



A study on microzooplankton community from the coastal waters of eastern Arabian Sea: emphasis on the dominance of heterotrophic dinoflagellates

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Abstract We studied the community composition of microzooplankton (MZP) from the surface waters off Candolim, Goa. The MZP communities were examined for the year 2013, covering different seasons and four stations (Near-shore: G3 & G4, offshore: G5 & G6). A total of 30 species belonging to 24 genera were recorded, which include loricate ciliates (LC: 14 species of 13 genera), aloricate ciliates (ALC: 5 species of 3 genera), heterotrophic dinoflagellates (HDS: 11 species of 8 genera), and copepod nauplii. The MZP abundance in the coastal waters varied spatially irrespective of different seasons, with higher abundance in the offshore stations (G5 & G6, 38–127 cells L⁻¹) and lower abundance in the near-shore stations (G3 & G4, 20–97 cells L⁻¹). The MZP community composition showed the dominance of HDS (16–85%) in the near-shore stations during most of the seasons and inferiority during NEM (16–18%). Moreover, all the coastal waters (near and offshore)

were dominated by HDS (58–85%) during spring inter-monsoon. The dominant species of HDS were *Dinophysis apicata*, *Dinophysis caudata*, *Prorocentrum micans*, *Protoperidinium breve*, *Protoperidinium latistriatum*, and *Protoperidinium granii*. The statistical analysis (Canonical correspondence analysis and Spearman's rank correlation) depicts that the MZP abundance and community composition were mainly controlled by salinity ($r = 0.4–0.7$). Whereas the dominance of HDS in the coastal waters could be the reason for its mixotrophic nature and diverse feeding mechanism. Thus, a strong positive correlation between the HDS and LC ($r = 0.73–0.92$) showed the feeding ability of HDS in their relative community.

Keywords Upwelling · Stratification · Seasonal hypoxia · Salinity · Near-shore · Foodweb

Introduction

The Arabian Sea experiences major intra-annual variability compared to other ocean basins, which is influenced by the reversal of atmospheric and ocean circulation (Kumar et al., 2000). The biological productivity of the eastern Arabian Sea (EAS) is dependent on the complex of physicochemical (coastal upwelling, seasonal hypoxia, intrusion of low saline waters) and biological processes during different seasons (Narvekar et al., 2021; Pillai et al., 2000). During the southwest monsoon (SWM),

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coastal upwelling induces a high biological production in the EAS through nutrient-rich waters. Moreover, moderate-high biological productivity continues during the northeast monsoon (NEM) due to the surface cooling effect or wind-driven ocean circulation (Banse & English, 1993; Madhupratap et al., 1996). The phytoplankton communities in the EAS are highly diverse due to a wide range of environmental conditions, and diatoms are the most dominant group during nutrient-rich SWM. Nonetheless, phytoplankton blooms occur during both SWM and NEM (Ahmed et al., 2016; Kumar et al., 2000; Simonsen, 1974). Zooplankton biomass in estuarine and coastal waters is significantly comprised of microzooplankton (MZP), and they are more effective grazers of phytoplankton than the mesozooplankton (Armengol et al., 2019; Pierce & Turner, 1992; Sherr & Sherr, 1994). Gauns et al. (2015) reported that the MZP in the coastal waters (estuarine) of the EAS is a vital grazer of phytoplankton, and their grazing rates on phytoplankton standing stock and daily primary production vary between 30–80% and 58–97%, respectively. In general, the abundance and biomass of MZP are dominated by ciliates; however, heterotrophic dinoflagellates (HDS) often take over 50% of MZP biomass and abundance during diatom bloom and survive in non-bloom conditions (Jyothibabu, Devi, et al., 2008; Lissaed, 1991; Sherr & Sherr, 2007). The HDS are non-photosynthetic and feed a wide range of prey from bacteria to larger diatoms by phagotrophic nutrition. Thus, they play an important role in energy transfer in marine ecosystems' classical and microbial food webs (Beers et al., 1971; Hansen, 1992; Lessard & Swift, 1985). Seasonally, the dominance of HDS in the MZP community from the oceanic region of the northern Indian Ocean (the Andaman Sea, Bay of Bengal and the Arabian Sea) and few studies from estuarine and coastal waters of EAS were reported during spring inter-monsoon (SIM) and SWM (Jyothibabu et al., 2003; Devi et al., 2010; Elangovan & Gauns, 2021).

