

Seasonal variation in the diversity of Holoplankton and Meroplankton in relation with primary productivity and physicochemical parameters in the nearshore regions of the Visakhapatnam Coast, India

Ishita Sahoo,¹ Ramesh Babu Kondamudi,¹ Srinivas Tatiparthi,² Deepu Visweswar Siddela,¹ Rama Chandra Ganesh P.¹

¹Department of Marine Living Resources, Andhra University, Visakhapatnam, Andhra Pradesh; ²ICFRE - Coastal Ecosystem Centre, ICFRE - Institute of Forest Biodiversity, Pandurangapuram, Visakhapatnam, Andhra Pradesh, India

ABSTRACT

The nearshore region of a coastal ecosystem is an everchanging, dynamic, transitional zone between land and open sea. It is a highly productive area because of sufficient sunlight and nutrients. The main aim of this research is to study the diversity and abundance of zooplankton especially holoplankton and meroplankton in relation with physicochemical factors for one year with their seasonality. Along with the diversity indices, multivariate ordination indices like Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) were applied to study the diversity and their relationship with physicochemical factors. PERMANOVA was also used to test whether the abundance and physicochemical factors differed significantly across sampling sites and seasons. The study showed that holoplankton diversity in the Fishing Harbour (FH) was highest during the pre-monsoon season and lowest

during the post-monsoon season. The meroplankton diversity was the highest during the pre-monsoon season and lowest during the monsoon season which was also recorded from the FH. Principal Component Analysis (PCA) showed that Salinity, pH, dissolved oxygen and primary productivity as the significant physicochemical parameters affecting the Holoplankton and Meroplankton diversity. Canonical Correspondence Analysis (CCA) for holoplankton showed that salinity, pH, dissolved oxygen and primary productivity were positively related with copepods. While non-copepod species were positively related with salinity, pH and dissolved oxygen except primary productivity. Similarly, meroplankton groups showed positive correlation with temperature only.

Corresponding author: Ishita Sahoo, Department of Marine Living Resources, Andhra University, Visakhapatnam, Andhra Pradesh, India.

E-mail: ishita.sahoo321@gmail.com

Key words: nearshore, Holoplankton, Meroplankton, diversity, primary productivity and Copepods.

Authors' contributions: all the authors made a substantive intellectual contribution. All the authors have read and approved the final version of the manuscript and agreed to be held accountable for all aspects of the work.

Conflict of interest: the authors declare no potential conflict of interest.

Funding: none.

Availability of data and materials: all data generated or analyzed during this study are included in this published article.

Acknowledgments: we would like to sincerely thank the Department of Marine living Resources for extending us the Marine Monitoring Laboratory for our research. We would also like to thank Mr. Anand Rao for his timely help in carrying out this study.

Received: 28 October 2024.

Accepted: 25 March 2025.

Publisher's note: all claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article or claim that may be made by its manufacturer is not guaranteed or endorsed by the publisher.

©Copyright: the Author(s), 2025

Licensee PAGEPress, Italy

Advances in Oceanography and Limnology, 2025; 16:13309

DOI: 10.4081/aiol.2025.13309

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0).

Introduction

Nearshore waters or regions are defined as areas located closer to the landmass than the open ocean. These regions typically consist of shallow waters characterised by significant variations in water movements (including wave actions and tidal effects), temperature and chemical composition compared to deeper waters. Several environmental factors typically interact to affect the coastal ecosystems.

Nearshore regions are transitional zone between the coast and the open ocean contributing to its varying physicochemical properties (Munk *et al.*, 2003). Therefore, these zones often called as frontal zones have increased diversity owing to the amalgamation of several species living here (Acha *et al.*, 2004).

Zooplankton are pelagic organisms known as drifters that move with the ocean currents. It is divided into two groups based on their lifespan as planktons: holoplankton and meroplanktons. Holoplanktons spend their entire lifecycle as plankton are the most dominant in the surf zone (Menendez *et al.*, 2023). Majority of holoplankton are made up of copepods. They form an integral part of the aquatic food web assisting in nutrient cycling by serving as primary food source for some fishes (Vakati, 2024). Majority of sedentary benthic inverte-

brates have a planktonic larva that allows them to disperse their offspring (Becker *et al.*, 2007). Meroplankton is composed of these larvae and several other fish larval forms that spend part of their lifecycle as planktons. The planktonic phase also allows access to the prolific upper water column (Pechenik, 1999; Palumbi, 2003). As meeting with a suitable benthic habitat ultimately determines larval success, seasonal fluctuation in the hydrodynamics also interacts with the timing of larval discharge (Metaxas 2001; Ayata *et al.*, 2011).

The diversity and distribution of zooplankton are greatly influenced by environmental variables such as temperature, salinity, pH, dissolved oxygen and turbulence (Srichandan *et al.*, 2018). Temperature, salinity and food supply are known to influence spatial changes in zooplankton community (Lawrence *et al.*, 2004). These environmental factors affect the zooplankton breeding and hence its composition (Greenwood *et al.*, 2001). Therefore, studying zooplankton in relation to the environmental factors in the nearshore regions carries great importance due to the variability of these factors in these waters and their effect on ecosystem (Ramdani *et al.*, 2009).

