Pakistan J. Zool., pp 1-11, 2024. DOI: https://dx.doi.org/10.17582/journal.pjz/20210619050616

Comparative Analysis of Zooplankton Population Dynamics in Polluted and Non-Polluted Coastal Zones of the Northern Arabian Sea

Nafisa Shoaib*, Venus A. Qadir, Tayyaba Hamid and Pirzada Jamal Ahmed Siddiqui

Centre of Excellence in Marine Biology, University of Karachi, Karachi

ABSTRACT

Zooplankton are minute aquatic animals with limited swimming capabilities drift within the water columns of ocean, seas or freshwater bodies to move great distance. Their remarkable tolerance to environmental stress designate them as an indicator species for assessing physical, chemical and biological processes in marine environments. In this study, monthly changes in zooplankton population were compared between two distinct sites: Gadani ship breaking yard on the Balochistan coast (a polluted site) and the Sandspit on the Sind coast (a non-polluted site) within the Northern Arabian Sea, Pakistan over a one-year period. Standard methods to record the abundance and diversity of zooplankton were employed revealing their variations across seasons and between sampling stations. In Gadani, Copepods dominated the zooplankton community, representing 41.6% compared to 19.8% in Sandspit. Notably, Sandspit exhibited the highest abundance of Bristle worm compared to Foraminifera, with Calanoid Copepod ranking third However, Gadani displayed the highest percentage of Calanoid Copepod followed by Cyclopoid and Herpecticoid. In Sandspit diversity and abundance of zooplankton was greater as compare to Gadani Ship breaking area. This variation may be due to pollution that reduces species diversity and promote population of tolerant species. Furthermore, the study identified the influence of four seasons on the physiological and chemical parameters of marine waters that shaped species composition and distribution of zooplankton.

Article Information
Received 19 June 2021
Revised 03 January 2024
Accepted 11 January 2024
Available online 10 October 2024 (early access)

Authors' Contribution
NS designed the study. NS, VAQ, TH and PJAS data collected. VAQ and NS performed the experiments, analysed the data and wrote the article.

Key words
Copepods, Pollution, Zooplankton, Foraminifera, Abundance, Gadani

INTRODUCTION

Zooplanktons are small sized animals that are weak swimmers and usually drift along the water currents. They act as primary consumers and carry out diurnal and nocturnal movements covering hundreds of meters. During the night, they feed on the water surface and graze the phytoplankton. They represent a link between the microbial portion and the large grazers (Lacerot *et al*., 2013). Zooplankton also plays a vital role in marine ecosystem by transferring energy from phytoplankton to higher tropic levels. They serve as an important food source to the marine organisms particularly to planktivorous fish. In plankton-based food webs, zooplankton is the major route for energy flux, making them an important element in functioning of marine ecosystems (Santos-Wisniewski *et al*., 2006; Chen *et al*., 2020).

The characteristics of zooplankton community structure are characterized by the intrinsic factors such as surface area, depth, trophic level, colour of water, and the biological community (Rahkola-Sorsa, 2008). Their abundance and biodiversity are linked to the health of marine ecosystems. The abundance and distribution of zooplankton are influenced by hydrographic condition and they have been suggested as good biological indicator species (Lan *et al*., 2004; Shin *et al*., 2022). Due to their small size, huge density, rapid metabolic activities, short life span, drifting nature, species diversity and high tolerance to the stress zooplankton are used as the indicator species for the physical, chemical and biological processes in marine environment (Gajbhiye, 2002). Potentiality of zooplankton as bioindicator is very high because their growth and distribution are dependent on some abiotic (e.g., temperature, salinity, stratification, pollutants) and biotic parameters (e.g., food limitation, predation, competition) (Beyst *et al*., 2001).