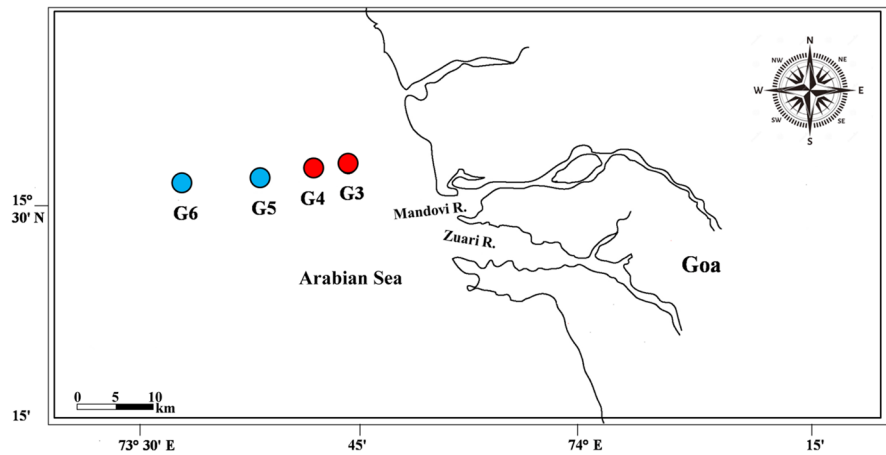
The MZP are very sensitive to environmental factors and their response to hydrographical changes has remained challenging and can cause cascading effects in marine food webs (Caron & Hutchins, 2013; Lopez-abbate, 2021). For example, the community composition of MZP is significantly influenced by environmental variables such as low saline conditions (Al-Yamani et al., 2019;

Jyothibabu et al., 2006). Likewise, temperature also has significant effects on MZP community composition, abundance, grazing, and growth efficiency (Caron & Hutchins, 2013). The MZP community composition in the estuarine systems of the Goa coast also varied due to the distinct hydrographical conditions; the HDS dominated in the Zuari (Saline) and Loricata ciliates (LC) in the Mondovi (less saline) estuarine systems (Elangovan & Gauns, 2021). Nonetheless, studies on the correlation between environmental variables and MZP community composition in Indian waters are fragmentary (Elangovan & Padmavati, 2017). The aim of the present study is to understand the response of MZP community to the complex physicochemical and biological process occurring in the coast of off Goa.

Materials and methods

The community composition of microzooplankton was studied from the coastal waters off Candolim, Goa, covering four seasons of the year 2013. The seasons are namely Spring-inter monsoon (SIM: March), late Southwest monsoon (SWM: September), Fall-inter-monsoon (FIM: October), and Northeast monsoon (NEM: November and December). The stations sampled cover two distinct regions viz., near-shore (G3: 15°31'N, 73°43'E & G4: 15°30'N, 73°42'E) and offshore (G5: 15°30'N, 73°38'E & G6: 15°29'N, 73°34'E, Fig. 1). The environmental variables such as surface water temperature, salinity, and dissolved oxygen were recorded by using a portable CTD Profiler (SBE19plus V2 SeaCAT). The phytoplankton biomass (chlorophyll *a*) was estimated by following the 90% acetone extraction method and analyzed in a fluorometer (JGOFS, 1994). One liter of surface water samples were collected for MZP taxonomic composition study and preserved with 1% acid Lugol's solution (JGOFS, 1994). The preserved samples were kept on standby for 24–48 h in the laboratory for settlement and concentrated up to 10 ml by removing the supernatant carefully through a plankton mesh with a pore size of 20 µm. One milliliter from the concentrated samples were taken in a Sedgwick-Rafter counting slide and analyzed under an inverted microscope (at 400×).

Fig. 1 Sampling stations at Candolim (CaTS) coastal waters, Goa (Near-shore: G3, G4, and offshore: G5, G6). The R. indicates rivers (Manovi and Zuari)



Statistical analysis

The MZP species diversity in different study stations was studied using (The Shannon-Weiner diversity indices) Primer 6-I statistical package. Besides, the statistical multivariate canonical correspondence analysis (CCA) and Spearman rank correlation were performed to understand the relationship between MZP species assemblages and environmental variables in different sampling stations. This multivariate and correlation analysis were carried out by using statistical software Past - UiO (Ver. 2.17) and Microsoft Office Excel 97-2003 Worksheet, respectively.

Results

Hydrography

During the study, the surface water temperature ranged between 27.2 and 29.4 °C. Salinity ranged from 23.3 to 35.2 psu, the maximum salinity was recorded at Stn. G3 (35.2 psu) during SIM. The dissolved oxygen (DO) concentration ranged between 3.6 and 5.3 ml L⁻¹, the low concentration of DO (3.6 L⁻¹) was recorded at Stn. G5 during NEM. The Chlorophyll *a* concentration ranged from 0.4 to 11.8 µg L⁻¹, the maximum Chlorophyll *a* concentration was recorded at Stn. G4 during SWM (Supplementary table 1).