Till date, most studies have focused on the offshore region or open ocean of Indian waters, beginning with Sewell's research in 1948. Notable studies include the Galathea expeditions and the International Indian Ocean Expedition (IIOE) in the Bay of Bengal during the 1950s. Additionally, qualitative, and quantitative studies of coastal waters were conducted by Raghuprasad and Jayaraman in 1954 and by Ganapathi and Rama Sharma in Visakhapatnam in 1958.

In hindsight, more diversity and distribution studies have been conducted in the Arabian Sea, with notable research by Madhupratap and Haridas (1990), Smith *et al.* (1998), Smith and Madhupratap (2005), Hitchcock *et al.* (2005), and Khandagale P. *et al.* (2022). This may be attributed to the high primary productivity in the Arabian Sea due to increased upwelling in coastal and oceanic regions.

In contrast, fewer studies have been conducted in the Bay of Bengal, with earlier research by Achuthankutty *et al.* (1980) and Ramaiah *et al.* (1996), and more recent studies by Rakesh *et al.* (2005) in both neritic and oceanic waters. Additional research has been carried out in the open oceanic waters of the Bay of Bengal by Abdullah Al M. *et al.* (2018) and Fernandes V. and Ramaiah (2009), and in coastal zones by Sahu G. *et al.* (2010) and M. Shanti *et al.* (2011).

Coastal areas and river outlets are characterised by abundant nutrient distribution, leading to high phytoplankton growth and primary productivity. Similarly, regions with prevalent upwelling exhibit high nutrient concentrations, making them more productive. Mostly high primary productivity regions are often associated with abundant and diverse marine life.

Given the fluctuating phenomenon of primary productivity and physico-chemical parameters occurring in the nearshore areas, this study aims to investigate how these factors impact zooplankton diversity and numerical abundance in the nearshore region of Visakhapatnam coast in the Bay of Bengal. Specifically, this research focuses on the major divisions of the zooplankton community, Holoplankton and Meroplankton diversity, numerical abundance and their relationship with primary productivity and abiotic factors.

Materials and Methods

Study site

The zooplankton sampling was conducted in the 3 study stations- Fishing Harbour (FSH), Rushikonda (RSK) and Mangmaripeta (MGP) from June 2022 to May 2023 (Figure 1). Rushikonda and Mangmaripeta are beaches with high aesthetic value with a coastal terrain lodging in many nutrients from the nearby hatcheries. While in Fishing Harbour is more of an area with trade and commercial perspective which can indirectly point to oil pollution and ballast water contamination showing an impact on the key research point of this study.

Sampling

The samples were collected with a plankton net having 150 μ mesh size by a horizontal net towing from the surface of the seawater. The depth at which the samples were collected was between 20-25 m during early morning hours. Then the physical factors surface seawater like temperature ($^{\circ}$ C), salinity (‰), pH and dissolved oxygen (mL^{-1}) were also measured. Sea surface temperature was measured using a thermometer, salinity with the help of a hand-held refractometer (Erma Hand Refractometer) and pH by using a portable pocket-size digital pH-meter. Dissolved oxygen was measured using the Winkler's method.

Primary productivity was measured using the light and dark bottle method and expressed as $\text{gCm}^{-2}\text{hr}^{-1}$. The zooplankton samples were collected by towing the net horizontally for 10 minutes at low velocity. The filtered sample was collected in a sample bottle out of which one part was used for diversity analysis and rest was used for biomass analysis. 10 ml of the sample was taken separately for sorting out and counting the holoplankton and meroplankton in Bogorov counting chamber under the microscopic (Stereo Zoom Microscope Model ZEISS- STEMI-2000C, Zeiss AxioPlan-2ie Imaging Manual Upright Microscope; Zeiss, Oberkochen, Germany) observation. The species were identified by referring to the taxonomic keys (Kasturirangan L.R. 1963; Al Yamani F.Y. *et al.* 2011; WoRMS website 2024).

Seasonal variation of all the above physicochemical and biological components were studied by classifying the components into three seasons- Monsoon (June, 2022, to September, 2022), post-monsoon (October, 2022, to January, 2023) and pre-monsoon (February, 2023, to May, 2023).

Statistical analysis

The species diversity indices like species richness (S), Margalef's diversity index (d), Pielou's evenness (J'), Shannon Weiner diversity index (H') and Simpson's index (H1-D) were employed. Multivariate analysis like Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) was performed to understand the correlation of physical parameters with the zooplankton. The diversity indices and multivariate analysis PCA and CCA were performed using PAST v.4 software package. Two-way PERMANOVA was performed on Bray-Curtis Similarity matrix to test the null hypothesis for significant differences in holoplankton and meroplankton abundance across sites and seasons. Two-way PERMANOVA was also conducted on Euclidean distance for environmental factors to test if the data is significantly different or not.

