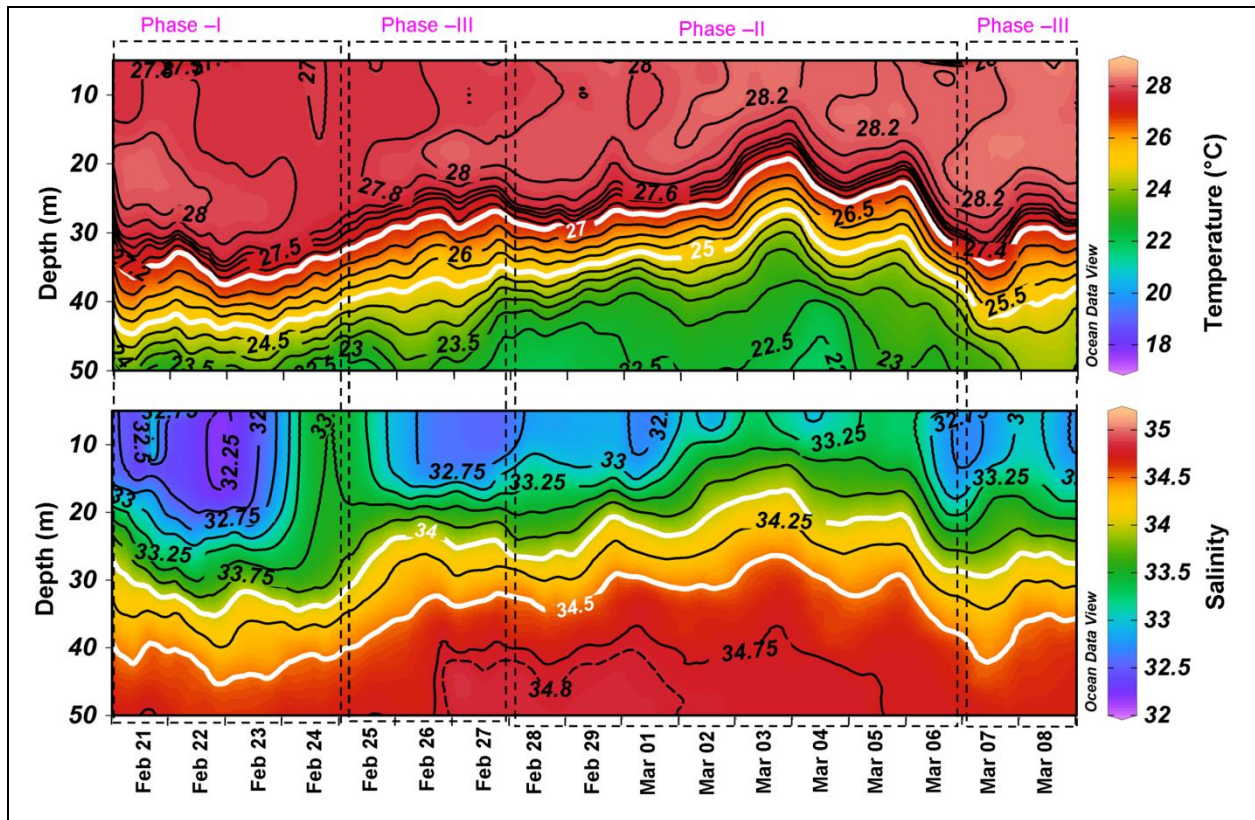


Figure 3. Temporal change of (a) temperature (in $^{\circ}$ C) and (b) salinity in the time period from February 21 to March 8 and the depth interval from 0 to 50 m at the study location. Isotherms of 25 $^{\circ}$ C and 27 $^{\circ}$ C and isohalines of 34 and 34.5 exhibit the shoaling from 25<sup>th</sup> February to 6<sup>th</sup> March (for additional information see text chapter 3.2). Black dotted lines represents the various phases of Eddy (for additional information see figure 5).

### 3.2 Vertical distribution of the temperature, salinity

Sea surface temperature ranged from 27.62  $^{\circ}$ C to 28.87  $^{\circ}$ C, and salinity ranged between 32.18 and 33.60. Vertical distribution of the temperature and salinity between the sampling days showed the noticeable differences, up slopping of the high saline ( $>34$ ) and cool subsurface waters (25  $^{\circ}$ C) from  $\sim$ 45m to 30m were found during the sampling period (Figure 3). In the top 10 m layer, temperature difference between the sampling days was  $<1.3$   $^{\circ}$ C and salinity difference between the sampling days were  $<1.5$  units, but in the subsurface layers (20 - 50m), the temperature difference ranged from 2  $^{\circ}$ C to 7  $^{\circ}$ C (Supplementary Table 1, Figure 2), salinity differences ranged from 0.4 to 2.24. The anomaly of the temperature and salinity during the sampling periods in various depth layers were presented in Figure 4. In overall temperature anomaly (TA) varied between -4.29 and 2.98, salinity anomaly (SA) was varied from -1.46 to 1.24. In subsurface layers (20m - 50m), TA

was in positive, and SA was in the negative side during February 21- 24, and it changed into the negative TA and positive SA, during the February 28 - March 06 (Figure 4).

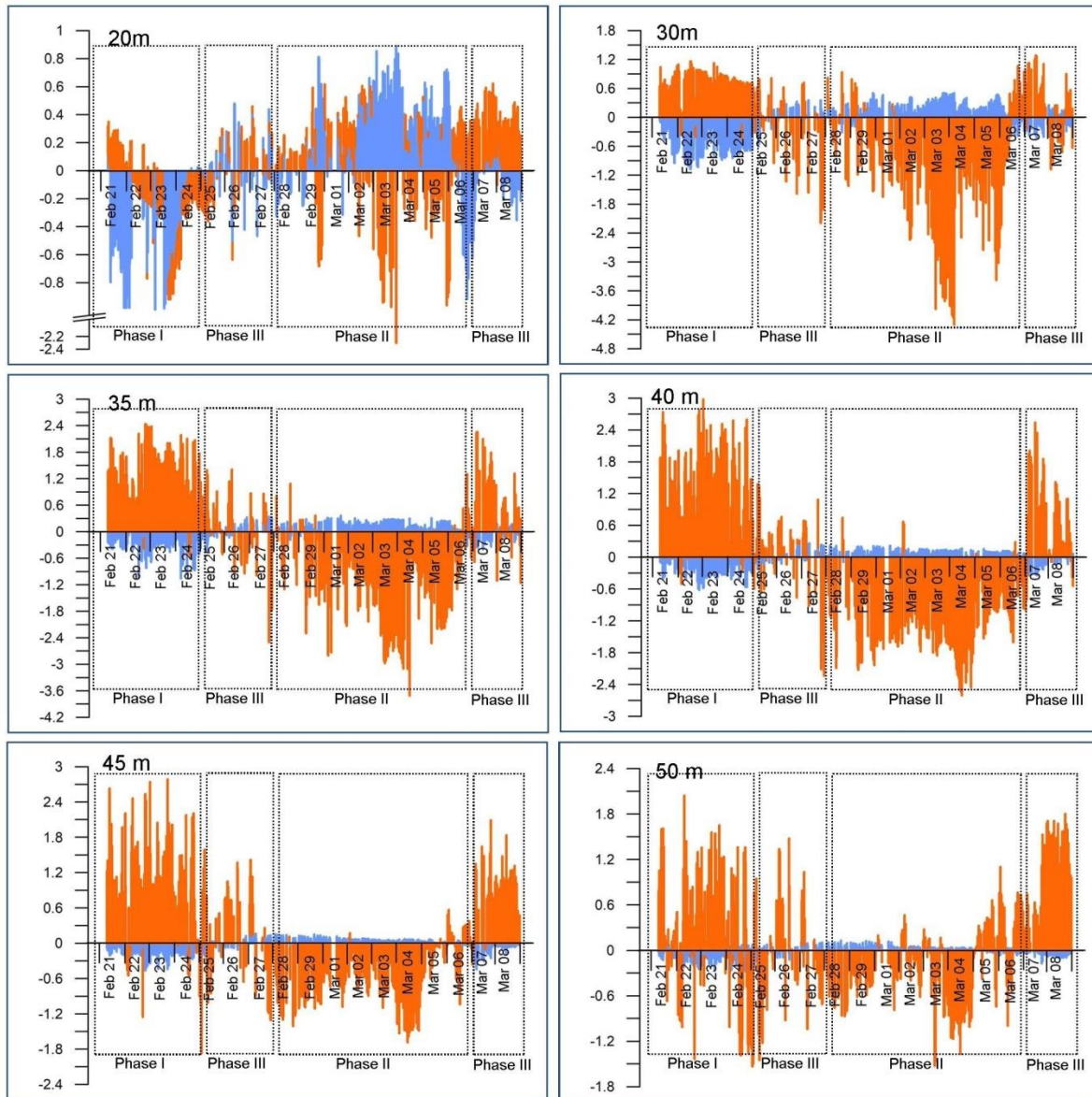


Figure - 4 – Anomalies of temperature (TA, orange bars) and salinity (SA, blue bars) for the period from February 21 to March 6 and the depths 20, 30, 35, 40, 45, and 50 Meters. Temperature Anomaly (TA) = (observed temperature) - (mean temperature of the period February 21 to March 08); Salinity Anomaly (SA) = (observed salinity)- (mean salinity of the period February 21 to March 08). The dotted lines represents various phases of eddy (for additional information see figure 5). During the initial sampling period, positive TA and negative SA correspond to the warm and low saline waters, whereas the negative TA and the positive SA in the subsurface layers during the core eddy phase (corresponds to the presence of cool high saline waters). The transition conditions TA and SA values are between the Pre-eddy and core eddy conditions.

### 3.3 Cluster and NMDS

Based on the SSHA, salinity, temperature, SA and TA in various depth layers, SIMPROF combined Cluster analysis delineated the sampling periods into three phases (Figure 5). Sampling days 21<sup>st</sup> February to 24<sup>th</sup> February grouped into phase I; Sampling days 28<sup>th</sup> February to 6<sup>th</sup> March grouped into phase II and the days of 25<sup>th</sup> February to 27<sup>th</sup> February and 7<sup>th</sup> and 8<sup>th</sup> March were grouped into phase III. SIMPROF analysis represents the cluster grouping was significant at  $P < 0.05$  level. In subsurface layers (20 -50m), Cluster I was relatively warm and less saline with positive TA and negative SA; this was changed into relatively cool and more saline with positive SA and negative TA during Cluster II (Figures 3 and 4). Phase III was intermittent between Phase I to Phase II. Relatively warm and low saline with high SSHA in cluster I represent the Pre-eddy phase; however the cool, high saline waters with comparatively lowest SSHA in cluster II represents the core eddy Phase. The intermittent condition of Phase III between Phase I and Phase II represents the transition conditions of eddy (Figures 3 and 4).