Microzooplankton diversity and abundance

In this study, a total of 30 species of MZP belonging to 24 genera were recorded. The near-shore waters recorded with 21 genera and 25 species, the dominant group was loricate ciliates (LC: 13 genera and 14 species) followed by heterotrophic dinoflagellates (HDS: 6 genera and 9 species) and aloricate ciliates (ALC: 2 genera and 2 species). Whereas the offshore waters were recorded with 20 genera and 25 species, the dominant group was HDS (8 genera and 11 species) followed by LC (9 genera and 9 species) and ALC (3 genera and 5 species). These results showed that the MZP diversity is distinct from near and offshore waters. Thus, the MZP community in the near-shore waters was diverse by LC and the offshore waters were diverse by HDS (Table 1). The MZP abundance ranged from 20 to 127 cells L⁻¹. Seasonally, the abundance of MZP in the near-shore waters was higher during the late SWM and FIM (57–88 cells L⁻¹). Whereas, the offshore waters were higher during late SWM (September) and NEM (98–127 cells L⁻¹). Overall, higher abundance was recorded in the offshore stations (G5 & G6, 38–127 cells L⁻¹) than in the near-shore stations (G3 & G4, 20–97 cells L⁻¹, Fig. 2).

Species composition

During the study, the MZP community composition comprised four major groups. The groups are LC, ALC, HDS, and copepod nauplii. The community

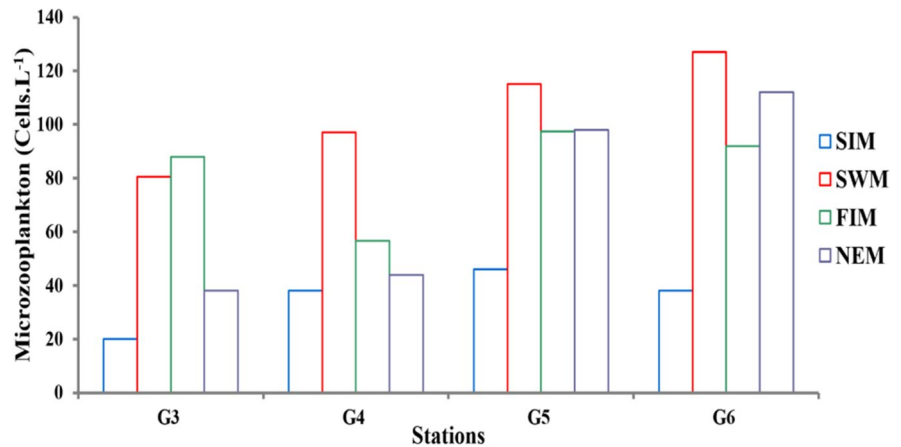
Table 1 List of microzooplankton species from near-shore and offshore waters of off Candolim, Goa

Microzooplankton (Cells.L ⁻¹)	Near-shore		Offshore	
	G3	G4	G5	G6
Tintinnids				
<i>Amphorella acuta</i>	1 (+)	1 (+)	1–12 (++)	2–15 (+++)
<i>Codonellopsis ostenfeldi</i>	2 (+)	2 (+)	1 (+)	-
<i>Codonellopsis tessellata</i>	2 (+)	-	-	-
<i>Codonellopsis</i> sp.	8 (++)	2 (+)	1–3 (+)	4 (+)
<i>Dadayiella gaymedes</i>	2 (+)	-	1 (+)	2–16 (+++)
<i>Eutintinnus lusus undae</i>	1 (+)	1 (+)	-	1–6 (++)
<i>Favella</i> sp.	1 (+)	-	-	-
<i>Helicostomella</i> sp.	2 (+)	2 (+)	4 (+)	6 (++)
<i>Leprotintinnus nordquisti</i>	4–5 (+)	1–8 (++)	2–6 (++)	10–19 (+++)
<i>Metacylis</i> sp.	-	1 (+)	-	1 (+)
<i>Protorhabdonella simplex</i>	-	1 (+)	-	-
<i>Rhabdonella poculum</i>	1 (+)	3 (+)	-	1–6 (++)
<i>Stenosemella parvicollis</i>	2 (+)	-	-	-
<i>Stenosemella</i> sp.	1–2 (+)	2–10 (++)	-	-
<i>Tintinnidium butschli</i>	1 (+)	-	-	-
<i>Tintinnopsis beroidea</i>	2 (+)	-	2 (+)	6 (++)
<i>Tintinnopsis karajacensis</i>	2–4 (+)	6 (++)	4–18 (+++)	6 (++)
<i>Tintinnopsis radis</i>	-	8 (++)	6 (+)	12 (+++)
<i>Tintinnopsis uryguayensis</i>	-	2 (+)	-	-
Heterotrophic dinoflagellates				
<i>Dinophysis apicata</i>	1 (+)	-	4–11 (+++)	1–28 (+++)
<i>Dinophysis caudata</i>	2–5 (+)	2–3 (+)	3–6 (++)	6–22 (+++)
<i>Gymnodinium</i> sp.	4–7 (++)	1 (+)	1–4 (+)	-
<i>Noctiluca scintillans</i>	-	-	1 (+)	7 (++)
<i>Ornithocerus magnificus</i>	-	-	-	2 (+)
<i>Podolamphus</i> sp.	1–2 (+)	1 (+)	5 (+)	2–16 (+++)
<i>Prorocentrum micans</i>	1–32 (+++)	6–24 (+++)	9–26 (+++)	6–24 (+++)
<i>Protooperidinium breve</i>	4–8 (++)	2–8 (++)	6–24 (+++)	8–32 (+++)
<i>Protooperidinium depressum</i>	4 (+)	3 (+)	1 (+)	1 (+)
<i>Protooperidinium granii</i>	1–10 (++)	2–9 (++)	2–3 (+)	4 (+)
<i>Protooperidinium latistriatum</i>	4 (+)	4–8 (++)	2–8 (++)	4–26 (+++)
<i>Protooperidinium ovatum</i>	1 (+)	1–2 (+)	1–2 (+)	2–8 (++)
<i>Protooperidinium stenii</i>	1–2 (+)	2–7 (++)	2–3 (+)	2–4 (+)
<i>Protooperidinium</i> sp.	4 (++)	2–11 (+++)	-	4 (+)
<i>Pyrophacus</i> sp.	1–2 (+)	6–9 (++)	1–4 (+)	2–12 (+++)
Ciliates				
<i>Halteria chlorelligera</i>	-	-	2 (+)	-
<i>Lohmaniella oviformes</i>	-	-	1 (+)	-
<i>Lohmaniella spiralis</i>	1 (+)	-	6 (++)	-
<i>Strombidium conicum</i>	2 (+)	-	2 (+)	1 (+)
<i>Strombidium minimum</i>	-	-	2 (+)	1 (+)
<i>Strombidium</i> sp.	2 (+)	-	-	-
Copepod nauplii	10–21 (+++)	14–22 (+++)	16–33 (+++)	2–56 (+++)