Holoplankton and meroplankton seasonal dynamics in Coastal Visakhapatnam

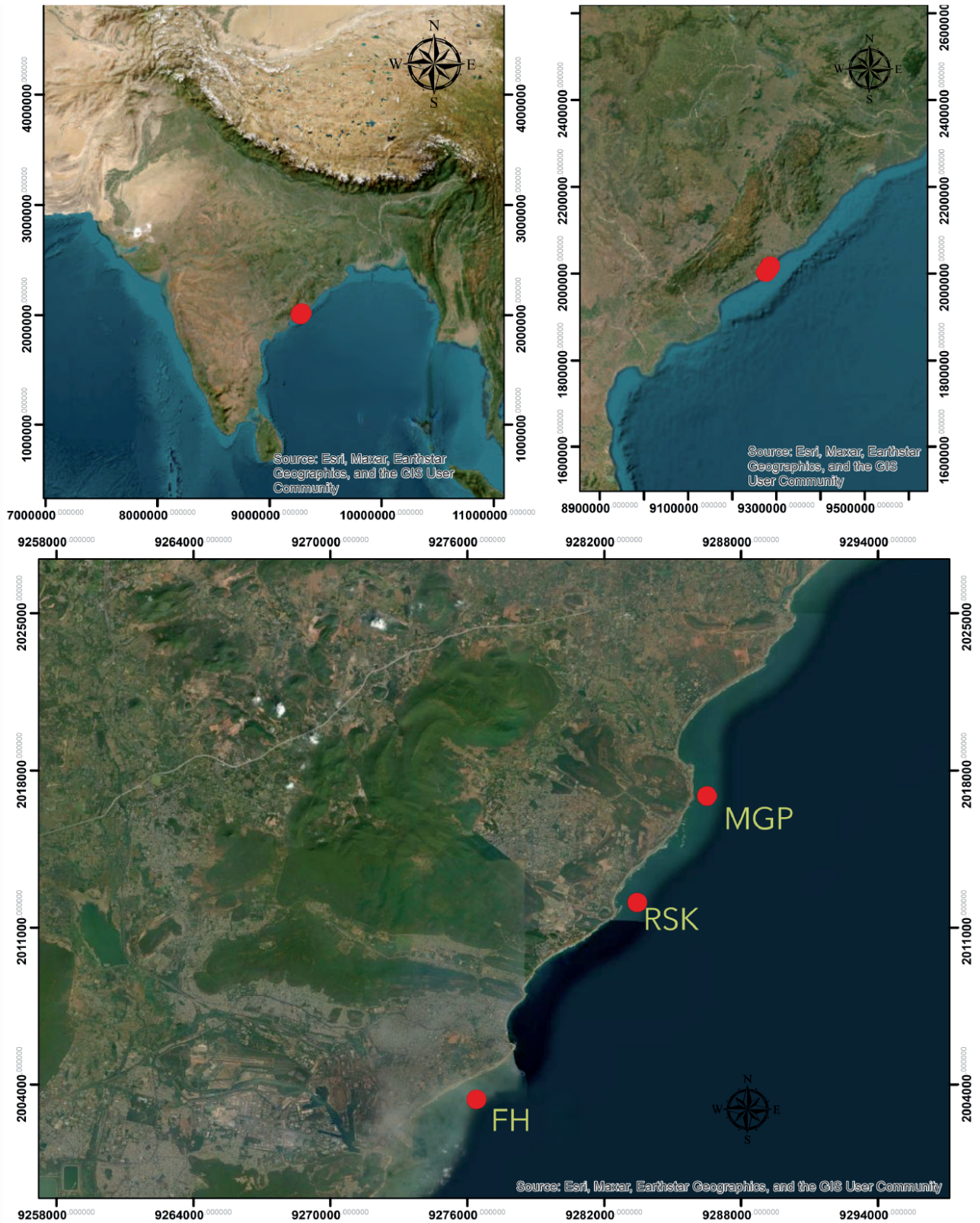


Figure 1. Study area showing the three stations of the Visakhapatnam coast. FH, Fishing Harbour; RSK, Rushikonda; MGP, Mangaripeta.

Cluster and non-metric multi-dimensional scaling (nMDS) analysis were used to investigate the community structure trends in the three sampling stations and seasons. The holoplankton and meroplankton abundance (ind m⁻³) were square root transformed for the analysis. The PERMANOVA, cluster and n-MDS analysis was performed using PRIMER v.6 software.

Results

Physicochemical factors

The study period of one year from June 2022 to May 2023 recorded a mean surface water temperature of 26.79±1.52°C. The surface water temperature ranged between 24°C in the month of November and December, 2022 (post-monsoon) and 30°C during the month of June, 2022 (monsoon). The studied data showed the lowest temperature at station Mangamaripeta (MGP) in the month of November and the highest temperature was recorded from two stations Mangamaripeta (MGP) and Rushikonda (RSK) in the month of December. The mean salinity recorded was 34.67±1.05‰. The salinity recorded for the year ranged between 27‰ in August, 2022 (monsoon) from the stations RSK and MGP and 40‰ in the month of February, 2023 (pre-monsoon) from the station Fishing Harbour (FH). The mean pH recorded was 7.68±2.77. The pH ranged from 7.3 in the month of August, 2022 (monsoon) to 7.9 both in the months of December, 2022 (post-monsoon) and April, 2023 (pre-monsoon). The minimum pH recorded was from FH and the maximum pH recorded was from MGP in the month of December, 2022 and FH and RSK during April, 2023. The mean dissolved oxygen recorded was 6.23±0.7mL⁻¹. The dissolved oxygen ranged from 3.37mL⁻¹ in the month of September, 2022 (monsoon) to 11.42mL⁻¹ in the month of June, 2022 (monsoon). The minimum dissolved oxygen was recorded from FH and maximum was from RSK. The seasonal variation in the physical factors is shown in *Supplementary Figure 1*.