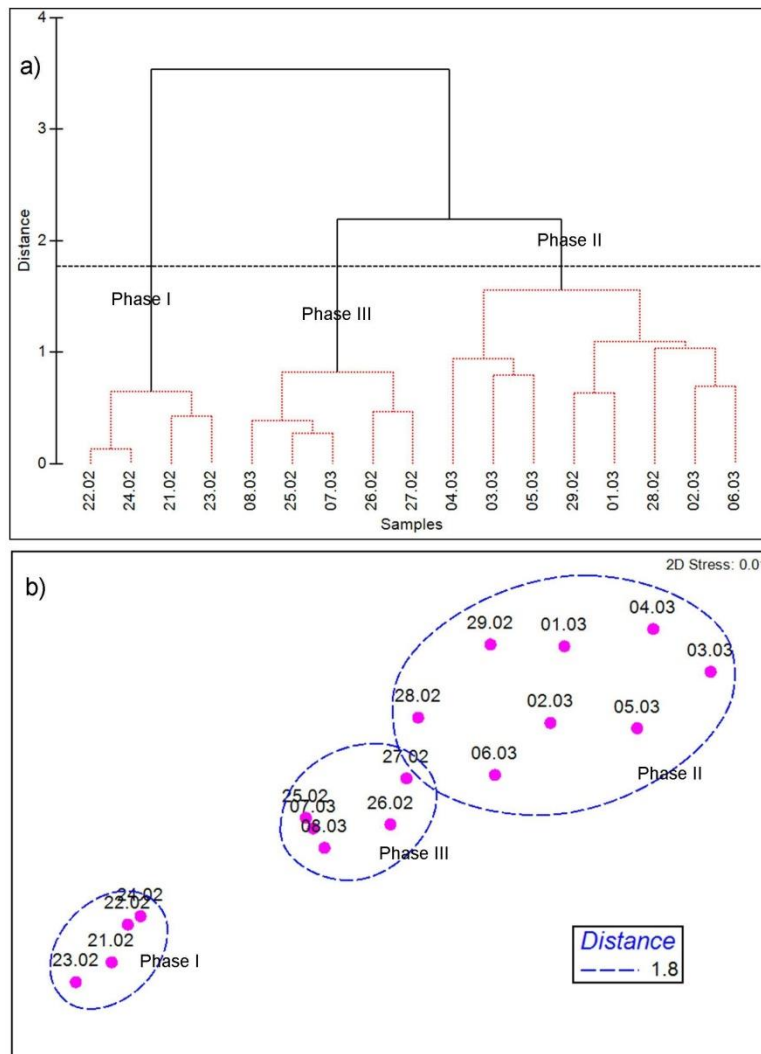


Figure 5- a) Euclidean distance matrix and group average linkage method of cluster and SIMPROF (Similarity Profile) combined results are presented in the form of the dendrogram. The dendrogram visualizes the delineation of sampling days based on the similarities of hydrographical parameters (salinity, temperature, SA and TA) in various depth layers viz., surface, 10, 20, 25, 30, 40 and 50m depth layers. In the dendrogram, solid black lines show the statistically significant segregations of the groups and red dashed lines indicate groups of samples not separated (at  $P < 0.05$ ) by SIMPROF. b) Cluster and SIMPROF results overlaid non-metric multidimensional scaling (NMDS) plot shows the relatedness, closeness and delineation of the sampling days. Slices and dashed lines represent the Euclidian distance cutoff value of 1.8. Sampling days 21<sup>st</sup> February to 24<sup>th</sup> February grouped into cluster I (phase I – Pre-eddy); 28<sup>th</sup> February to 6<sup>th</sup> March grouped into cluster II (phase II - Core eddy) and 25<sup>th</sup> February to 27<sup>th</sup> February and 7<sup>th</sup> and 8<sup>th</sup> March were grouped into cluster III (phase III - Transition phase). Cluster III located between cluster I and II indicate the intermittent between the Pre-eddy and core eddy, but this is more closeness with the Cluster II. SIMPROF analysis showed the cluster assemblages were significant at the level of  $P < 0.05$ .

Parameter	Phase	Surface	10m	20m	30m	50	75m	100m
Dissolved oxygen (mg.L <sup>-1</sup> )	Pre-eddy	6.09± 0.36	6.2 ± 0.29	5.81 ± 0.4	5.14 ± 0.99	3.41 ± 2.56	0.83 ± 0.13	0.51 ± 0.04
	Core-eddy	6.54 ± 1.09	6.36 ± 0.90	5.39 ± 1.27	2.97 ± 0.77	1.23 ± 0.43	0.43 ± 0.17	0.28 ± 0.21
	Transition	6.71 ± 0.67	6.61 ± 0.61	6.64 ± 0.66	4.99 ± 1.60	1.33 ± 0.44	0.42 ± 0.24	0.41 ± 0.21
Nitrate (µM)	Pre-eddy	0.51 ± 0.19	1.19 ± 0.70	1.87 ± 0.89	3.85 ± 1.47	11.69 ± 4.85	18.79 ± 4.49	21.03 ± 2.55
	Core-eddy	0.45 ± 0.08	1.12 ± 0.41	3.12 ± 0.40	6.90 ± 1.29	16.08 ± 2.18	15.46 ± 3.19	18.74 ± 4.49
	Transition	0.63 ± 0.15	0.87 ± 0.45	2.39 ± 1.09	4.88 ± 1.62	15.09 ± 3.25	18.60 ± 4.18	20.62 ± 3.52
Phosphate (µM)	Pre-eddy	0.45 ± 0.09	0.54 ± 0.05	0.61 ± 0.09	0.97 ± 0.18	1.86 ± 0.40	2.21 ± 0.23	2.36 ± 0.19
	Core-eddy	0.61 ± 0.28	0.56 ± 0.16	0.71 ± 0.17	1.19 ± 0.25	1.82 ± 0.27	1.95 ± 0.19	2.24 ± 0.15
	Transition	0.49 ± 0.19	0.48 ± 0.09	0.49 ± 0.10	0.83 ± 0.19	1.76 ± 0.17	2.08 ± 0.11	2.21 ± 0.11
Silicate (µM)	Pre-eddy	4.05 ± 1.49	4.25 ± 1.76	4.27 ± 1.43	6.11 ± 3.48	18.45 ± 2.41	23.63 ± 2.57	26.73 ± 2.96
	Core-eddy	4.91 ± 0.43	5.78 ± 1.62	6.56 ± 2.17	10.16 ± 3.21	18.86 ± 1.65	19.77 ± 3.02	26.61 ± 1.97
	Transition	4.05 ± 1.16	3.89 ± 1.58	4.56 ± 2.44	6.99 ± 2.02	15.96 ± 0.99	21.95 ± 2.12	24.01 ± 1.94

Table -1- Vertical distribution of dissolved oxygen and nutrients (mean ± standard deviation) in various eddy phases during the study period February 21 - March 08 in the study site. Pre-eddy, core eddy and transition grouping of sampling day according to Figure 5. Total number of number of samples = 136; N=32 in Pre eddy ; N= 40 in transition and N= 64 in core eddy.

### 3.4 Vertical distribution of Dissolved oxygen, nutrients and Chlorophyll-*a*

Temporal changes of the dissolved oxygen during the sampling period were presented in Figure 6. Dissolved oxygen 0.8 mg.L<sup>-1</sup> isolines were found below 70 m during the pre-eddy conditions, but this was reached to the 50m water column during core eddy phase. In 75 m layer, dissolved oxygen was 0.8 mg. L<sup>-1</sup> in phase I but this was 0.40 mg. L<sup>-1</sup> in core eddy (Table 1). Temporal variations of dissolved oxygen in the surface layer comparable between the eddy phases (ANOVA, F= 2.325; N= 136; DF=2; P>0.05), but in subsurface layers (30m, 50m, 75m and 100m), the dissolved oxygen differences were noticeable between the eddy phases (ANOVA, P<0.05) (Table 2). Vertical distribution of the major nutrients nitrate, phosphate and silicate concentrations were varied between the phases of eddy (Figure 7). In surface layer nitrate concentration varied between 0.29 to 0.76µM; phosphate concentration was 0.27 to 0.80 µM; silicate concentration was 2.01 to 6.09 µM. Nitrate, phosphate and silicate differences between the eddy phases were comparatively



less, however subsurface layers (20m, 30m and 50m), nutrients concentrations were increased ~1 -3 folds in eddy conditions than the pre-eddy conditions (Figure 7).

Parameters	N		Surface	10 m	20m	30m	50m	75m	100m
Dissolved oxygen (mg.L <sup>-1</sup> )	13 6	F ratio	0.38	0.6 3	2.33	3.87	14.11	4.78	3.21
		P value	0.68	0.5 4	0.10	P<0.05 *	P<0.00 1**	P<0.05 *	P<0.0 5*
Phosphate (µM)	13 6	F ratio	1.73	1.8 3	2.14	3.39	5.45	6.18	3.67
		P value	0.18	0.1 7	0.12	P<0.05 *	P<0.05 *	P<0.05 *	P<0.0 5*
Silicate (µM)	13 6	F ratio	2.00	2.0 5	3.99	5.83	7.49	7.02	4.02
		P value	0.14	0.1 3	P<0.05 *	P<0.05 *	P<0.05 *	P<0.05 *	P<0.0 5*
Nitrate (µM)	13 6	F ratio	0.031	1.0 6	2.33	3.24	3.58	8.87	4.54
		P value	0.97	0.3 5	0.10	P<0.05 *	P<0.05 *	P<0.00 1**	P<0.0 5*
Chlorophyll <i>a</i> (µg.L <sup>-1</sup> )	40 8	F ratio	1.64	2.8 0	36.28	25.52	6.04	4.48	2.17
		P value	0.195	0.0 62	P<0.00 1**	P<0.00 1**	P<0.00 1**	P<0.05 *	0.115
Integrated Chlorophyll <i>a</i> (mg.m <sup>-2</sup> ) (0-100m)	40 8	F ratio P value	36.405 P<0.00 1**						
Mesozooplankton abundance (Ind.m <sup>-2</sup> ) (0-100m)	68	F ratio P value	9.602 P<0.00 1**						
Copepods abundance (Ind.m <sup>-2</sup> ) (0-100m)	68	F ratio P value	7.021 P<0.00 1**						
Larger predators abundance (Ind.m <sup>-2</sup> ) (0-100m)	68	F ratio P value	7.795 P<0.00 1**						

Table - 2 - ANOVA results comparison of dissolved oxygen, nutrients, Chlorophyll *a*, integrated Chlorophyll *a*, mesozooplankton abundance, copepods abundance, larger predators abundance between eddy phases (pre eddy, core eddy and transition). N= number of samples, DF=2, significance \*P<0.05 level, \*\*P<0.001 level.

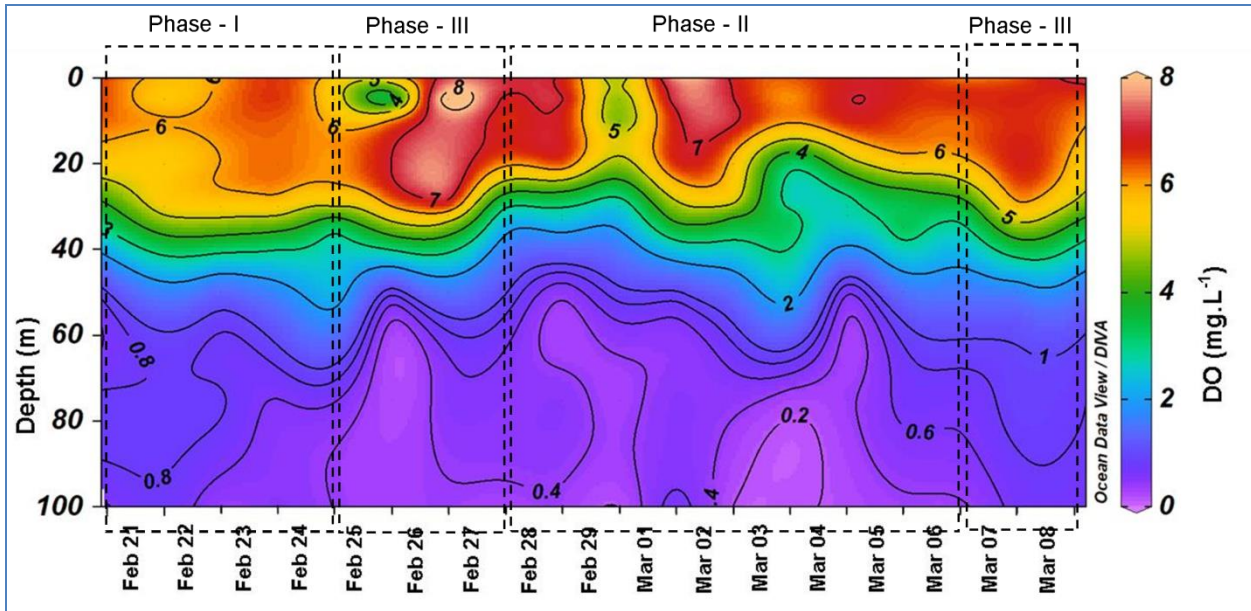


Figure 6 - Temporal change of dissolved oxygen (mg/L) in the time period from February 21 to March 08 and in the depth interval from 0 to 100m measured at the study location. The vertical spurts in the low oxygen waters in subsurface layers are prominent, especially at 40-70 m depth during the February 26 to March 06 (eddy period). The dotted lines represents various phases of eddy (for additional information see figure 5).