Marine coastal ecosystems are zooplankton rich and they are among the most productive environments in the world. Zooplankton is the main predator on phytoplankton and it is sensitively influenced by the fluctuations of environmental factors (Eisner *et al*., 2014; Zhao *et al*., 2022). The zooplankton plays an important role in the structure and functioning of coastal ecosystems. Moreover 75% of the marine fish feed on plankton and

* Corresponding author: nafisashoaib@gmail.com
0030-9923/2024/0001-0001 $ 9.00/0

the availability of zooplankton as feed for larval fish is one factor that determines strength of commercial important fish species (Kane, 1993). Zooplanktons are involved in regulation of nutrients and phytoplankton population on which they feed. They consume large quantities of bacteria (Wroblewski, 1980), phytoplankton (Calbet *et al*., 2000) and organic detritus (Steinberg *et al*., 1998) and at the same time, they are preyed by higher trophic level such as fishes (Beaugrand *et al*., 2003).

Different studies have focused on the significance of the relationship between phytoplankton and zooplankton in marine ecosystems (Tan *et al*., 2004). An increase in nutrients can enhance phytoplankton productivity, leading to improved feeding conditions for zooplankton (Hansen *et al*., 2000; Sun *et al*., 2022). Elevated nutrient levels may also alter zooplankton species diversity and succession (Park and Marshall, 2000). Marine pollution due to industrialization and anthropogenic substances induces algal bloom which causes eutrophication affecting population of zooplankton present in the surrounding environment and they exhibit rapid changes in their populations when disturbance occurs. Therefore, they are used as indicator species for water pollution (Jakhar, 2013). Zooplankton species act as consumers of phytoplankton, particularly during algal blooms. At the early stage of algal bloom development, copepods, through their intensive grazing, are able to influence the food web structure and shift the phytoplankton species composition (Tan *et al*., 2004). Oceanographic processes such as temperature, salinity, wind forcing, current patterns, flooding and ebbing of the tides controlling the structure of plankton communities and generally reflected in patterns of abundance through space and time (Paffenhofer and Mazzocchi, 2003). Their community composition, richness and diversity also serve as good indicators of ecosystem health (Baliarsingh *et al*., 2014). In addition, climate change and human exploitation play a crucial role in zooplankton community and coastal ecosystems (Beaugrand *et al*., 2002; Bagheri *et al*., 2017). It is, therefore, important to assess species diversity and community structure of the zooplankton for evaluating potential fishery resources which have direct implications for commercial fisheries. The present study conducted monthly sampling from the coastal waters of Gadani ship breaking yard on the Balochistan coast and Sandspit on the Sind coast in Pakistan over a period of one-year and revealed variations in zooplankton populations across seasons and between sampling stations. The information obtained by the study may be utilized by different user groups, including government and non-government organizations working in the fishery industry.

MATERIALS AND METHODS

The seawater samples were collected from Sandspit (Sindh coast) and Gadani ship breaking area (Baluchistan coast) for the analysis of zooplankton, distribution and abundance with reference to seasons and physico-chemical parameters (Fig. 1). Sandspit is located at the South west of the Karachi, Sind. It is 14.5 km long, the approximate distance from Karachi to Sandspit is 18 kilometers and Gadani is 50 kilometers. Gadani ship breaking yard is the world's third largest ship breaking yard due to ship-breaking activities Gadani coastal area is considered most polluted (Saleem *et al*., 2016). Sandspit backwater is known as a nursery ground for fish and shellfish. Both Baluchistan coast and Sindh coast are important for economically important fisheries.