Primary productivity

The primary productivity rate was measured and expressed as gCm⁻²hr⁻¹ (*Supplementary Figure 2*). The mean net primary productivity rate observed was 0.0467±0.332 gCm⁻²hr⁻¹. The minimum net primary productivity recorded from station Fishing harbour was 0.0013 gCm⁻²hr⁻¹ in the month of July, 2022 (monsoon). Maximum net primary productivity recorded was 0.4142 gCm⁻²hr⁻¹ from Rushikonda in the month of April, 2023 (pre-monsoon).

Principal Component Analysis

PCA was carried out to understand the variance and correlation of the physical factors as shown in *Supplementary Figure 3*. PC-1 showed 94% variance with eigen value 0.0826 and PC-2 showed 5% variance with eigen value 0.048. Estimated salinity (0.018), pH (0.008) and dissolved oxygen (0.132) showed positive correlation. The temperature (0.027) and primary productivity showed negative correlation.

Total zooplankton

After a study period of one year a total of 117 taxa were identified during the study covering 44 families belonging to 18 major groups of zooplankton. Copepods were the most abundant groups contributing about 80% to the zooplankton population followed by chaetognaths comprising 4.69%. The other major groups observed were Decapod larvae (3.79%), Sergestid species like *Lucifer hansenii* (3.57%) and Cladocerans (3.35%) (as shown in *Supplementary Figure 4*).

The Holoplankton community

The holoplanktons accounted for 94% of the total zooplankton. From the total holoplankton, majority group belonged to copepods in which 46.23% were calanoid copepods, 35.05% were cyclopoid copepods and rest 4.48% were harpacticoid copepods. The non-copepods accounted for 14.23% of the holoplankton community.

Family wise, the major dominating family in calanoid copepods were Paracalanidae, then Calanidae and Eucalanidae. While Oithonidae followed by Corycaeidae were dominant in cyclopoid copepods. But the species of *Oithona brevicornis* dominated the entire zooplankton community. Euterpinidae was the most dominant family in harpacticoid copepods. In non-copepods the dominant family belonged to Sagittidae of chaetognath, Podonidae in Cladocera, *etc.*

Seasonal variation in species diversity

The number of species ranged from 4 to 59. Highest number of species (59) was recorded from RSK during the pre-monsoon season and lowest (4) was recorded from the FH station during the post-monsoon.

More diversity ($d=12.32$, $H'=3.702$) was obtained during the pre-monsoon season from the FH station. While less diversity ($d=1.802$, $H'=1.075$) was seen during the post-monsoon season from the FH station. Evenness was maximum ($J'=1.015$) during the post-monsoon season from the RSK station, minimum ($J'=0.296$) during the pre-monsoon season at the MGP station. The Simpson's index(1-D) ranged from 0.562 to 0.959 (*Supplementary Figure 5*).

Meroplankton community

The meroplankton community accounted for only 6% of the total zooplankton. The decapod larvae were the dominant group accounting for 62.38% of the total meroplanktons. The next major group was Leptomedusae (12.26%), molluscan larvae (11.89%), Cirripedia larvae (6.09%), Fish larvae (3.77%), Phyllosoma larvae (2.45%) and Octopus larvae (0.42%).

The decapod larvae constituted of Anomura and Brachyura crab Zoea and crab Megalopa larvae. Various specimens of shrimp larvae in different stages like nauplius, zoea and mysid stages were found. The shrimp larvae mainly belonged to the two families of Penaeidae and Palaemonidae family. Molluscan veligers comprised mainly of bivalve and gastropod veligers and pteropods which included a family of Scaphopod gastropod veliger. Polychaete larvae, phyllosoma larvae, *Obelia* sps. along with other leptomedusae, *Diphyes* sp. And octopus' larvae made up the rest of the meroplankton community.

The meroplankton diversity (d) ranged between 0 and 18.76 during the monsoon in FH and pre-monsoon in FH respectively. Evenness (J') was minimum ($J'=0.355$) in pre-monsoon at RSK and maximum in pre-monsoon at FH. Simpson's index ($1-D$) ranged between 0 and 1.039.

Canonical Correspondence Analysis

The CCA was performed for 3 different plots- one for dominant copepods belonging to each family, second is for dominant species for various other families and order of non-copepods groups and third one for meroplankton groups.

In the first plot axis-1 (*Supplementary Figure 6A*) showed 52.86% variability and axis-2 with 20.6% variability. The holoplankton copepod species *Centropages bradyi* (5.27), *Sapphirina sp.* (3.65), *Tortanus gracilis* (3.59), *Nannocalanus sp.* (2.58) and *Clausocalanus sp.* (0.56) showed strong positive correlation with physical factors like salinity, pH, dissolved oxygen and primary productivity in the stations of RSK and FH during the pre-monsoon and RSK station during the monsoon season.