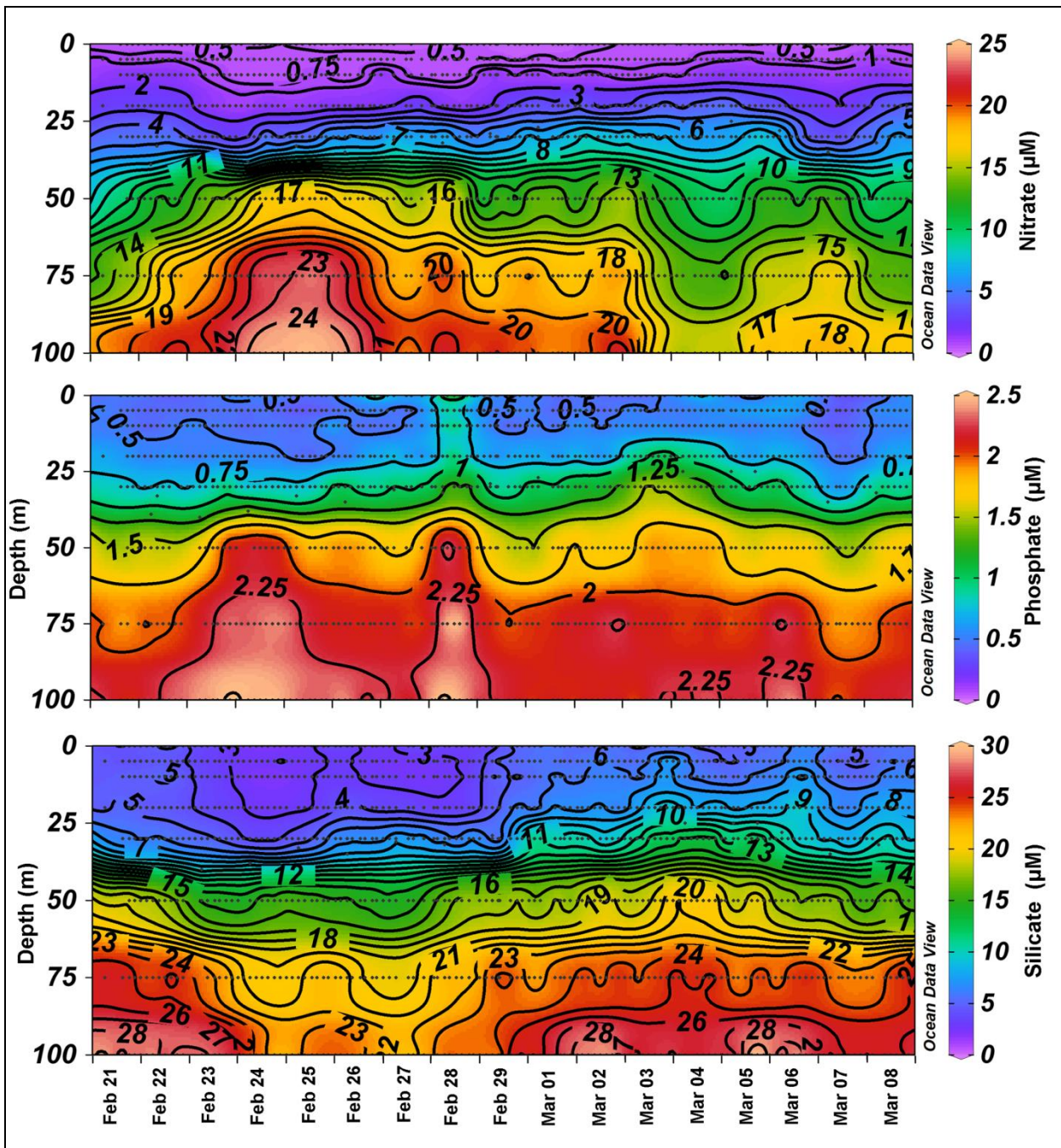


Figure 7 –Temporal change of dissolved nitrate, phosphate and silicate (all in  $\mu\text{M}$ ) in the time period from February 21 to March 08 and in the depth interval from 0 to 100 m measured at the study location. Nutrients were higher during the core eddy phases compared to the initial phase.

Chlorophyll *a* was ranged from 0.2 to 0.45  $\mu\text{g. L}^{-1}$  in the surface layer and differences between the eddy phases were comparable (ANOVA,  $F=1.64$ ,  $N=408$ ,  $DF=2$ ,  $P>0.05$ ) (Table 2). Upsloping of the Deep Chlorophyll *a* Maxima (DCM) was found in the core of eddy conditions, depth of DCM was in Av. 38 m in pre-eddy conditions, Av. 23m in core eddy condition and Av. 32m in the periphery condition. Vertical distribution pattern shows that subsurface Chlorophyll *a* concentration was relatively high compared to the surface. DCM layer Chlorophyll *a* was high in

pre-eddy conditions compared to other phases of the eddy (Figure 8). The overall depth-integrated Chlorophyll *a* (0-100m) was high in eddy transition compared to core eddy and pre eddy phases (Figure 8b).

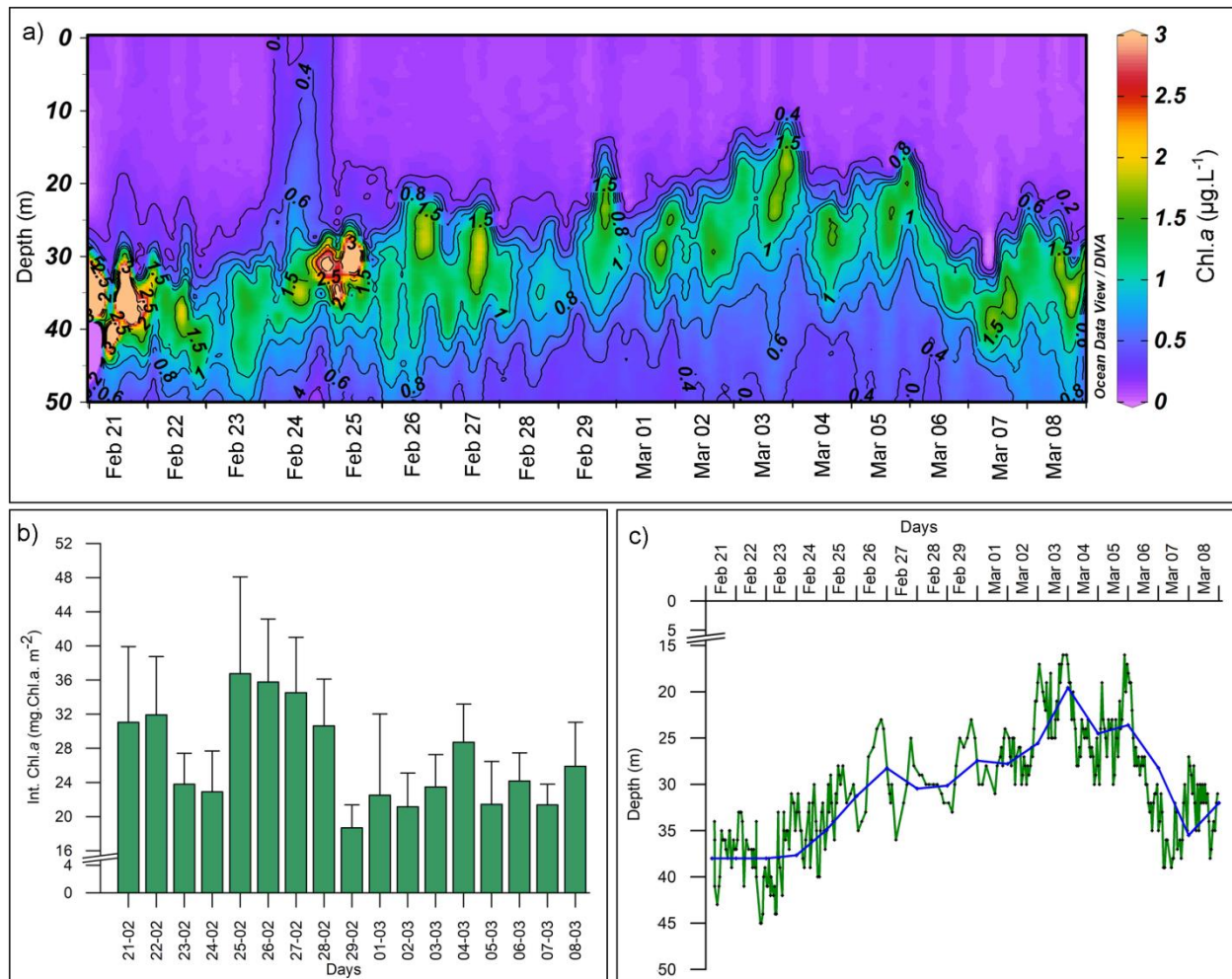


Figure 8. Variations of Chlorophyll *a* in the time period from February 21 to March 8 measured at the study location: (a) Temporal change of the Chlorophyll *a* ( $\mu\text{g/L}$ ) in the depth interval from 0 to 50 m, (b) Change of 0-100m depth integrated values of Chlorophyll *a* (day mean and standard deviation) and Int.Chl - a concentration in  $\text{mg.m}^{-2}$ , (c) Change of the Deep Chlorophyll Maximum layer (DCM) depth (m). DCM layer becomes shallower from  $\sim 40\text{m}$  of pre eddy period (February 21 to February 24) to  $\sim 20\text{m}$  of core eddy phase was quite evident.

### 3.5. Mesozooplankton abundance and community structure

Mesozooplankton abundance ranged between 34097 and 72559  $\text{No.m}^{-2}$  during the study period. Zooplankton abundance significantly differed between the eddy phases (ANOVA,  $F=9.602$ ;  $N=68$ ;  $DF=2$ ,  $P<0.05$ ) (Figure 9a; Table 2). Total mesozooplankton abundance was less in Pre-eddy ( $39510 \pm 3703 \text{ No.m}^{-2}$ ), moderate in the transition ( $41633 \pm 5407 \text{ No.m}^{-2}$ ) and highest in core eddy phase ( $62320 \pm 9653 \text{ No.m}^{-2}$ ) (Figure 10; Table 3). Altogether 22 mesozooplankton groups were reported in the present study in that copepod abundance was ranged from 28819 to 69297  $\text{No.m}^{-2}$  and

it contributes 76% to 98.4% in the total abundance. As like the total mesozooplankton abundance, copepod abundance was high in core eddy phase ( $55592 \pm 6570 \text{ No.m}^{-2}$ ) compared to transition ( $38719 \pm 5554 \text{ No.m}^{-2}$ ) and pre-eddy phase ( $37919 \pm 3642 \text{ No.m}^{-2}$ ) (Figure 10). The larger predator's (hydromedusae, siphonophores, ctenophores, and chaetognaths abundance) ranged from  $106 \text{ No.m}^{-2}$  to  $4400 \text{ No.m}^{-2}$  and their contributions were found 0.27 % to 9.67 % in the total mesozooplankton abundance. Their temporal differences were significant (ANOVA,  $F= 7.021$ ;  $N=68$ ,  $DF=2$ ,  $P<0.05$ ). Larger predator's abundance was relatively 3-5 folds higher in the core ( $2612 \pm 790 \text{ No.m}^{-2}$ ) and transition ( $1854 \pm 666 \text{ No.m}^{-2}$ ) conditions compared to pre-eddy ( $506 \pm 473 \text{ No.m}^{-2}$ ) (Figure 9 and Table 3). The other groups altogether contribute <5% to the total abundance.