(+ : 1–5 Cells.L⁻¹), (++) : 6–10 Cells.L⁻¹), and (+++) : 11–100 Cells.L⁻¹) Indicates the occurrence of species and scale of their abundance in the study stations

(-) Indicates the absence of species in the study stations

Fig. 2 Microzooplankton abundance in the coastal waters of off Candolim, Goa



composition of MZP in the near-shore waters was dominated by HDS in most of the seasons (16–74%) and their low abundance was during the NEM (16–18%). In comparison, the LC were dominated during the NEM (32–50%) than the other seasons (10–32%). Moreover, the copepod nauplii (14–53%) also contributed significantly to the total MZP

abundance. The offshore waters were mostly dominated by HDS (48–85%) in most of the seasons and low abundance during the late SWM (28%). Conversely, the LC (35–51%) followed by the copepod nauplii (19–29%) were dominant during the late SWM. However, all the coastal waters (near: G3, G4, and offshore: G5, G6) were dominated by HDS

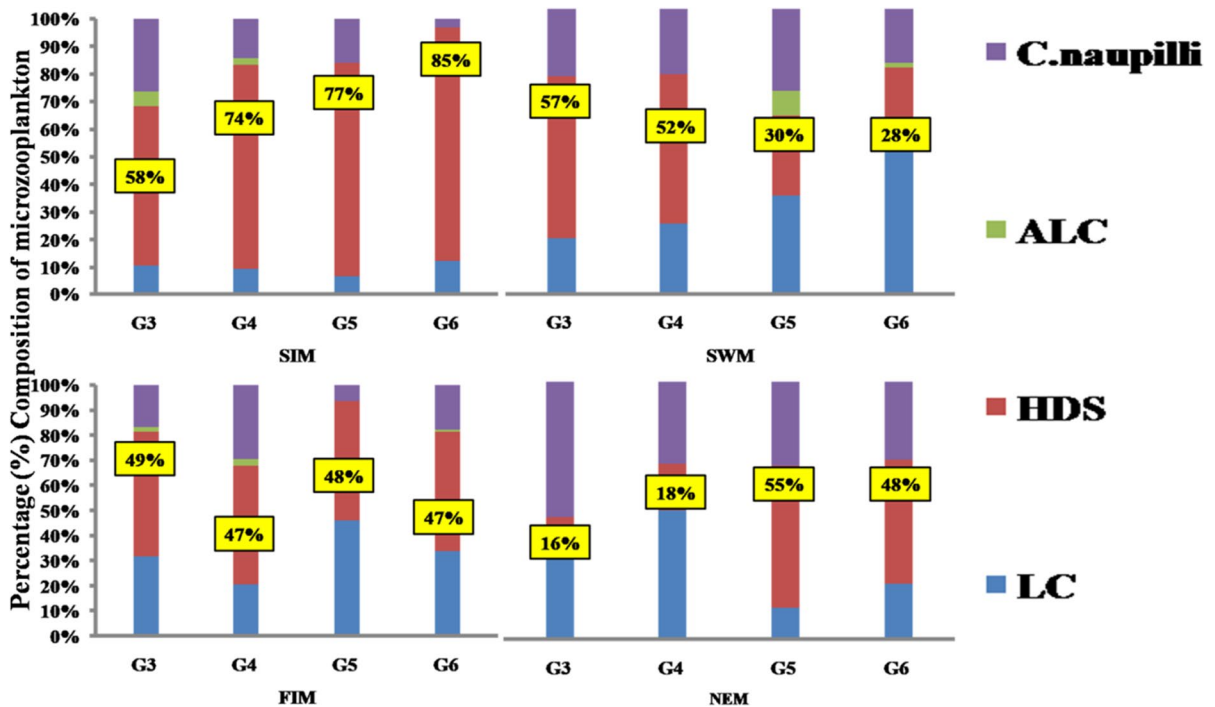


Fig. 3 Microzooplankton community composition in the coastal waters of off Candolim, Goa. The percentage indicates the contribution of HDS to the total microzooplankton abundance