Axis-1 showed 54.14% variability while axis-2 showed 32.59% variability in the second plot of CCA (*Supplementary Figure 6B*). The holoplankton non-copepod species like *Pseudevadne tergestina* (1.69), *Brachionus sp.* (1.43) and ostracod (1.58) showed strong positive correlation with salinity, pH and dissolved oxygen in the pre-monsoon season in all 3 stations of FH, RSK and MGP. Other non-copepod species like *Tintinnopsis gracilis* (0.47), *Favella sp.* (0.39), *Oikopleura* (0.10) and *Moina sp.* (0.09) also showed positive correlation with salinity, pH and dissolved oxygen in pre-monsoon season in all 3 stations as mentioned above. Unlike copepod species the primary productivity showed negative correlation with non-copepod species.

In the third CCA plot (*Supplementary Figure 7*), axis-1 showed 70.2% variability while 19.36% variability was shown in axis-2. Temperature showed strong positive correlation with meroplankton groups such as Cnidarians (2.20), Podocopida larvae (1.57), molluscan larvae (1.49) and Ichthyoplankton (1.29) during the monsoon season in the stations of RSK and MGP and pre-monsoon season in FH station.

PERMANOVA analysis

The PERMANOVA analysis conducted for holoplankton abundance in between seasons and sampling sites showed significant variation across seasons (Pseudo F- 1.75 and p-value=0.012). But it did not show significant variation between sampling sites (Pseudo F=1.75 and p-value=0.062) (Table 1).

PERMANOVA results for meroplankton showed significant variation in between seasons (Pseudo F value=2.23 and p-value=0.04) than for sampling sites (Pseudo F=2.23 and p-value=0.87) (Table 1).

PERMANOVA results for physicochemical factors indicated significant variation across seasons (Pseudo F value=10.87 and p-value=0.007). But there were no significant variations in between sampling sites (Pseudo F value=2.32 and p-value=0.09).

The cluster analysis and n-MDS was plotted to determine the resemblance in abundance in between sampling stations and seasons. There was greater resemblance between stations in the monsoon and post-monsoon season. But the RSK station exhibited least resemblance with other stations during the pre-monsoon (*Supplementary Figure 8*).

The meroplankton exhibited more resemblance between sites during monsoon season. During post-monsoon and pre-monsoon, FH and MGP stations were more closely related, with the exception of RSK, which was too different (*Supplementary Figure 9*).

Table 1. Results of permutational multivariate analysis of variance (PERMANOVA) for meroplankton and holoplankton assemblages both main and Pair-wise tests.

Meroplankton				
Source	df	Pseudo-F	P(perm)	P (MC)
SE	2	22.282	0.039	0.083
SI	2	0.57266	0.874	0.780
Res	4			
Pair-wise tests				
Groups	t	P (perm)	P (MC)	
M, PM	16.124	0.193	0.187	
M, PR	16.345	0.177	0.168	
PM, PR	12.456	0.286	0.311	
Holoplankton				
Source	df	Pseudo-F	P (perm)	P (MC)
SE	2	34.735	0.012	0.020
SI	2	17.556	0.062	0.154
Res	4			
Pair-wise tests				
Groups	t	P (perm)		
M, PM	19.641	0.097		
M, PR	20.902	0.094		
PM, PR	15.300	0.187		

SE, Seasonal Effect; SI, Site Effect; M, Monsoon; PM, Post-Monsoon; PR, Pre-Monsoon.

Discussion

According to the results obtained in PCA, salinity, pH and dissolved oxygen emerged as the significant physicochemical factors that influenced the holoplankton and meroplankton diversity and abundance in the monsoon, post-monsoon and pre-monsoon season. Many environmental studies have employed PCA which is regarded as a useful resource for understanding the natural environment (Aruga *et al.*, 1993; Wenning and Erickson, 1994).

From the *Supplementary Figure 5*, it is clear that the holoplankton diversity (S, d, H') was high during the pre-monsoon, reduces in the monsoon and becomes least during the post-monsoon (Santhanam & Perumal 2003; Perumal *et al.*, 2008). Evenness was highest during the post-monsoon indicating less diversity when the opposite occurs during the pre-monsoon season. The Simpson's index (1-D) indicates that the holoplankton community is dominated by one or a few species. The study of diversity indices can be helpful to understand the ecosystem health (Ismael and Dorgham, 2003; Cardoso *et al.*, 2012).

In the holoplankton, cyclopid copepods (Stephen 1988; Fernandes & Ramaiah 2019) especially *Oithona brevicornis* and *Oithona simplex* emerged out as highest contributing species in terms of abundance. The reason for *Oithona brevicornis* (Giesbrecht, 1892) to be so abundant in nearshore region as it is a euryhaline copepod (Deevey, 1948) and most commonly found in shallow waters of tropical and temperate areas of Pacific, Indian and Atlantic Ocean (Shuvalov, 1980; Razouls *et al.*, 2005-2015). Salinity has been widely recognized as the primary factor determining the spatial and temporal distribution of zooplankton (Goswami, 1982; Woolridge, 1999; Dalal and Goswami, 2001; Megalhaes *et al.*, 2006).