Groups	Pre- eddy	Transition	Core eddy
1 Hydromedusae	$33.6 \pm 23.4$	$208.1 \pm 194.7$	$144.1 \pm 65.8$
2 Siphonophores	$60.2 \pm 36.8$	$163.1 \pm 139.7$	$284.5 \pm 243.4$
3 Ctenophores	$12.4 \pm 24.8$	$59.5 \pm 53.7$	$76.1 \pm 47.8$
4 Thalacians	$5.3 \pm 10.6$	$424.6 \pm 581.4$	$222.8 \pm 211.5$
5 Chaetognaths	$399.9 \pm 400$	$1878.6 \pm 650$	$2887.9 \pm 903.6$
6 Copepods	$37919 \pm 3642$	$38719 \pm 5554$	$55592 \pm 6570$
7 Cladocera	$390.5 \pm 211.4$	$70.8 \pm 158.2$	$90.9 \pm 245.6$
8 Mysids	$1.7 \pm 3.5$	$28.3 \pm 38.8$	$25.7 \pm 12.5$
9 Euphasids	$17.1 \pm 12.3$	$8.5 \pm 7.8$	$9.1 \pm 12.1$
10 Isopods	-	$2.8 \pm 3.9$	$4.4 \pm 5.3$
11 Amphipods	-	$73.8 \pm 69.18$	$71.7 \pm 46.7$
12 Lucifers	$26.5 \pm 20.2$	$61.1 \pm 59.4$	$73.4 \pm 28.3$
13 Appendicularians	$412.2 \pm 74.98$	$22.6 \pm 31.1$	$852.9 \pm 429.7$
14 Stomatopods	-	$5.7 \pm 7.8$	$5.3 \pm 6.3$
15 Ostrocods	$7.1 \pm 14.1$	$72.2 \pm 23.1$	$364.5 \pm 636.5$
16 Pteropods	-	-	$10.7 \pm 22.7$
17 Polychates and Larvae	$97.3 \pm 63.8$	$363.8 \pm 457.4$	$232.7 \pm 216.9$
18 Decapods and larvae	$58.4 \pm 54.3$	$193.9 \pm 83.2$	$175.1 \pm 160.8$
19 Molluscans larvae	$5.3 \pm 4.6$	-	$11.8 \pm 3.3$
20 Echinoderms larvae	$19.4 \pm 16.3$	$14.2 \pm 19.38$	-
21 Fish eggs	$244.2 \pm 196.5$	$460.1 \pm 433.4$	$155.7 \pm 147.4$
22 Fish larvae	$3.5 \pm 4.1$	$42.5 \pm 13.2$	$64.6 \pm 48.9$
Total mesozooplankton Abundance (0-100m)	$39510 \pm 3703$	$41633 \pm 5407$	$62320 \pm 9653$

**Table – 3** The abundance of 22 Mesozooplankton groups (Mean and Standard deviation) in the depth interval 0 - 100m during three eddy phases: Pre-eddy, Core eddy, and Transition. Data sets are in  $\text{Ind.m}^{-2}$ . The represented values are the Mean and SD of the particular phase. Mean and SD was calculated in entire observations with in the eddy phase (number of samples  $N= 16$  in pre-eddy phase;  $N= 32$  in core eddy phase and  $N= 20$  in the transition phase).

### 3.6. Copepod abundances and species community structure

Altogether, 64 species were reported during the study period; among that 44 species belongs in order calanoida; 3 species belong to order cyclopoida; 8 species belong to order Poecilostomatoida, and 9 species belong to order harpacticoida (Table - 4). Copepods species diversity was ranged from 2.47 to 2.95. Copepods diversity ( $H'$ ) was high in the core eddy conditions ( $2.89 \pm 0.19$ ) compared to transition ( $2.69 \pm 0.15$ ) and pre-eddy conditions ( $2.47 \pm 0.24$ ) (Supplementary Figure 2). Percentages of copepod orders, contribution in total abundance were differed between the eddy phases, during pre-eddy conditions the Poecilostomatoids contribution were high (52.2%) in the total abundance compared to calanoids (41%), however in the eddy condition the calanoids contribution (62.9% in transition; 65.7% in core eddy) exceeds than the Poecilostomatoids (Figure 10) . Altogether 14 species were found as the dominant species; in that seven species (*Acrocalanus* sp., *Calocalanus pavo*, *Paracalanus parvus*, *Corycaeus danae*, *Eucalanus elongatus*, *Farnulla gibulla*, *Oncaea venusta*) were commonly found as dominant species in the entire sampling period (Table 5).

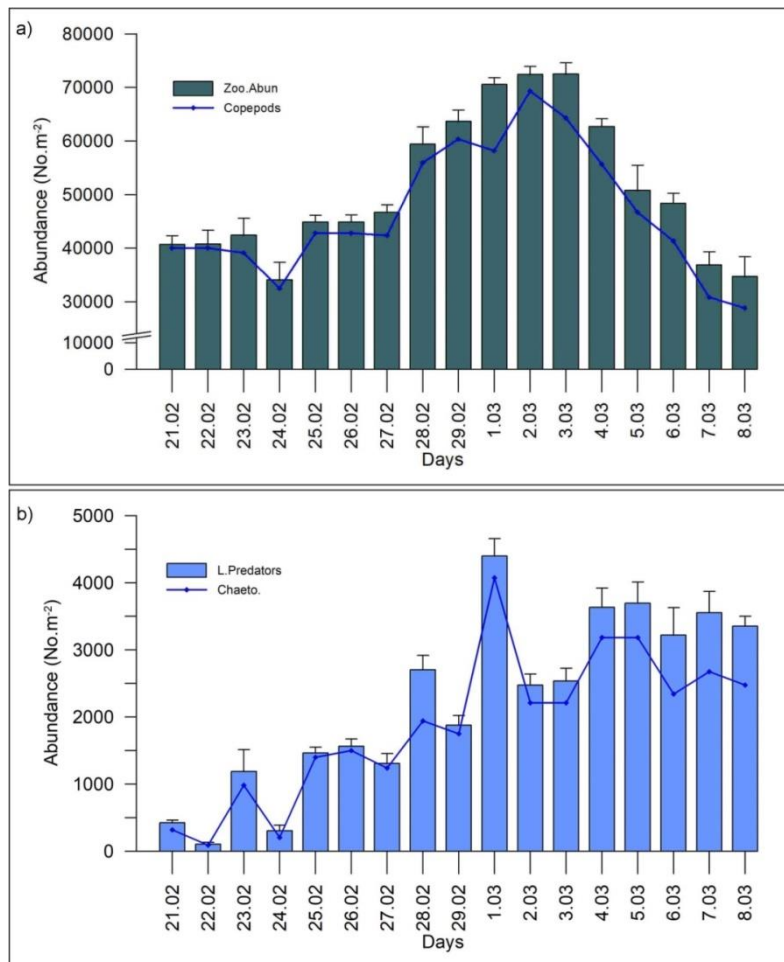


Figure 9. Mesozooplankton abundance in the time period from February 21 to March 08 at the study location and depth interval from 0-100m measured at the study location (a) Abundances of total mesozooplankton and copepods (No.m<sup>-2</sup>), (b) abundances of larger predators and chaetognaths (No./m<sup>-2</sup>). The represented values are the daily mean and SD values of the four samplings of a specific day. Zooplankton, copepods and larger predator abundance were relatively less during the Pre-eddy period compared to eddy phases.

	21.02. 2016	22.02. 2016	23.02. 2016	24.02. 2016	25.02. 2016	26.02. 2016	27.02. 2016	28.02. 2016	29.02. 2016	01.03. 2016	02.03. 2016	03.03. 2016	04.03. 2016	05.03. 2016	06.03. 2016	07.03. 2016	08.03. 2016	2016
<i>Order:</i>																		
<i>Calanoida</i>																		
1	<i>Acartia danae</i>																	
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2	<i>Acartia spinicauda</i>																	
	+	-	+	+	-	-	-	-	+	+	+	+	+	+	+	+	+	-
3	<i>Acrocalanus</i>																	
	++		++	++	++	++	++	++	++	++								
4	<i>Acrocalanus monachus</i>																	
	+	+	+	+	+	+	+	+	+	+	+	++	+	+	+	+	++	++
5	<i>Calanopia minor</i>																	
	+	+	-	+	-	+	+	-	+	-	-	+	+	+	+	+	+	-
6	<i>Calanus tenuicornis</i>																	
	+	-	+	-	-	+	+	-	+	+	++	+	-	-	-	-	-	-
7	<i>Calocalanus pavo</i>																	
	+	+	+	+	+	+	+	+	++	++	+	+	++	++	+	+	+	+
8	<i>Candacia discaudata</i>																	
	+	-	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	-
9	<i>Candacia pachydactyla</i>																	
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-
10	<i>Canthocalanus pauper</i>																	
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
11	<i>Centropages gracilis</i>																	
	-	-	-	-	-	+	+	-	+	+	+	+	-	-	-	-	-	-
12	<i>Centropages calaninus</i>																	
	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
13	<i>Centropages elongatus</i>																	
	+	+	+	-	-	-	-	-	+	+	+	+	-	-	-	+	-	-
14	<i>Centropages furcatus</i>																	
	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	-
15	<i>Centropages tenuiremis</i>																	
	+	-	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	-
16	<i>Clausocalanus arcuicornis</i>																	
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
1	<i>Cosmocalanus</i>																	
	+	+	+	+	+	+	+	+	+	+	+	+	-	-	+	+	+	+