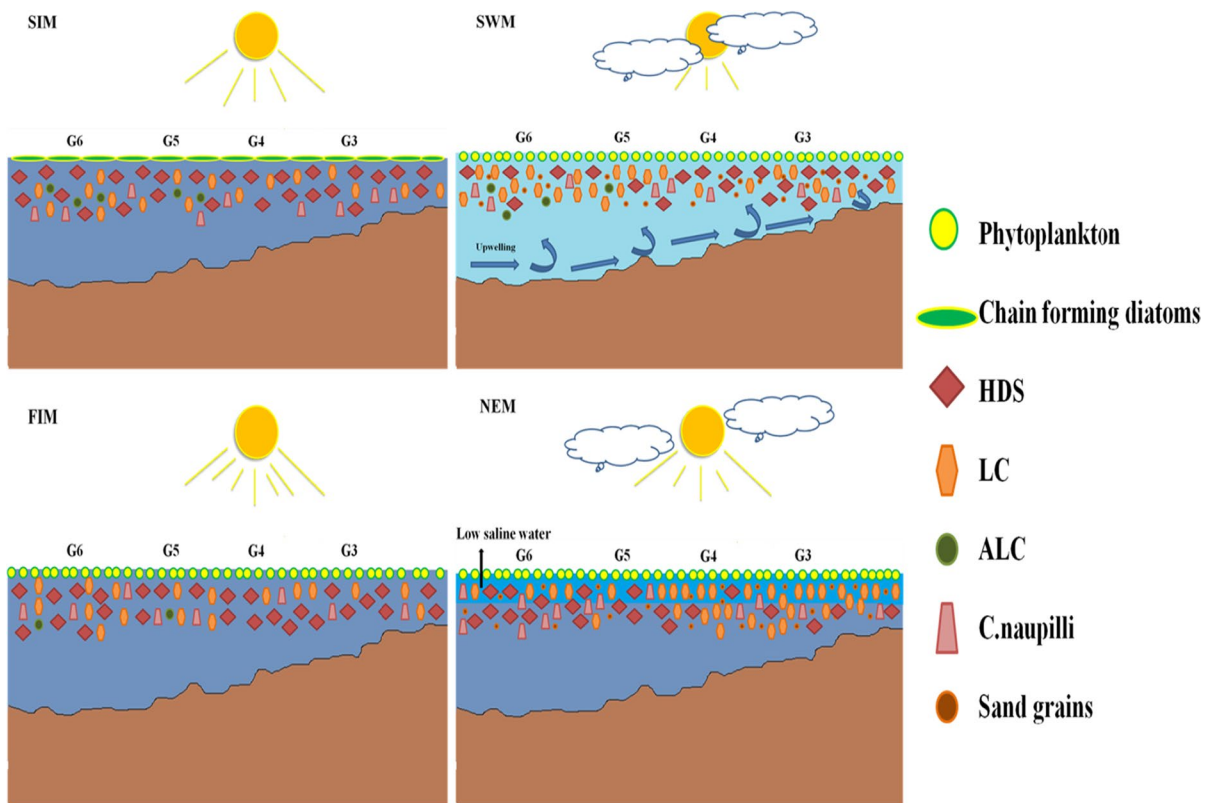


Fig. 4 Schematic diagram shows the different environmental conditions and microzooplankton community composition during different seasons in the coastal waters of off Candolim, Goa - India

(58–85%) during the SIM and the ALC contributed only 1–9% to the total MZP abundance. These results showed that the MZP community in the coastal waters off Candolim (Goa coast) are mainly dominated by HDS (16–85%) followed by LC (7–51%) and copepod nauplii (3–33%; Figs. 3 and 4).

A total of six species of HDS were most dominated. Which include, *Dinophysis apicata*, *Dinophysis caudata*, *Prorocentrum micans*, *Proto-peridinium breve*, *Proto-peridinium latistriatum*, and *Proto-peridinium granii*. Moreover, five species of LC such as *Amphorella acuta*, *Codonellopsis tessellata*, *Dadayiella gaymedes*, *Leptotintinnus nordquisti*, and *Tintinnopsis karajacensis* were also dominated.