Same is reflected in the meroplankton community. According to the study conducted by Brandao C.M. *et al.*, (2020) the numerical abundance of meroplanktons were quite high irrespective of the hydrological conditions. But the meroplanktons in this research are found to be much less abundant in population. This may be because of pollution caused by tourism, trading and transportation occurring along the coast. Although they are more diverse during the pre-monsoon season followed by monsoon and decreases in the post-monsoon season. Here also the Simpson's index indicates that the meroplankton community is dominated by one or few species.

Previously the studies conducted by Sahu G. & Satpathy K. (2010) showed good correlation of density of zooplankton with salinity. The CCA analysis showed that in the holoplankton community, both copepod and non-copepod species (density or numerical abundance) were strongly correlated with salinity, pH and dissolved oxygen mostly during the pre-monsoon and monsoon season when it was high in almost all three stations (*Supplementary Figure 6*). But only copepod species were affected by primary productivity in the pre-monsoon season when primary productivity was high. However, in case of meroplankton community, showed strong positive correlation with temperature when it was high during the monsoon and pre-monsoon season (*Supplementary Figure 7*).

From the PERMANOVA analysis it was observed that both the holoplankton and meroplankton variation was signif-

icant across seasons, but between stations was not significant. This same variation was seen in environmental factors as well. This phenomenon can occur because most zooplankton vary seasonally in abundance due to their life-history strategies and environmental preferences (Klais *et al.*, 2016). The clustering analysis and the n-MDS plot showed that the abundance between the sampling stations were evenly distributed (*Supplementary Figure 8 and 9*). This indicates that the oceanographic features are localized between the stations (Lee *et al.*, 2005).

Conclusions

As the salinity, dissolved oxygen and pH increased from monsoon to pre-monsoon, the diversity and density of holoplankton increased while meroplankton were affected more by temperature variation. As for primary productivity, except for copepods, it did not affect the non-copepod and meroplankton groups showing negative correlation with them.

In conclusion, it can be said that physical factors- salinity, pH and dissolved oxygen played a significant role in regulating the holoplankton abundance and diversity; and temperature in case of meroplanktons. Hence the diversity and abundance of holoplankton and meroplankton increased from monsoon to pre-monsoon season in the nearshore region of coastal Visakhapatnam, east coast of India. Seasonal variation in holoplankton and meroplankton abundance and diversity of the Visakhapatnam coast were more pronounced in seasonal variation than spatial variation because of its geographic location and influence of hydrological parameters. Therefore, more studies should be conducted here to further understand this phenomenon.

References

- Abdullah Al M, Akhtar A, Kamal AHM, et al., 2017. Seasonal pattern of zooplankton community and their environmental response in subtropical maritime channel systems in the Bay of Bengal, Bangladesh. *Acta Ecologica Sinica*. 38:316-24.
- Acha EM, Mianzan HW, Guerrero RA, et al., 2004. Marine fronts at the continental shelves of 550 austral South America physical and ecological processes. *Journal of Marine Systems*. 44:83-105.
- Achunthakutty CT, Madhupratap M, Nair SRS, Rao TSS, 1980. Zooplankton biomass and composition in the western Bay of Bengal during the late SW Monsoon. *Indian Journal of Marine Science*. 9:201-6.
- Al- Yamani FY, Skryabin V, Gubanov A, et al., 2011. *Marine Zooplankton Practical Guide*. Kuwait Institute for Scientific Research; Kuwait City, Kuwait.
- Aruga R, Negro G, Ostacoli G, 1993. Multivariate data analysis applied to the investigation of river pollution. *Fresenius' Journal of Analytical Chemistry*. 346:968-75.
- Becker BJ, Levin LA, Fodrie FJ, McMillan PA, 2007. Complex larval connectivity patterns among marine invertebrate populations. *Proc Natl Acad Sci USA*. 104: 3267-72