7	<i>anus</i>																	
	<i>darwini</i>																	
1	<i>Eucalanus</i>													++	++	++		
8	<i>elongatus</i>	+	+	+	+	+	+	+	++	++	++	++	++	+	+	+	++	+
1	<i>Euchaeta</i>																	
9	<i>marina</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2	<i>Euchirella</i>																	
0	<i>sp.,</i>	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-
2	<i>Haloptilis</i>																	
1	<i>sp.,</i>	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	-	-
2	<i>Heterohab</i>																	
2	<i>dus</i>																	
	<i>papilliger</i>	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	-
2	<i>Labidocer</i>																	
3	<i>a acuta</i>	-	-	-	-	-	+	+	-	+	-	-	+	+	+	-	-	-
2	<i>Mesocala</i>																	
4	<i>nus</i>																	
	<i>tenuicorni</i>																	
	<i>s</i>	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	<i>Metacalan</i>																	
5	<i>us</i>																	
	<i>aurivilli</i>	-	-	-	-	+	+	-	-	-	-	+	+	-	-	-	-	-
2	<i>Nannocal</i>																	
6	<i>anus</i>																	
	<i>minor</i>	+	+	+	+	+	+	+	-	+	+	-	+	-	-	+	+	-
2	<i>Neocalan</i>												++					
7	<i>us gracilis</i>	+	+	+	+	+	+	+	-	+	+	+	+	-	-	-	-	-
2	<i>P.serricau</i>																	
8	<i>datus</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	++	++
2	<i>Paracalan</i>		++						++	++	++			++	++	++	++	++
9	<i>us parvus</i>	++	+	+	++	+	++	++	+	+	+	-	++	+	+	+	+	+
3	<i>Paracand</i>																	
0	<i>acia</i>																	
	<i>simplex</i>	+	-	+	+	+	+	-	-	+	+	+	+	-	-	+	+	-
3	<i>Pareucala</i>																	
1	<i>nus</i>																	
	<i>attenuatus</i>	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-
3	<i>Phaenna</i>																	
2	<i>spinifera</i>	+	-	+	-	+	+	+	-	+	+	+	+	+	+	+	+	+
3	<i>Pleuroma</i>																	
3	<i>mma</i>					++	++	++	++		++							
	<i>indica</i>	-	-	+	+	+	+	+	+	++	+	+	+	+	+	++	++	+
3	<i>Pontella</i>																	
4	<i>danae</i>	-	-	+	-	-	+	+	+	+	+	-	+	+	+	+	+	-
3	<i>Pontella</i>																	
5	<i>fera</i>	-	-	-	-	-	-	-	-	-	-	+	+	-	-	+	+	-
3	<i>Pontellina</i>																	
6	<i>plumata</i>	-	-	-	-	-	+	++	+	+	+	+	+	-	-	+	+	-
3	<i>Pontellops</i>																	
7	<i>is armata</i>	-	+	-	-	-	+	+	+	+	+	+	+	-	-	+	+	-

3	<i>Rhincalanus</i>																	
8	<i>cornutus</i>	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-
3	<i>Subeucalanus</i>																	
9	<i>eucalanus</i>	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	-
4	<i>Temora discaudata</i>	+	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
4	<i>Temora turbinata</i>	+	+	+	+	+	+	+	++	+	++	+	+	+	+	+	+	+
4	<i>Tortanus sp.</i>	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	<i>Undeuchaea plumosa</i>	-	-	+	-	-	-	-	-	-	-	+	+	-	-	-	-	-
4	<i>Undinula vulgaris</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	++	++

Order:

<i>Cyclopoida</i>																		
1	<i>Oithona plumifera</i>	-	-	+	+	+	+	-	+	+	+	+	+	-	-	-	+	+
2	<i>Oithona similis</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3	<i>Oithona spinirostris</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Order:

<i>Harparcticoida</i>																		
1	<i>Clytemnestra rostrata</i>	-	-	-	-	-	+	+	+	+	+	-	+	-	-	+	+	+
2	<i>Clytemnestra scutellata</i>	-	-	+	+	+	+	+	+	+	-	+	+	-	-	-	+	+
3	<i>Copilia mirabilis</i>	-	+	+	-	-	-	-	+	+	+	+	+	+	+	+	+	-
4	<i>Euterpina acutifrons</i>	+	+	++	++	+	+	+	+	+	+	+	+	+	+	+	+	+
5	<i>Macrosetella gracilis</i>	-	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+
6	<i>Macrosetella oculata</i>	-	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+
7	<i>Microsetella norvegica</i>	+	+	+	+	+	+	+	-	+	-	+	+	+	+	+	+	+
8	<i>Microsetella rosea</i>	+	+	+	+	+	+	-	+	+	+	-	+	+	+	-	+	+

9	<i>Miracia efferata</i>	-	-	+	+	+	+	-	+	+	-	-	+	+	+	+	+	
Order:																		
Poecilostomatoida																		
1	<i>Corycaeus danae</i>	++	+	++	-	++	+	+	+	+	+	+	+	+	+	+	+	
2	<i>Corycaeus sp.</i>	+	+	+	++	+	+	+	+	+	+	+	+	+	+	++	+	
3	<i>Farranula gibbula</i>	++	++	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
4	<i>Farranula gracilis</i>	+	-	+	+	+	+	+	-	+	+	+	+	+	+	+	+	
5	<i>Oncaea media</i>	+	+	-	+	-	-	-	+	+	-	+	+	-	+	+	+	
6	<i>Oncaea venusta</i>	*	*	*	*	*	++	++	++	++	++	++	++	++	++	++	++	
7	<i>Sapphirina</i>	-	+	-	-	+	+	+	+	+	+	-	+	+	+	+	+	
8	<i>Sapphirina auronitens</i>	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	

Table – 4 Copepods species composition in the study site from February 21 to March 8. Symbols represent the mean percentage of contribution in each copepod species to the total copepod abundance in a sampling day (N=4). Minus sign indicates absence, + indicates 0.1 – 5.0 % contribution, ++ indicates 5.1 - 10% contribution, +++ indicates 10 –25% contribution and \* indicates 25.1 to 50%. Altogether 64 species reported in the present study, among that 44 species belong to order Calanoida, three species belongs to Cyclopoida, nine species belongs to Harpacticoida and eight species belongs to Poecilostomatoida.

In the eddy phase *Canthocalanus pauper*, *Pseudodiaptomus serricaudatus*, *Undinula vulgaris*, *Temora turbinata* (upwelling indicator) found as the common dominant species in addition to the common dominant forms, but their abundances were absent or less in the pre-eddy conditions (Tables – 4 and 5). Noticeably, *Pleuromamma indica* (Oxygen Minimum Zones - OMZ indicator) found as one of the dominant species during the core eddy phase, but their abundances were less in the transition and absent in the pre-eddy conditions.

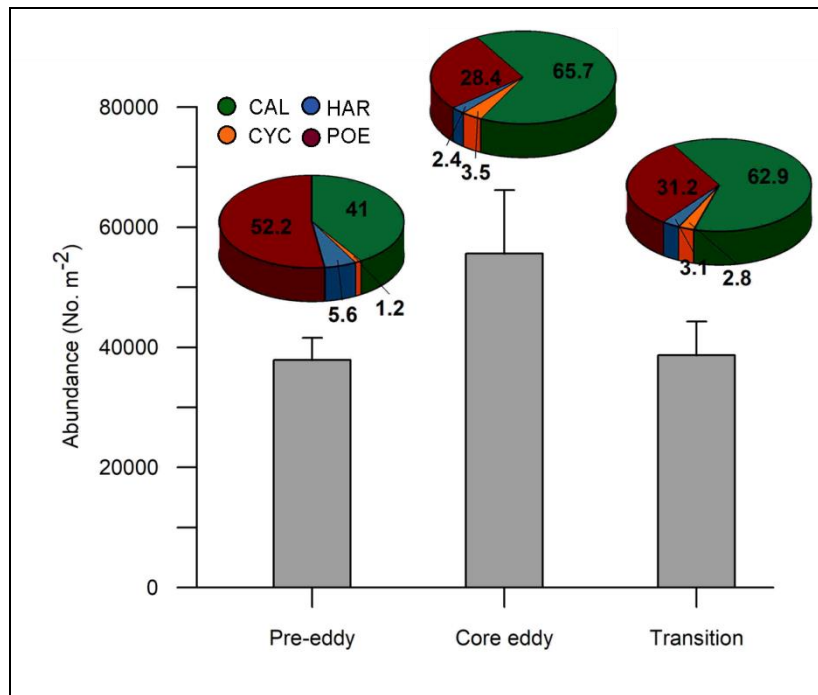


Figure 10. (a) Copepod abundance (No.m<sup>-2</sup>) and percentage of contribution of four orders (pie chart) to the total copepods for the phases pre-eddy (phase I), core-eddy (phase II) and transition (phase III). Abundances with means (grey bars) and standard deviations (error bars) of a specific phase. Data = total copepods abundance in 0-100m; four copepod orders: Calanoida (CAL), Cyclopoida (CYC), Herpacticoida (HAR), and Poecilostomatoida (POE).

Indicator species (INDVAL >50%) analysis represents copepods community composition differed between the pre-eddy and eddy conditions. *Acartia danae*, *Acartia spinicauda*, *Centropages* are found as indicator species in the pre-eddy conditions, and these species commonly found in coastal waters of BoB (Table 6). Twelve species such as *Calanus tenuicornis*, *Candacia discaudata*, *Candacia pachydactyla*, *Cosmocalanus darwini*, *Eucheta marina*, *Haloptilis* sp., *Heterohabdus papilliger*, *Pleuromamma indica*, *Rhincalanus cornutus*, *Subeucalanus*, *Copilia mirabilis*, *Sapphirina auronitens* found as the indicator species of core eddy phase. This study is the first report, showing the presence of offshore and OMZ layer abundant species (*Pleuromamma indica*) in coastal waters of the western Bay of Bengal.

Dominant species	Pre-eddy	Transition	Core eddy
<i>Acrocalanus</i> sp.	0.125	0.178	0.112
<i>Calocalanus pavo</i>	0.024	0.027	0.029
<i>Canthocalanus pauper</i>	-	0.021	0.029
<i>Centropages calaninus</i>	0.029	-	-
<i>Corycaeus danae</i>	0.070	0.035	0.038
<i>Eucalanus elongatus</i>	0.025	0.030	0.067
<i>Euterpina acutifrons</i>	0.044	0.021	-
<i>Farranula gibbula</i>	0.039	0.043	0.022
<i>Oncaea venusta</i>	0.371	0.201	0.197
<i>Paracalanus parvus</i>	0.074	0.080	0.083
<i>Pleuromamma indica</i>	-	0.021	0.064
<i>Pseudodiaptomus serricaudatus</i>	-	0.026	0.021
<i>Temora turbinata</i>	-	0.022	0.037
<i>Undinula vulgaris</i>	-	0.048	0.029

**Table – 5** List of the dominant species (dominance index value  $Y_i \geq 0.02$ ; calculated using the equation of  $(Y_i = N_i / N) \times f_i$ ) and their dominance values ( $Y_i$ ) in various phases of the eddy conditions during the time series periods. – sign represents species are absent or their dominance values are less than 0.02 during that phase.

Pre-eddy	Transition	Core eddy
<i>Acartia spinicauda</i> (79.9)	<i>Pontellina plumata</i> (73.7)	<i>Calanus tenuicornis</i> (97)
<i>Euterpina acutifrons</i> (51)	<i>Sapphirina nigromaculata</i> (66.2)	<i>Candacia discaudata</i> (89.1)
		<i>Candacia pachydactyla</i> (58.8)
		<i>Cosmocalanus darwini</i> (65.4)
		<i>Eucheta marina</i> (63.1)
		<i>Haloptilis</i> sp., (87.6)
		<i>Heterohabdus papilliger</i> (54.2)
		<i>Pleuromamma indica</i> (55.1)
		<i>Rhincalanus cornutus</i> (65.3)
		<i>Sub eucalanus</i> sp., (69.7)
		<i>Copilia mirabilis</i> (70.9)
		<i>Sapphirina auronitens</i> (68.4)

Table -6 List of the indicator species (INDVAL score >50%) for three eddy phases: pre-eddy, core eddy and transition. Indicator species, INDVAL, calculated using Equ.3.

### 3.7. Interrelationships between the hydrographical and Biological parameters

The detailed Multivariate RDA analysis visualized the interrelationships between the biological parameters (Dominant and indicator copepods species abundance, total mesozooplankton abundance and integrated Chl - *a*) and environmental parameters (Salinity in 20, 30, 35 and 40m; Temperature in 20, 30, 35 and 40m; Nitrate concentration in 20 and 30m; Subsurface DO and Sea surface height anomaly - SSHA).