Diversity indices

The number of species (S) ranged from 5 to 21, and the maximum number of species (21) was recorded

during the late SWM at offshore stations (G5 & G6). The species diversity (H') ranged from 2.1 to 4.1, and the maximum diversity (3.5–4.1) was recorded during the late SWM and FIM in all the stations. The species richness ranged from 1.5 to 5.3 and the maximum richness (4.5–5.3) was recorded during the late SWM and FIM in all the stations. Likewise, the evenness value ranged from 0.93 to 0.98, and the maximum richness (0.97–0.98) was recorded during the late SWM in all the stations (Supplementary Table 2).

Canonical correspondence analysis (CCA)

The relationships between the MZP and the environmental variables were studied by CCA analysis considering different seasons and stations. The results show that the first and the second ordination axis

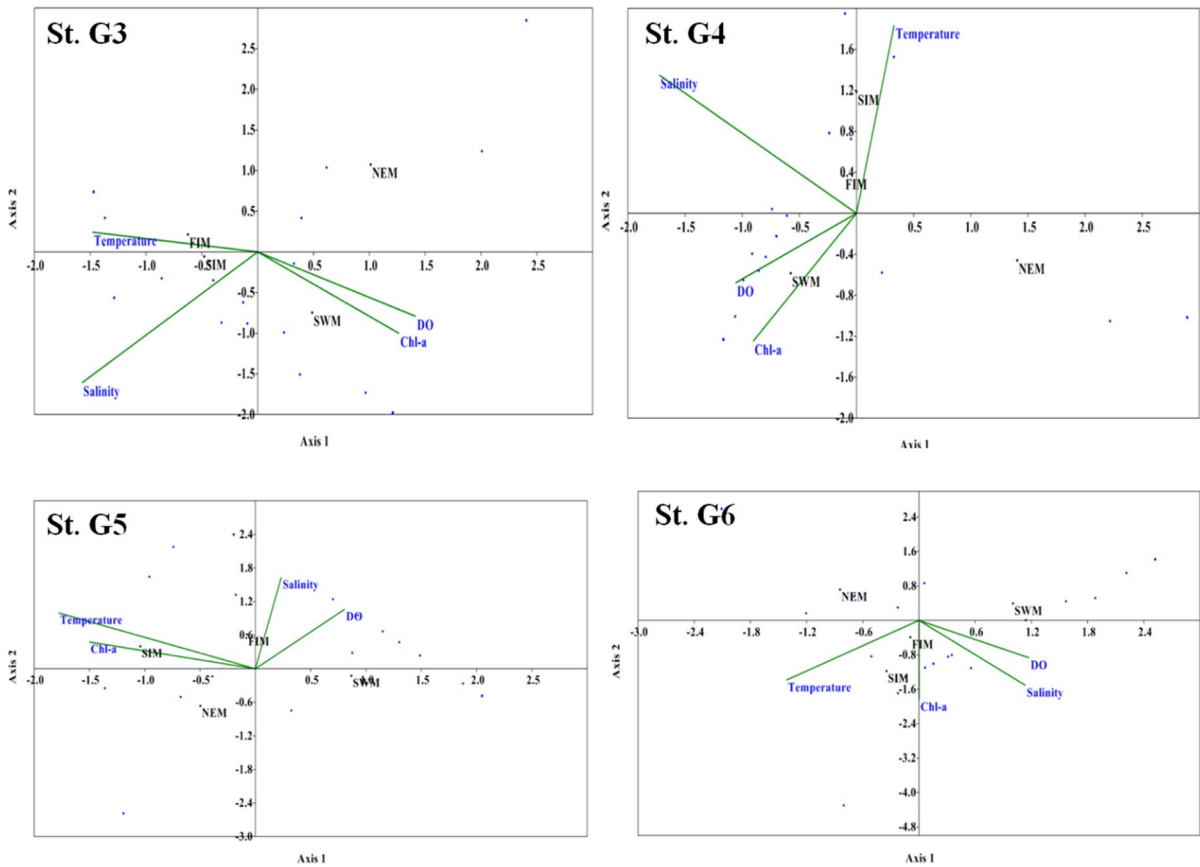


Fig. 5 The results of CCA analysis illustrate the relationship between the MZP assemblages and environmental parameters from the coastal waters of off Candolim, Goa

of CCA analysis of environmental variables were correlated with the MZP assemblages. During the NEM and SWM seasons, the MZP assemblages in the near-shore waters (Sts. G3 and G4) were mainly influenced by temperature, chlorophyll *a* and dissolved oxygen. While the SIM and the FIM seasons were mainly influenced by salinity and temperature. In offshore waters (Sts.G5 and G6), the MZP assemblages are mainly influenced by salinity and dissolved oxygen during the SWM and FIM. Whereas, salinity, chlorophyll *a*, temperature, and dissolved oxygen were influenced during the NEM and SIM. The results generally revealed that salinity, temperature, and dissolved oxygen are major environmental factors influencing the MZP assemblage in the study stations (Fig. 5).