- Brandão MC, Garcia CAE, Freire AS, 2020. Meroplankton community across oceanographic fronts along the South Brazil shelf. *Journal of Marine Systems*. 208:103361.
- Cardoso SJ, Roland F, Loverde-Oliveira SM, De Moraes Huszar VL, 2012. Phytoplankton abundance, biomass and diversity within and between Pantanal wetland habitats. *Limnologia*. 42:235-41.
- Dalal SG, Goswami SC, 2001. Temporal and ephemeral variations in copepod community in the estuaries of Mandovi and Zuari—west coast of India. *Journal of Plankton Research*. 23:19-26.
- Deevey GB, 1948. The zooplankton of Tisbury Great Pond. *Bulletin of Bingham Oceanographic Collection*. New Haven. 12:1-44.
- Dias CO, Teixeira Bonecker AC, Salustiano de Castro M, et al., 2021. Holoplankton and meroplankton of the three western Atlantic Sedimentary Basins. *Marine Biology Research*. 16:695-713.
- Dipper F, 2022. *Elements of Marine Ecology*. Fifth edition. Butterworth-Heinemann; Oxford, UK,
- Fernandes V, Ramaiah N, 2009. Mesozooplankton community in the Bay of Bengal (India): Spatial variability during the summer monsoon. *Aquatic Ecology*. 43:951-3.
- Fernandes V, Ramaiah N, 2019. Spatial structuring of zooplankton community through partitioning of habitat and resources in the Bay of Bengal during the spring intermonsoon. *Turk Journal of Zoology*. 43:68-93.
- Ganapati PN, Ramasarma DV, 1958. Hydrography in relation to the production of plankton off Waltair coast. *Andhra University Memoir of Oceanography*. 2:168-92.
- Goswami SC, 1982. Distribution and biodiversity of copepods in the Mandovi–Zuari estuarine system. *Indian Journal of Marine Science*. 11:292-5.
- Greenwood A, O’Riordan RM, Barnes DKA, 2001. Seasonality and vertical zonation of zooplankton in a semi-enclosed sea lough. *Journal of the Marine Biological Association of the UK*. 81:213-20.
- Hitchcock GL, Lane P, Smith S, et al., 2002. Zooplankton distributions in coastal waters of the northern Arabian Sea, August, 1995. *Deep Sea Res. Part-II Top. Stud. Oceanography*. 49:2403-23.
- Ismael AA, Dorgham MM, 2003. Ecological indices as a tool for assessing pollution in El-Dekhaila Harbour (Alexandria, Egypt). *Oceanologia*. 45:121-31.
- Kasturirangan LR, (1963). A key to the Identification of the more common Planktonic Copepoda of Indian Coastal waters. Available from: https://cmarz.whoi.edu/resources/copepods/Key_Plankton_Copepoda_Indian_Coast_Waters_1963_Kasturirangan.pdf
- Khandagale PA, Mhatre VD, Thomas S, 2022. Seasonal and spatial variability of zooplankton diversity in North Eastern Arabian Sea along the Maharashtra Coast. *Journal of Marine Biological Association of India*. 64:2293-304.
- Lawrence D, Valiela I, Tomasky G, 2004. Estuarine calanoid copepod abundance in relation to season, salinity, and land-derived nitrogen loading, Waquoit Bay, MA. *Estuar Coast Shelf Sci*. 61:547-57.
- Magalhaes A, da Costa RM, Liang T-H, et al., 2006. Spatial and temporal distribution in density and biomass Pseudodiaptomus species (Copepoda: Calanoida) in the Caete’ River estuary (Amazon north of Brazil). *Brazilian Journal of Biology*. 66:421-30.
- Munk P, Hansen, BW, Nielsen TG, Thomsen HA, 2003. Changes in plankton and communities across 730 hydrographic fronts off West Greenland. *Journal of Plankton Research*. 25: 815-30.
- Lee O, Nash RDM, Danilowicz BS, 2005. Small-scale spatio-temporal variability in Ichthyoplankton and Zooplankton Distribution in relation to a tidal mixing front in the Irish Sea. *ICES Journal of Marine Science*. 62:1021-30.
- Palumbi SR, 2003. Population genetics, demographic connectivity, and the design of marine reserves. *Ecol Appl*. 13:146-58.
- Pechenik JA, 1999. On the advantages and disadvantages of larval stages in benthic marine invertebrate life cycles. *Mar Ecol Prog Ser*. 177:269-97.
- Perumal NV, Rajkumar M, Perumal P, Rajasekhar KT, 2009. *Journal of Environmental Biology*. 30:1035-46.
- Raghuprasad R, Jayaram R, 1954. Preliminary studies on certain changes in the Plankton and hydrobiological conditions associated with the swarming of Notiluca. *Proceedings of Indian Academy of Science*. 40:49-57.
- Rakesh M, Raman AV, Sudarshan D, 2006. Discriminating zooplankton assemblages in Neritic and Oceanic waters: A case for the northeast coast of India, Bay of Bengal. *Marine Environmental Research*. 61:93-109.
- Ramaiah N, Chatterji A, Madhuratap N, 1996. A study on the zooplankton of the Budhabalanga Estuary, Orissa Coast. *Proceedings of Indian National Science Academy*. 62:1-4.
- Razouls C, de Bovée F, Kouwenberg J, Desreumaux N, 2005-2015. Diversity and Geographic Distribution of Marine Planktonic Copepods. Available from: <http://copepodes.obs.banyuls.fr/en>
- Klais R, Lehtiniemi M, Rubene G, et al., 2016. Spatial and Temporal Variability of Zooplankton in a temperate semi-enclosed sea: Implications for monitoring design and long-term studies. *Journal of Plankton Research*. 38:652-61.
- Sahu G, Mohanty AK, et al., 2010. Zooplankton diversity in the nearshore waters of Bay of Bengal, off the Rushikulya Estuary. *The IUP Journal of Environmental Sciences*. 4:61-85.
- Santhanam P, Perumal P, 2003. Diversity of zooplankton in the Parangipettai coastal waters, southeast coast of India. *Journal of Marine Biological Association of India*. 45:144-51.
- Shuvalov VS, 1980. Cyclopoid Copepods of Oithonidae family of the World Ocean. *Nauka, Leningrad*. 1-197.
- Smith SL, Madhuratap M, 2005. Mesozooplankton of the Arabian Sea: Patterns influenced by seasons, upwelling and oxygen concentration *Progresses in Oceanography*. 65: 214-39.
- Srichandan S, Balliarsingh SK, Prakash S, 2018. Zooplankton Research in Indian Seas: A Review. *Journal of Ocean University of China*. 17:1149-58.
- Stephen R, 1988. Oncaidae (Copepoda: Poecilostomatoida) in the Indian Ocean with comments on the species of Lubbockia and Conaea. *Mahasagar*. 21:35-43.
- Vakati V, 2024. Copepod in Focus: Synthesis and Trends Overview, *International Journal of Zoological Sciences*. 4:18-22.