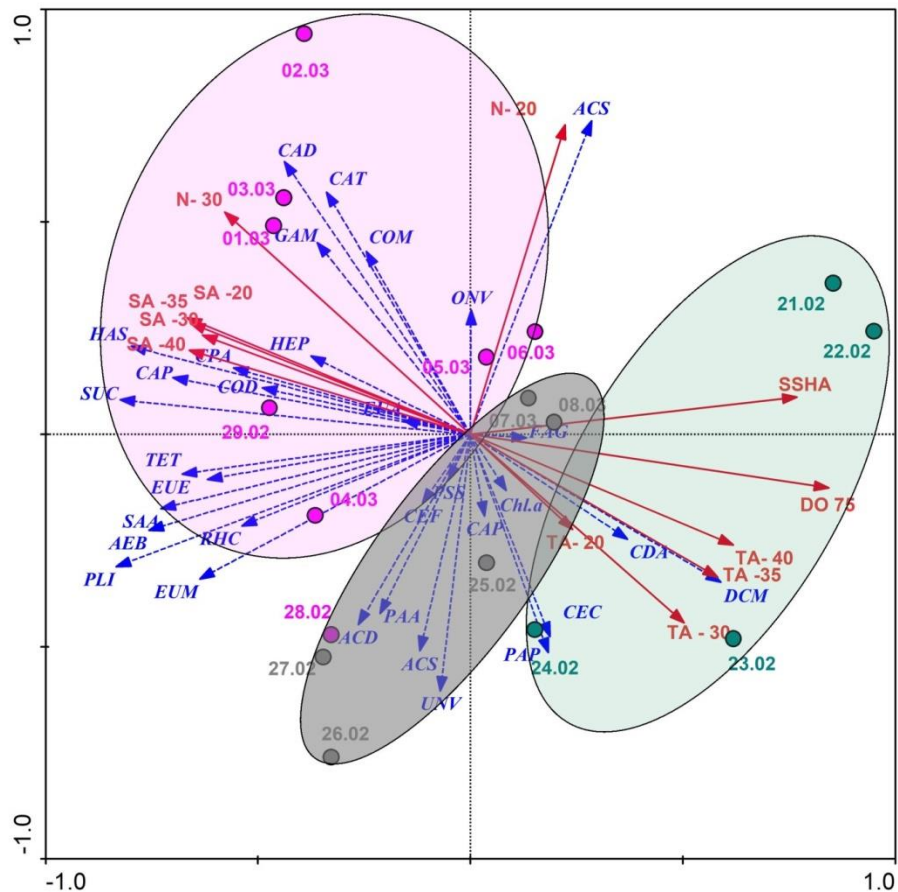


Figure 11 - Redundancy analysis (RDA); triplot of the relationship between the biological variables (Blue dotted arrows) and the environmental parameters (Red arrows). In RDA triplot environmental variables are represented in solid red arrows and biological variables represented in blue dotted lines. Pre-eddy (Phase I) sampling days were represented by the green circles; Core eddy (Phase II) sampling days – pink filled circles; transition conditions (Phase III) Grey filled circles. Daily mean values of parameters were used for the creation of RDA triplot. Copepods species abundances (Ind.m<sup>-2</sup>) were log transformed and centered before the analysis of RDA. For showing the various phases and their characteristic feature, eclipses are drawn and shaded with various colors; these are just overlay circles. The green shaded portions show that the phase I (Pre-eddy) characteristics; Pink shaded portions show that the Phase II (core eddy) hydrography and the species distribution; grey shaded portions show the transition conditions (Phase III). RDA triplot was created using CANOCA 4.5 software. Ordination significance was tested with the Monte Carlo permutation test, and the results

show that the ordination pattern was significant and the axes explain the 78.8% interrelationships between hydrographical and copepods species distribution. Abbreviations; SA-20 – Salinity 20m; SA-30 – Salinity 30m; SA – 35- Salinity 35m ; SA-40 – Salinity 40m; TA-20 – Temperature 20m; TA – 30 – Temperature 30m; TA – 35 – Temperature 35m; TA-40- Temperature 40m; N-20 – Nitrate 20m; N-30 – Nitrate 30m; DO -75 – Dissolved oxygen - 75m; SSHA – Sea surface height anomaly; ACS - *Acrocalanus* sp; CAP - *Calocalanus pavo*; CPA - *Canthocalanus pauper*; CEC - *Centropages calaninus*; COD- *Corycaeus danae*; EUE - *Eucalanus elongates*; EUA - *Euterpina acutifrons*; FAG- *Farranula gibbula*; ONV - *Oncaea venusta*; PAP-*Paracalanus parvus*; PLI- *Pleuromamma indica*; PSS- *Pseudodiaptomus serricaudatus*; TET- *Temora turbinata*; UNV- *Undinula vulgaris*; ACD- *Acartia spinicauda*; POP - *Pontellina plumata*; CAT- *Calanus tenuicornis*; CAD - *Candacia discaudata*; CAP- *Candacia pachydactyla*; COD - *Cosmocalanus darwini*; EUM- *Eucheta marina*; HAS- *Haloptilis* sp. ; HEP- *Heterohabdus papilliger*; RHC- *Rhincalanus cornutus*; SUC- *Subeucalanus* sp.; COM- *Copilia mirabilis*; SAA- *Sapphirina auronitens*.

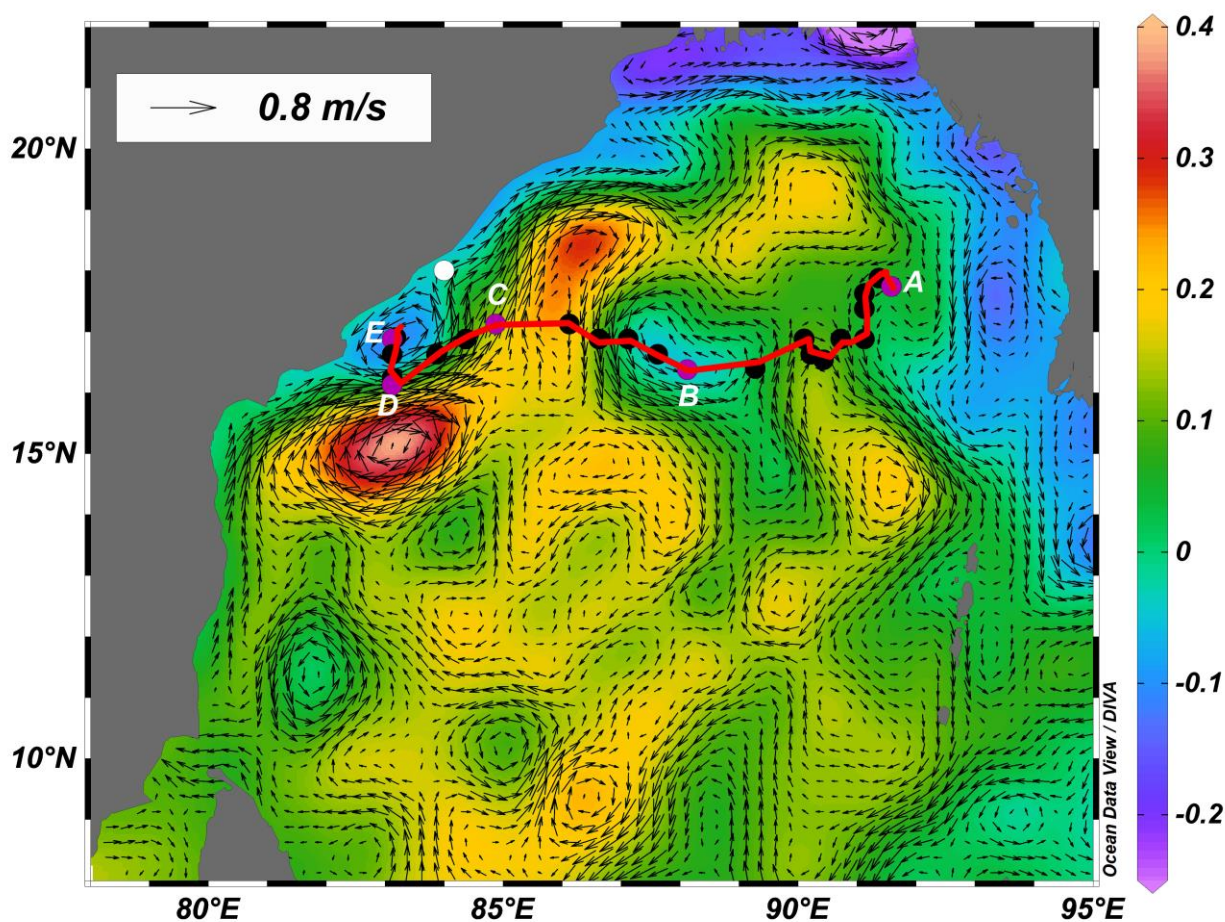


Figure – 12. Dynamics of the northeast Bay of Bengal formed eddy (position A to E) and their positions (small dots) during the various time periods. In the presented figure, SSHA (background colour) and geostrophic currents (overlaid small arrows) is the condition of the second week of February 2016. In small arrows represents the direction of the flow and the length represents the speed of the currents. Almost 1° south of the study point (white circle) one cold core eddy was

sighted at Position E. The detailed analysis of SSHA and geostrophic currents shows that this eddy was initially formed in Northeast Bay of Bengal during the first week of May (Position A) and it reached at the point E during the second week of February and path of their movements from their origin are shown by the solid lines and their position in various periods are presented in black and pink dots. Eddy was in position, the first week of May 2015 at location A (91.5°E; 17.5°N) in the northeast Bay of Bengal. It was at position B (84.87 °E and 17.12 °N) in the third week of September, at C (84.87 °E and 17.12 °N) in the first week of December, at D (83.1°E; 16.1°N) in the last week of January 2016 and at E (83.12 °E and 16.87 °N) in the second week of February before it moved to its position of the current study undertaken. Vertical colour bars represent the SSHA. Positive SSHA with clock wise geostrophic currents circulation represents the warm core eddy, and negative SSHA with an anticlock wise circulation of the geostrophic currents represents the cold core eddy feature.

Environmental parameters altogether explained the 78.8 % variance of the mesozooplankton abundance, copepods community structure and integrated Chl - *a* differences. The presented ordination pattern was significant (Monte Carlo permutation test,  $F=2.65$ ;  $P<0.05$ ). The environmental axis SSHA, subsurface DO, and temperature oriented in the right-hand side of the plot with the pre-eddy sampling days (green circles). Increasing gradients of the salinity and the nutrients and negative gradients of the SSHA, subsurface DO, and Temperature was oriented the left-hand side of the plots with the core eddy sampling days (pink circles) (Figure 11). The orientation pattern of the hydrographical parameters represents that, pre-eddy conditions were relatively warmer, oxygen-rich, high SSHA on the other hands they had less nutrients and less saline; whereas the core eddy phase was characterised as the negative SSHA, cooler, nutrient-rich and relatively high saltier. The transition conditions were characterized as the intermittent between the pre-eddy and core eddy conditions. The integrated Chlorophyll *a* concentrations were high in the transition condition, and this axis was oriented the right-hand side of the plot and opposite to the MSP abundance indicates their negative relationship. DCM layer is deeper in the pre-eddy conditions; this was oriented the right-hand side of the plot with the high temperature and less nutrients. The orientation of copepod species axes was represented the copepods community structure differed with the hydrographical settings (Figure 11). The indicator species of the core eddy (*Calanus tenuicornis*, *Candacia discaudata*, *Candacia pachydactyla*, *Cosmocalanus darwini*, *Eucheta marina*, *Haloptilis* sp., *Heterohabdus papilliger*, *Pleuromamma indica*, *Rhincalanus cornutus*, *Sub eucalanus* sp., *Copilia mirabilis*, *Sapphirina auronitens*) were oriented the left-hand side of the plot, with the increasing gradients of the salinity and the decreasing gradients of the subsurface temperature and dissolved oxygen with the core eddy associated hydrography.