Spearman rank correlation

Spearman rank correlation and coefficients (*r*) analysis were carried out to understand the influence of environmental variables on MZP and HDS. The correlation between salinity and MZP showed positive during the late SWM ($r = 0.45$) and FIM ($r = 0.76$), and negative correlation during the SIM ($r = -0.02$) and NEM ($r = -0.88$). Nonetheless, temperature showed a positive correlation with MZP during the SIM (0.15) and NEM (0.13, Table 2). During the late SWM, the correlation between HDS and environmental variables showed a positive correlation with temperature ($r = 0.73$), dissolved oxygen ($r = 0.65$), and chlorophyll *a* ($r = 0.83$). Moreover, the salinity ($r = 0.61, 0.04$) and tintinnids ($r =$

0.73, 0.92) showed positive correlation during the SIM and FIM (Table 3). These results show that the MZP abundance was influenced by salinity ($r = 0.45\text{--}0.76$) and the HDS abundance was mainly influenced by LC (tintinnids; $r = 0.73\text{--}0.92$) and salinity ($r = 0.61\text{--}0.04$).

Discussion

This study revealed that the MZP diversity in the coastal waters off Candolim varied spatially; the near-shore waters are diverse with LC and offshore waters diverse with HDS. The LC are diverse in many coastal regions due to their need for fine grains and mineral flakes (Elangovan & Padmavati, 2017; Gauns, 2000). Moreover, they have a euryhaline and eurythermal nature to sustain different environmental conditions (Biswas et al., 2013; Modigh & Castaldo, 2002). Whereas the HDS are diverse and ubiquitous in the oceanic region due to their different mode of feeding mechanisms (Jyothibabu et al., 2006; Sherr & Sherr, 2007). During the late SWM, the higher abundance of MZP and Chlorophyll *a* concentration in the coastal waters (Near and offshore) was possibly due to coastal upwelling. The eastern Arabian Sea experience seasonal upwelling during the SWM, which brings nutrient-rich cold water and enhances the biological production (phytoplankton) in the coastal waters (Banse, 1968; Naqvi et al., 2000). The MZP are a major consumer of phytoplankton, which consume 67% of phytoplankton daily growth and play an intermediate role between the microbial loop and higher trophic levels (Calbet & Landry, 2004; Sherr & Sherr, 1988). During the FIM, the abundance of MZP in the near-shore waters could be due to the availability of phytoplankton (diatoms and dinoflagellates). The light and nutrient availability are favorable conditions for phytoplankton proliferation, which support high phytoplankton abundance in the SIM (Devassy & Goes, 1988; Naik et al., 2020; Subrahmanyam, 1959). For most part of the year, the maximum abundance of MZP in the offshore stations than the Nearshore might be due to the dominance of HDS. The water column during the NEM remains stratified through the intrusion of low saline waters from the Bay of Bengal (Jyothibabu, Madhu, et al., 2008). The dinoflagellates can survive in different environmental conditions (Prey availability)

Table 2 Spearman rank correlation coefficients (r): environmental parameters (Hydrography, Chlorophyll *a*) and MZP

SIM	Temperature	Salinity	DO	Chl <i>a</i>	MZP
Temperature	1				
Salinity	0.96	1			
DO	-0.48	-0.60	1		
Chl <i>a</i>	0.06	0.15	0.43	1	
MZP	0.15	-0.02	0.78	0.44	1
SWM	Temperature	Salinity	DO	Chl <i>a</i>	MZP
Temperature	1				
Salinity	-0.45	1			
DO	0.63	-0.7	1		
Chl <i>a</i>	0.43	-0.97	0.83	1	
MZP	-1	0.45	-0.62	-0.42	1
FIM	Temperature	Salinity	DO	Chl <i>a</i>	MZP
Temperature	1				
Salinity	-0.86	1			
DO	-0.67	0.27	1		
Chl <i>a</i>	0.95	-0.73	-0.85	1	
MZP	-0.61	0.76	-0.16	-0.33	1
NEM	Temperature	Salinity	DO	Chl <i>a</i>	MZP
Temperature	1				
Salinity	-0.57	1			
DO	0.53	0.34	1		
Chl <i>a</i>	-0.24	0.93	0.6	1	
MZP	0.13	-0.88	-0.74	-0.97	1

by reducing their rate of metabolism (Sherr & Sherr, 2007). Besides, the dinoflagellates are well adapted to neritic waters (continental shelves) due to their wide tolerance to low saline conditions, stratification and nutrient availability (De Vernal et al., 2013). However, the near-shore waters were dominated by LC more than HDS during the NEM. The dominance of LC in the coastal (near-shore) waters during the NEM possibly due to favorable temperature (27–28 °C), salinity (22–23), high chlorophyll *a* (phytoplankton; 1.4–2.8 $\mu\text{g L}^{-1}$), and availability of fine sand grains through river runoff (Elangovan & Gauns, 2021). During SIM, the low abundance of LC and dominance of HDS in all the stations (Near and offshore) could be due to the abundance of chain-forming diatoms. The coastal and open waters of the Arabian Sea are known for the dominance of chain-forming diatoms during the SIM. These include *Bacillaria* sp., *Thalassiosira* sp., *Chaetoceros* sp., and *Rhizosolenia* sp. (Padmakumar et al., 2017; Sawant &