Wenning RJ, Erickson GA, 1994. Interpretation and analysis of complex environmental data using chemometric method. *Trends in Analytical Chemistry*. 13:446-57.

Wooldridge TH, 1999. Estuarine zooplankton community structure and dynamics. In: Allanson BR, Baird D. (eds.), *Estuaries*

of South Africa. Cambridge University Press; Cambridge, United Kingdom. p. 141-66.

World Register of Marine Species (WoRMS) Editorial Board, 2024. World Register of Marine Species. Available from: <https://www.marinespecies.org>

Online supplementary material:

Supplementary Figure 1. Graphical representation of seasonal variation in physical factors: temperature, salinity, pH and dissolved oxygen.

Supplementary Figure 2. Graphical representation of seasonal variation in primary productivity. F, Fishing Harbour; R, Rushikonda; M, Mangmaripeta; M, Monsoon season; PM, Post-Monsoon; PR, Pre-Monsoon.

Supplementary Figure 3. Principal Component Analysis (PCA) graph representing a summary of physical factors. T, Temperature; S, Salinity; DO, Dissolved Oxygen; PP, Primary Productivity in three seasons (M, Monsoon season; PM, Post-Monsoon; PR, Pre-Monsoon) and three stations (F, Fishing Harbour; R, Rushikonda; M, Mangmaripeta).

Supplementary Figure 4. Pie chart representing the percentage of major groups of zooplankton.

Supplementary Figure 5. Graphical representation of diversity indices (S, Number of species; H', Shannon Weiner index; J', evenness) in three seasons (M, Monsoon season; PM, Post-Monsoon; PR, Pre-Monsoon) and three stations (F, Fishing Harbour; R, Rushikonda; M, Mangmaripeta).

Supplementary Figure 6. Canonical Correspondence analysis of Holoplankton groups with environmental factors. A) Dominant species from all family of copepods. Parvc- Parvocalanus crassirostris, Para- Paracalanus sp., Nanc- Nannocalanus sp., Sube- Subeucalanus crassirostris, Eucls- Eucalanus subcrassus, Euag- Euaugaptilus sp., Claus- Clausocalanus sp., Euch- Euchaeta marina, Luci- Lucicutia sp., Metr- Metridia sp., Labi- Labidocera acuta, Acard- Acartia danae, Canb- Candacia bradyi, Centb- Centropages bradyi, Pseum- Pseudodiaptomus marina, Temot- Temora turbinata, Tortg- Tortanus gracilis, Oithb- Oithona brevicornis, Oiths- Oithona simplex, Oncac- Oncaea clevei, Corya- Corycaeus agilis, Sapp- Sapphirina sp., Eutr- Euterpina, Micrs- Microsetella sp., Clytm- Clytemnestra sp. B) Dominant species of other non-copepod families. Parsg- Parasagitta sp., Kroht- Krohnitta sp., Penl- Penilia sp., Psudt- Pseudevadne tergestina, Moi- Moina sp., Oiko- Oikopleura sp., Amph- Amphipoda, Ostr- Ostracoda, Pleubrobrachia, Tingr- Tintinnopsis gracilis, Favl- Favella sp., Brach- Brachionus sp., Lucih- Lucifer hanseni, Form- Foraminifera, Salp- Salpidae in three seasons (M, Monsoon season; PM, Post-Monsoon; PR, Pre-Monsoon) and three stations (F, Fishing Harbour; R, Rushikonda; M, Mangmaripeta).

Supplementary Figure 7. Canonical Correspondence Analysis (CCA) of Meroplankton groups with environmental factors. Deca, Decapod larvae; Molsc, Molluscan larvae; Ichthy, Ichthyoplankton; Podoc, Podocopidae (Barnacle) Larvae; Polyc, Polychaete larvae; Cnidr, Cnidarians; Bryoz, Byzoan larvae in three seasons (M, Monsoon season; PM, Post-Monsoon; PR, Pre-Monsoon) and three stations (F, Fishing Harbour; R, Rushikonda; M, Mangmaripeta).

Supplementary Figure 8. n-MDS Plot showing distribution of Holoplankton abundance in stations. FH, Fishing Harbour; RSK, Rushikonda; MGP, Mangmaripeta and across seasons (M, Monsoon season; PM, Post-Monsoon; PR, Pre-Monsoon) on Bray-Curtis similarity index.

Supplementary Figure 9. n-MDS Plot showing distribution of Meroplankton abundance in stations. FH, Fishing Harbour; RSK, Rushikonda; MGP, Mangmaripeta and across seasons (M, Monsoon season; PM, Post-Monsoon; PR- Pre-Monsoon) on Bray-Curtis similarity index.