#### 4. Discussion

Meso-scale eddy occurrences are consistent features in the Bay of Bengal (Prasanna Kumar et al., 2002; 2004; Jyothibabu et al., 2015). The reported cold core eddy diameter was 100-150 kilometres and movement speed was ~ 4-5 kilometres per day (Figure 2) this was in accordance with the previously reported cold core eddy natures of the BoB (Prasanna Kumar et al., 2002; 2004; Jyothibabu et al., 2015; Sarma et al., 2018). EICC flow equatorward during the Northeast Monsoon period and it changes its direction during the February and flows poleward during March – May (Shetye et al., 1991; Shetye et al., 1993; Shetye et al., 1996; Shankar, 2000; Shankar et al., 2002; Shenoi, 2010). During the study period, the geostrophic currents show that as EICC flows (North of 15°) northward (Figure) and their vicinity several eddies were found (Prasanna Kumar et al., 2002; 2004; Jyothibabu et al., 2008a; Fernandes and Ramaiah, 2009; Patnaik et al., 2014). During the first week of February, one cold core eddy was sighted 1° south of the present study site, which is slowly moved northward along with coastal currents and passing through the study site during our time series period. The eddy movement is causing significant variation in hydrographic condition, and it differed from the local ecosystem (Huang et al., 2010; Condie and Condie, 2016). Time series observations delineated into three groups based on the hydrographical conditions, like pre-eddy, transition and core eddy conditions. In the initial (pre-eddy) condition subsurface layer was warm (positive TA), less saline (negative SA), more oxygenated, less nutrients; it changed into relatively cool (negative TA), high saline (positive TA), less oxygenated and nutrients rich in core eddy (Figures 3-7). In core eddy phase, pumping of the nutrients found below the 20m. In the 75m water column, the dissolved oxygen concentration was >0.8 mg.L<sup>-1</sup> in pre-eddy condition and this reduced <0.4 mg.L<sup>-1</sup> during the core eddy conditions. In the surface layer, hydrographical differences were comparable between the eddy phases, however, up slopping of cool, nutrient-rich and less oxygenated waters were found in subsurface layers (below the 20m water column). This observation was in agreement with earlier reports about the surface stratification associated with high riverine inputs inhibit the eddy pumping to subsurface layers in the Bay of Bengal (Sarma et al., 2018; Jyothibabu et al., 2008a; Prasanna Kumar et al., 2007; Fernandes and Ramaiah, 2014).

Nutrients pumping by the mesoscale processes enhance productivity (Prasanna Kumar et al., 2004; Sarma et al., 2018; Mahadevan, 2014). Chlorophyll *a* concentration in the surface layer was comparable between the sampling days; however, in subsurface layer temporal difference was noticeable. The interrelationship between the DCM layer and nutrients was evident in the RDA plot. The depth-integrated Chl - *a* was relatively high in eddy phases compared to pre-eddy and DCM layer shallower in core eddy phase compared to pre eddy conditions. The pattern of integrated Chl -

*a* and DCM layer changes in core eddy phase was according with the previous studies of Prasanna Kumar et al., (2007); Madhu et al., (2006) ; Jyothibabu et al., (2008a) and Sarma et al., (2018). Coastal waters of BoB was characterised as less productive during the SIM period compared to other monsoon seasons associated with less runoff and more stratification (Gauns et al., 2005; Madhu et al., 2006; Paul et al., 2008; Jyothibabu et al., 2008a). The phytoplankton biomass and standing stock depend upon the phytoplankton composition, size, availability of nutrients, light, grazers abundance, etc., (Jyothibabu et al., 2003; Madhu et al., 2006; Jagadeesan et al., 2017b; Sarma et al., 2018). Integrated Chl - *a* concentration was relatively high in eddy transition (outer rings) than core eddy. Core eddy has high Mesozooplankton abundance, high nutrients but less Chl. *a* indicates that eddy mediated phytoplankton increase seems to be decreased by the zooplankton grazing in core eddy (Banse, 1994; Gasparini and Castel 1997).

In the present study, mesozooplankton abundance was increased from 1 to 1.5 folds in cold core eddy compared to the coastal water masses, and this pattern was similar with earlier studies (Fernandes, 2008; Fernandes and Ramaiah, 2009). Larger planktonic predator's abundance was high in transition and core eddy compared to pre-eddy. Mesozooplankton abundance and community structure were significantly differed between the eddy and non-eddy water masses due to differences in hydrographical parameters, phytoplankton productivity, predator abundance (Rakesh et al., 2006; Rakesh et al., 2008; Jagadeesan et al., 2013; Jagadeesan et al., 2017b). Among the zooplankton groups, copepods contribute 76% to 98.4% of total zooplankton abundance; this is in agreement with the previous reports of Indian waters (Smith and Madhupratap, 2005; Rakesh et al., 2006; Rakesh et al., 2008). Oceanic eddies can potentially act as the environmental capsule and capable of transporting viable populations across an ocean habitat (Condie and Condie, 2016). Cold core eddy supports the phytoplankton enhancement (Prasanna Kumar et al., 2007; Jyothibabu et al., 2015; Condie and Condie, 2016; Sarma et al., 2018) also favours the growth and development of the zooplankton (Logerwell and Smith, 2001; Mackas et al., 2005) and it act as feeding and breeding grounds for small pelagic fishes and larger predators (Young et al., 2001; Kai and Marsac, 2010).

The copepod community composition differed between core eddy and pre-eddy conditions (Table 5 and 6). Poecilostomatoids abundance (*Oncaea* and *Corycaeus danae*) was high compared to calanoids during the pre-eddy condition (Figure 10). Copepod community structure is highly variable with the food quantity, size and food preference (Anjusha et al., 2013; Jagadeesan et al., 2013; Jagadeesan et al., 2017b). Generally, calanoids contribution in total abundance was high in productive coastal waters (Gowsami and Padmavati, 1996; Madhupratap et al., 1996; Fernandes, 2008; Rakesh et al., 2008; Fernandes and Ramaiah, 2009; Fernandes and Ramaiah, 2014;

Jagadeesan et al., 2013; Jagadeesan et al., 2017a). During the SIM the phytoplankton productivity was less, and *Trichodesmium* blooms were reported in coastal and offshore waters of the Bay of Bengal (Madhu et al., 2006; Jyothibabu et al., 2008a; Paul et al., 2008; Ramaiah et al., 2010). Poecilostomatoids food ranges varied from smaller flagellates, microzooplankton to larger chaetognaths and appendicularians (Turner, 1986; Turner and Tester, 1997; Go et al., 1998; Wu et al., 2004). They have a pseudo pelagic mode of swimming to reduce respiratory losses (Nishibe and Ikeda, 2008) and maximise their energy utilisation for reproduction (Turner, 2004). Low phytoplankton production with high abundance of the microbial food web components (Jyothibabu et al., 2003; Madhupratp et al., 2003; Madhu et al., 2006; Ramaiah et al., 2010; Sarma et al., 2016) and the reproductive and physiological adaptations of Poecilostomatoids increased over the calanoids during the SIM.

Eddy mediated nutrient pumping increase the phytoplankton productivity compared to its adjacent environment (Prasanna Kumar et al., 2004; Prasanna Kumar et al., 2007; Ramaiah et al., 2010; Jyothibabu et al., 2015; Sarma et al., 2018;) and it alters the copepods community from the local environments (Fernandes, 2008; Fernandes and Ramaiah, 2014). During the core eddy conditions, the calanoids abundance was higher than the Poecilostomatids. Altogether seven species were found as the common dominant forms, in that calanoids copepods such as *Acrocalanus*, *Calocalanus pavo*, *Centropages calaninus*, *Eucalanus elongates* and *Paracalanus parvus* are generally considered herbivorous or omnivorous copepods, they feed on both the phytoplankton and microzooplankton and changing their food preferences according to their surroundings. However, their growth and production were relatively high in phytoplankton productive conditions; this may be the reason their abundance high in core eddy and periphery condition. In core eddy, *Temora turbinata*, *Pleuromamma indica*, *Pseudodiaptomus serricaudatus*, *Canthocalanus pauper*, *Undinula vulgaris* are found as the dominant species, in addition to the common dominant species. *Temora turbinata* and *Pseudodiaptomus serricaudatus* are the opportunistic species and found swarms in productive upwelling conditions (Padmavati and Gowsami, 1996; Madhupratap et al., 1990; Madhupratap et al., 1992; Rakesh et al., 2008; Jagadeesan et al., 2013;). In *Pleuromamma* genus seven species were reported in the Indian Ocean, in that *Pleuromamma indica* (endemic to the Indian Ocean) is most dominant (85%) and ability to survive in low oxygen waters, so they considered OMZ indicator (Saraswathy, 1986; Saraswathy and Iyer 1986; Goswami et al. 1992). Noticeably, the observation of *Pleuromamma indica* abundance during the present study is the first report in from coastal water of Bay of Bengal. *Pleuromamma indica* is strong vertical migrator species and their abundance generally found in OMZ layers especially core of OMZ region (Gowsami et al., 1992) in

the Bay of Bengal; in some cases *Pleuromamma indica* appearance was reported within 100m stratum associated with up slopping of oxygen minimum layers by cold core eddy (Fernandes, 2008; Fernandes and Ramaiah, 2009).

Cold core eddy phase was unique from the coastal conditions of SIM. Indicator species of cold core eddy is *Haloptilis* sp., *Heterohabdus papilliger*, *Pleuromamma indica*, *Rhincalanus cornutus*, *Copilia mirabilis*, *Sapphirina auronitens*, *Candacia discaudata*, *Candacia pachydactyla*; *Eucheta marina*, *Rhincalanus cornutus*, *Calanus tenuicornis* *Cosmocalanus darwini*. Out of 12 indicator species, *Haloptilis* sp., *Heterohabdus papilliger*, *Pleuromamma indica*, *Rhincalanus cornutus* occurrence were earlier reported in OMZ layer, and other 8 species occurrences were reported mostly in oceanic water masses of Indian Ocean (Sewell and Fage, 1948; Vinogradov and Voronina 1961; Madhupratap and Haridas, 1986; Padmavati et al., 1998; Smith et al., 1998; Smith and Madhupratap, 2005; Fernandes et al., 2009).

In general, core eddy contains the mixer of coastal and oceanic forms, whereas pre-eddy phase contains only the coastal forms. Copepod community structure indicates the occurrences of the oceanic water masses in the core and periphery of the eddy, and this differed from the normal coastal water conditions (pre-eddy). Oceanic species occurrences in the coastal waters indicate the continuity of the water masses from the oceanic regions through the eddy movements. Cyclonic and anticyclonic eddies are common in the Bay of Bengal, in that anticyclonic eddies are numbers are high compared to cyclonic eddies (Chen et al., 2007; Chen et al., 2012; Dandapath and Chakraborty, 2016). Cyclonic eddies are smaller, energetic and had a longer life span compared to anticyclonic eddies in the Bay of Bengal (Sarma et al., 2018). Eddies are the partially isolated environment and move from their origin. Generally, eastern BoB formed eddies are advected towards the western Bay of Bengal, while their movement, they carry eddy trapped water masses, which is entirely distinct from the surrounding water masses (Condie and Condie, 2016). The planktonic communities present in the eddy trapped waters are sustained and retained for a few days to several months (Mackas et al., 2005; Mahadeven, 2014; Condie and Condie, 2016), depending upon the eddy nature, eddy energy, life span, swimming speed and vertical migration features of organisms etc., (Mackas et al., 2005; Condie and Condie, 2016). *Pleuromamma indica* distribution differed between the latitudes, and their high abundance was the reported North of 10° N and 85° E - 95° E in the Bay of Bengal.