Table 3 Spearman rank correlation coefficients (r): environmental parameters (Hydrography, Chlorophyll *a*), LC and HDS

SIM	Temperature	Salinity	DO	Chl <i>a</i>	LC	HDS
Temperature	1					
Salinity	0.47	1				
DO	-0.62	-0.12	1			
Chl <i>a</i>	-0.62	-0.02	0.99	1		
LC	-0.24	0.00	-0.55	-0.49	1	
HDS	-0.16	0.61	-0.21	-0.09	0.73	1
SWM	Temperature	Salinity	DO	Chl <i>a</i>	LC	HDS
Temperature	1					
Salinity	-0.45	1				
DO	0.63	-0.70	1			
Chl <i>a</i>	0.43	-0.96	0.83	1		
LC	-0.97	0.51	-0.79	-0.54	1	
HDS	0.73	-0.92	0.65	0.83	-0.71	1
FIM	Temperature	Salinity	DO	Chl <i>a</i>	LC	HDS
Temperature	1.00					
Salinity	-0.86	1.00				
DO	-0.67	0.27	1.00			
Chl <i>a</i>	0.95	-0.73	-0.85	1.00		
LC	-0.30	-0.07	0.26	-0.22	1.00	
HDS	-0.23	0.04	-0.07	-0.04	0.92	1.00
NEM	Temperature	Salinity	DO	Chl <i>a</i>	LC	HDS
Temperature	1.00					
Salinity	-0.57	1.00				
DO	0.53	0.34	1.00			
Chl <i>a</i>	-0.24	0.93	0.60	1.00		
LC	0.90	-0.58	0.28	-0.24	1.00	
HDS	-0.02	-0.80	-0.83	-0.94	0.11	1.00

Madhupratap, 1996). The LC (tintinnids) prey selection depends on the oral diameter of their lorica (4 times of the prey) and can feed on the size range of 2 to 20 μm (Dolan et al., 2002, 2006). Earlier studies also reported that the LC could not feed on larger cells and was found to be in low abundance due to the abundance and blooms of chain-forming diatom (Elangovan et al., 2012; Elangovan et al., 2018; Lee & Kim, 2010). Conversely, the HDS are recognized as a significant grazer of chain-forming diatoms, and they can feed on prey larger than their size (Horner et al., 2005; Lissaed, 1991; Saito et al., 2006; Sherr & Sherr, 2007). During this study, the greater contribution of copepod nauplii to the total MZP abundance was due to their wide range of feeding efficiency. The copepod nauplii can feed efficiently on nano-flagellates, dinoflagellates, diatoms, and ciliates (Almeda et al., 2011; White & Roman, 1992). The

low abundance of ALC during the study might be due to the grazing pressure of copepod nauplii (Gauns, 2000; Gomez, 2007). The positive correlation of the MZP abundance with salinity and temperature was due to their favorable conditions as reported previously (Elangovan et al., 2012; Kamiyama & Tsujino, 1996). Likewise, the positive correlation of the HDS abundance with temperature and dissolved oxygen were due to their ability to survive different environmental conditions. The HDS are able to sustain in different concentrations of dissolved oxygen and a wide range of temperatures (Barton et al., 2016; Elangovan & Gauns, 2021; Rocke et al., 2013). The strong correlation between the HDS and LC were might be the feeding ability of HDS on larger cells (loricate ciliates), which determine the predominance of HDS in the MZP community by substituting LC. The HDS are grazers and parasites of LC (tintinnids) ciliates,

which can feed the entire tintinnid or consume the ciliate (tintinnid) zooid from the outside of the lorica (Coats et al., 2020; Uchida et al., 1997).

Conclusion

The present study revealed that HDS followed by LC primarily dominates the MZP community in the coastal waters off Goa. Moreover, the contribution of copepod nauplii (14–53%) to the total MZP abundance is also essential to mention here, which indicates their efficiency in transferring energy from a wide range of prey and acting as a significant primary consumer. The dominance of HDS in all the stations during most of the year indicates their ability to sustain during low prey abundance and different environmental conditions (temperature, salinity, and dissolved oxygen). Thus, the HDS can be used as model organisms for climate change studies. The correlation between HDS and LC shows the possibility of HDS grazing on LC, which indicates the dominance of HDS over their relative community. However, the studies on prey and parasite association between HDS and LC are needed to be carried out for a better understanding of the dominance of HDS and their essential role in the functioning microbial food web in coastal waters.

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Author contribution The study conception and design were made by Mangesh Gauns. Material preparation, data collection, and analysis were performed by Sai Elangovan S. The first draft of the manuscript was written by Sai Elangovan S and all authors remarked on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability Data will be available on request

Declarations

Ethics approval All authors have read, understood, and have complied as applicable with the statement on “ethical responsi-

bilities of authors” as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

Competing interests The authors declare no competing interests.

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