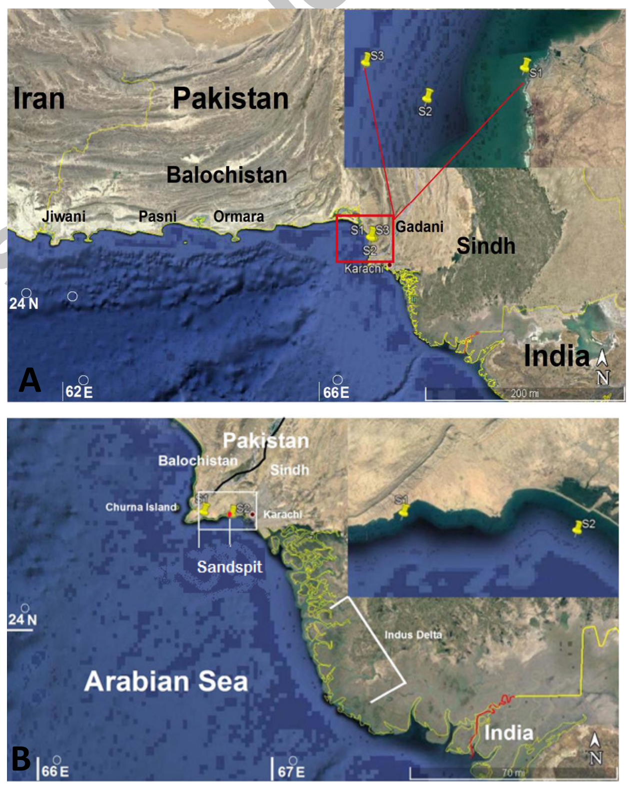

Fig. 1. Study area at A, Gadani (Baluchistan), S1, S2, and S3 are the stations; B, Sandspit (Sindh), the sites are indicated as S1 and S2.

Zooplankton samples from these two sites were collected by vertical hauls from a depth of 10 m using a 55 µm mesh size net. Three, replicate samples (250 ml each) were taken every month for a period of one year for zooplankton abundance diversity. Water quality parameters including water temperature, salinity, pH, dissolved oxygen, nitrate, nitrite, ammonia, phosphate and chlorophyll *a* were determined according to Strickland and Parsons (1972). Mercury thermometer for temperature, refractometer (Atago, Japan) for salinity and pH meter (Hanna. Inc) for pH was used. Dissolved oxygen was determined by Winkler method (Strickland and Parsons, 1972). For enumeration of zooplankton, the samples were first preserved in 4% formalin and binocular microscope (Olympus CX-31) was used to identify the major taxonomic groups and presented in (no.ind./m^3) number per cubic meter (Goswami, 2004).

Statistical analysis

Statistical analysis of data was carried out using PRIMER version 7 software and using PAST version 3 software. The biodiversity of zooplankton was calculated according to Shannon and Wiener (1949).

RESULTS

Table I shows water parameters which were variable throughout the year in Gadani and Sandspit. In order to check the seasonal abundance of zooplankton, seasons were divided into autumn inter-monsoon (October–November), northeast monsoon (December–February), spring intermonsoon (March–April), and south-west monsoon (May–September).

Table I. Environmental parameters at Gadani and Sandspit station.

Parameters	Mean	SD	SE	Range (Min-Max)
Gadani station				
Temp. °C	25.667	4.053	2.866	20-31
Saliniy (ppt)	35.333	2.498	1.767	31-38
pH	8.075	0.469	0.332	7-8.7
Oxygen (ppm)	9.275	1.076	0.761	7.7-10
Nitrate (ppm)	9.967	0.049	0.035	9.8-10
Nitrite (ppm)	0.200	0.001	0.001	0.19-.20
Phosphate (ppm)	3.583	1.564	1.106	1.4-5
Ammonia (ppm)	1.750	0.544	0.384	0.09-2.5
Chlorophyll (µ/l)	0.946	1.088	0.769	0.5-2.4
Sandspit station				
Temp. °C	25.333	3.916	2.769	19-30
Saliniy (ppt)	35.833	2.588	1.830	32-39
pH	8.108	0.355	0.251	7.7-8
Oxygen (ppm)	8.683	1.765	1.248	11-6.2
Nitrate (ppm)	9.983	0.039	0.028	9.9-10
Nitrite (ppm)	0.300	0.195	0.138	0.02-0.5
Phosphate (ppm)	2.667	1.614	1.142	0.42-4.9
Ammonia (ppm)	1.958	0.396	0.280	1.4-2.5
Chlorophyll (µ/l)	0.600	0.498	0.352	0.08-1.2