The higher abundance of *Pleuromamma indica* and presence of offshore and other OMZ reported forms in cold core eddy phase is indicative of their entrainment from the northeastern and central Bay of Bengal by eddies. For explaining the actual role of eddy about the presences of the oceanic and OMZ reported species in the coastal waters, we used eddy tracking mechanism for

explaining the continuity of the oceanic waters in the coastal waters. The detailed analysis of the eddy genesis shows that this eddy was initially formed ~9 months before in the Northeastern offshore (~91.5°E; 17.5°N) and it moves in the western side of the Bay of Bengal (Figure 2 and 12). Later eddy moved along with the EICC and transverse through the study site during the sampling period (Figures 2 and 12). The detailed analysis of copepods community structure explains that this northeastern offshore formed cold core eddy retains the eddy trapped waters in their path. Eddy movements and coastal currents together play a significant role in carrying the oceanic water mass characteristics with the plankton communities in the coastal waters of the Bay of Bengal. The similar kind of observations about five months old cold core eddy carries the parental water mass with zooplankton composition was reported by Strzelecki et al., (2007) and Saito et al., (2014) in the western coast of Australia and the western Aleutian Islands. The eddy trapped copepods and zooplankton communities sustain within the eddy (Condie and Condie, 2016). This study is the first kind of information about northeastern offshore BoB formed cold core eddy carries the plankton community in coastal waters on their path.

## 5. Conclusion

The mesozooplankton community structure of a cold core eddy, moving through a coastal location (Bheemunipatnam) in the western Bay of Bengal (BoB), was studied continuously for seventeen days (21<sup>st</sup> February to 8<sup>th</sup> March 2016) during Spring Intermonsoon. Cluster and NMDS analysis delineated the entire sampling days into 3 different clusters based on temperature, salinity, TA and SA such as phase I (Pre-eddy -21<sup>st</sup> February to 24<sup>th</sup> February), phase II (Core eddy – 28<sup>th</sup> February to 6<sup>th</sup> March) and phase III (Transition phase – 25<sup>th</sup> February to 27<sup>th</sup> Feb and March 7 and 8 ). The phase I was characterized as a comparatively warm, low saline, less nutrient, and oxygenated subsurface water. During phase II, cool, nutrient-rich and oxygen deficient waters in the subsurface layers of the study location indicating the presence of a cold core eddy. Phase III is an intermediate condition between the phases I and II. Sub surface chlorophyll maxima (SCM) was shoaled to 23m in Phase II from a depth of 38 m at the beginning of the study. Mesozooplankton abundance was high during phase II (62320 No.m<sup>-2</sup>) compared to phase III (41633 No.m<sup>-2</sup>) and phase I (39510 No.m<sup>-2</sup>). The larger carnivorous were noticeably high during phase II compared to other phases. Altogether 64 copepod species were identified of which, seven were dominant throughout the observation. In addition to that, *Temora turbinata*, *Pleuromamma indica*, *Pseudodiaptomus serricaudatus*, *Canthocalanus pauper*, *Undinula vulgaris* were found as the dominant species in core eddy phase. Twelve species were found as the Indicator species in the core eddy conditions. The high abundance of the *Temora turbinata* (upwelling indicator), *Pleuromamma indica* (Low oxygen

tolerant and highly central BoB reported) and occurrence of oceanic, OMZ (Oxygen minimum zone) layer reported forms in core eddy phase is an indicative of their entrainment by eddies. Eddy genesis and their movement tracking appear that this north eastern offshore formed cold core eddy (9 months before this observation) advected to western coastal Bay of Bengal and traversing through the study site with northward flowing EICC during the sampling period. Copepod species composition indicates the eddy trapped biological communities were sustained and retained in the core over a long period, and it advected over a long distance. This study is the first kind of information about northeastern offshore formed cold core eddy carries the plankton community to coastal waters of western BoB in their path and explains the core eddy is an independent ecosystem compared to surrounding environments. This study further supports the copepods community structure can be used as an indicator of eddy water masses.

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Data availability statement: The datasets will be published in the public data repository of CSIR-National Institute of Oceanography (CSIR-NIO). It can be accessed by anybody by giving individual request to Director CSIR-NIO or Scientist-in-charge of CSIR-NIO Regional Centre, Visakhapatnam, as per the Institutional policy.

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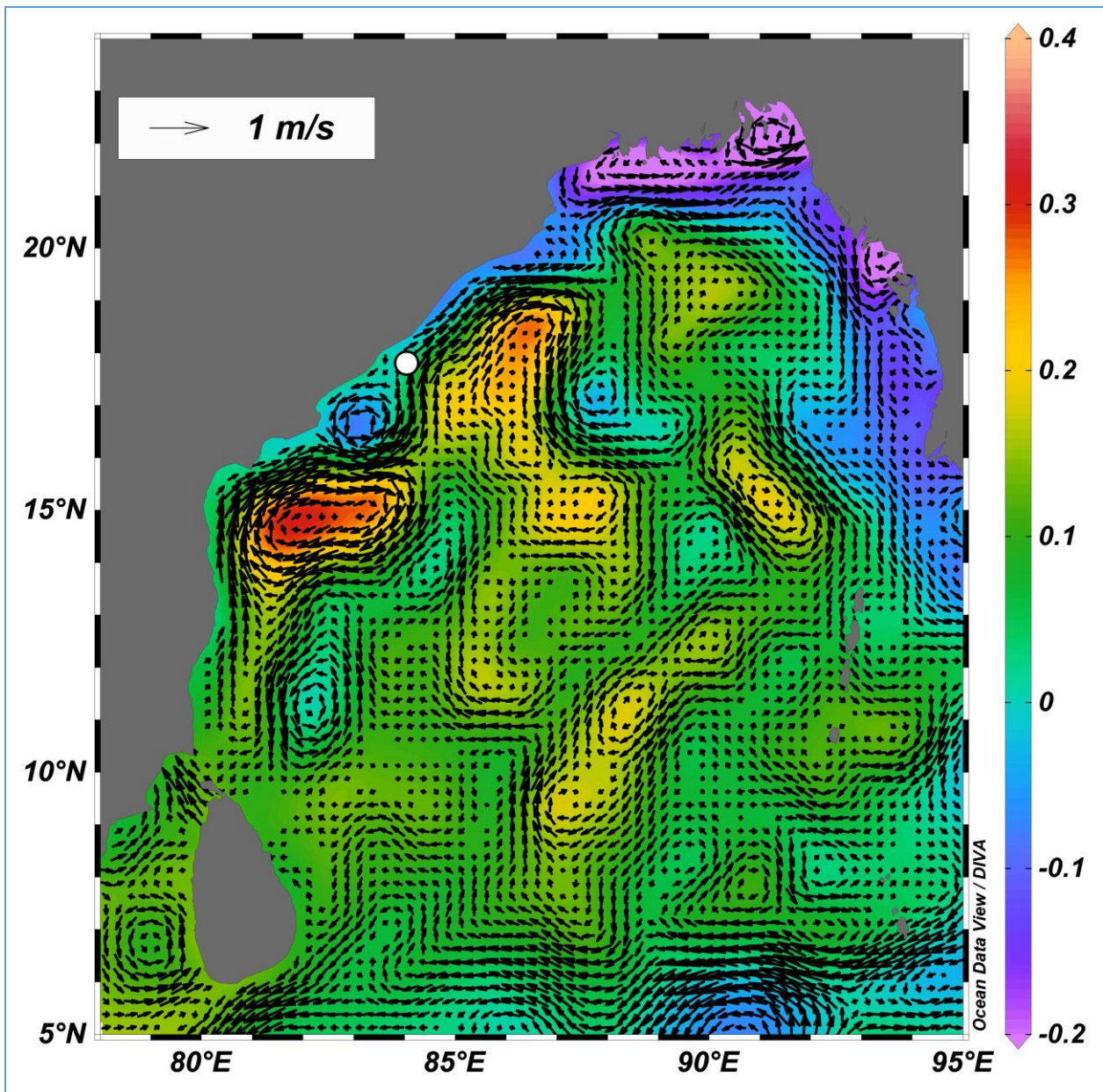
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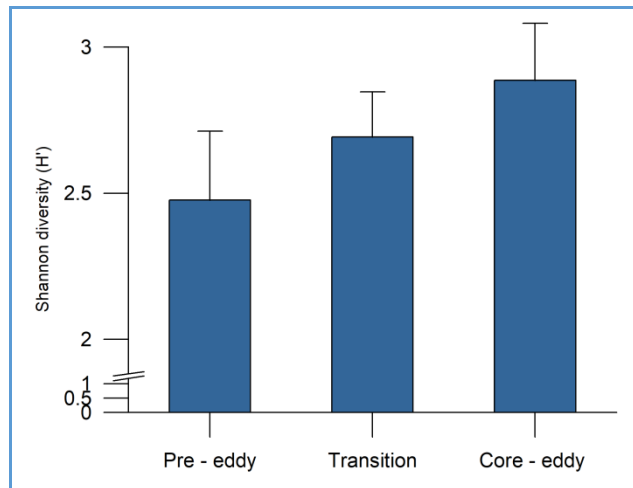
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Supplementary Figure -1- Sea Surface Height Anomaly- SSHA, and Geostrophic currents in the Bay of Bengal during the first week of February 2016 represents the several eddy formations. The geostrophic current flow (small arrows) directions show that East India Coastal Current (EICC). The arrows represent the direction of the current flow, and the length of the arrows represents the velocity currents. The current velocity of the geostrophic currents corresponds with reference arrow (1.0 m/s arrows). The preset study locations were marked as white circles. Vertical Color bars represent values of SSHA, positive colour values with the clockwise circulation of the geostrophic currents indicates the warm core eddy and negative SSHA and anticlockwise circulation of the currents represents cold core eddy. The geostrophic currents and SSHA showed the several eddy formations during the spring intermonsoon period in the Bay of Bengal.



Supplementary Figure 2 – Copepods diversity (Shannon wiener) in various phases of the eddy. Diversity calculation data =Copepods species abundance (0-100m) and the diversity values are mean (Bar)  $\pm$  SD (Error bars). Number of samples is 16 in pre-eddy phase; 32 in core eddy phase and 20 in the transition phase.

Depth	Temperature ( $^{\circ}$ C)	Salinity	Temperature Anomaly	Salinity Anomaly
0m	27.62 to 28.87	32.18 to 33.60	0.47 to 0.88	-0.69 to 0.79
5m	27.63 to 28.92	32.18 to 33.60	-0.36 to 0.92	-0.63 to 0.78
10m	27.63 to 28.49	32.18 to 33.73	-0.31 to 0.54	-0.71 to 0.84
15m	26.82 to 28.48	32.18 to 34.42	-1.14 to 0.52	-0.99 to 1.25
20m	25.66 to 28.48	32.19 to 34.46	-2.3 to 0.52	-1.37 to 0.89
25m	24.66 to 28.52	32.47 to 34.56	-3.09 to 0.77	-1.46 to 0.63
30m	22.70 to 28.27	33.19 to 34.77	-4.30 to 1.28	-1.07 to 0.51
35m	21.90 to 28.04	33.44 to 34.86	-3.71 to 2.44	-1.06 to 0.37
40m	27.75 to 27.33	34.02 to 34.95	-2.60 to 2.98	-0.62 to 0.31
45m	21.42 to 26.07	34.26 to 34.95	-1.87 to 2.79	-0.46 to 0.22
50m	21.13 to 24.07	34.48 to 34.94	-1.53 to 2.01	-0.28 to 0.18

Supplementary table– 1 Temperature, salinity, and their anomaly range in various depth layers during the study period. In top 10m layers the differences in salinity and temperature were relatively less compared to subsurface layers. Number of observations = 408.