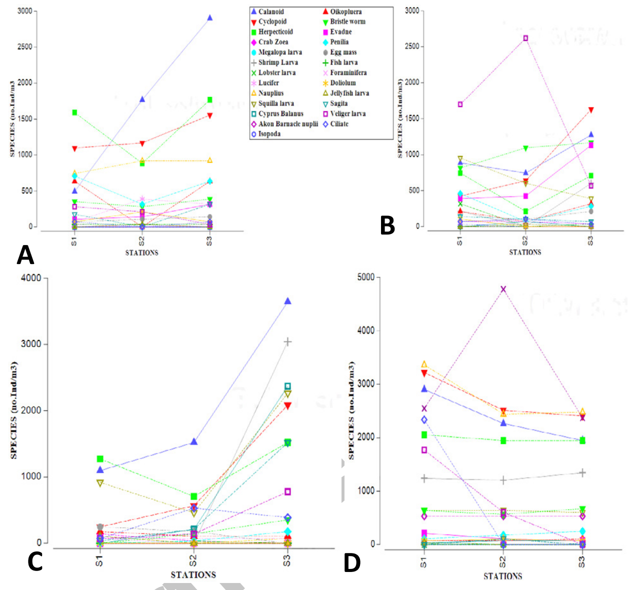

Fig. 2. Abundance of species (individuals/m^3) in (A) Autumn Inter Monsoon (October and November), (B) North East Monsoon (December, January and February), (C) Spring Inter Monsoon (March and April), (D) South West Monsoon (May to September) in Gadani Ship breaking area.

Variation in the zooplankton abundance was observed in all the three stations in four seasons in Gadani (Fig. 2). The peak abundance of zooplankton is in south west monsoon than in spring inter monsoon, autumn inter monsoon and north east monsoon at coastal waters of Gadani. Abundance of zooplankton varied from 176-12631 individuals/m^3. The peak zooplankton abundance occurred in April and the lowest abundance was recorded in December. Copepod dominate the zooplankton group, highest percentage was recorded of Calanoid 18.80% than Cyclopoid 14.78% and Herpecticoid 11.44%. Percentage abundance of zooplankton species was highest in Station III as compared to Station I and Station II during 2016-2017 in Gadani ship breaking area (Fig. 3).

Pearson correlation coefficient was applied to observe the relationships between zooplankton communities with Hydrographical parameters and nutrients. Zooplankton abundance was positively correlated with temperature and chlorophyll *a* whereas inverse correlation was observed with salinity, pH, dissolve oxygen, nitrate, nitrite, phosphate and ammonia in station 1. Zooplankton abundance was positively correlated with temperature whereas inverse correlation was observed with salinity, pH, dissolve oxygen, chlorophyll *a*, nitrate, nitrite, phosphate and ammonia in stations 2 and 3 (Table II).

Table II. Correlation (Pearson) of total abundance of zooplankton with water parameters at Gadani in station I, II and III.

	Abundance St. 1	Temp	Salinity	pH	Oxygen	Nitrate	Nitrite	Phosphate	Ammonia
Gadani station I									
Temperature	0.145								
Salinity	-0.294	-0.170							
pH	-0.436	0.101	0.791*						
Oxygen	-0.441	0.061	0.477	0.843*					
Nitrate	-0.429	0.078	0.825*	0.988*	0.810*				
Nitrite	-0.408	0.083	0.849*	0.951*	0.763*	0.985*			
Phosphate	-0.740	0.378	0.304	0.435	0.309	0.475	0.509		
Ammonia	-0.080	0.272	0.708*	0.876*	0.689*	0.875*	0.854*	0.300	
Chlorophyll	0.010	0.406	-0.206	0.021	0.359	0.027	0.070	0.149	0.157
Gadani station II									
Temperature	0.189								
Salinity	-0.290	-0.170							
pH	-0.447	0.101	0.791*						
Oxygen	-0.490	0.061	0.477	0.843*					
Nitrate	-0.445	0.078	0.825*	0.988*	0.810*				
Nitrite	-0.436	0.083	0.849*	0.951*	0.763*	0.985*			
Phosphate	-0.557	0.378	0.304	0.435	0.309	0.475	0.509		
Ammonia	-0.028	0.272	0.708*	0.876*	0.689*	0.875*	0.854*	0.300	
Chlorophyll	-0.008	0.406	-0.206	0.021	0.359	0.027	0.070	0.149	0.157
Gadani station III									
Temperature	0.061								
Salinity	-0.239	-0.170							
pH	-0.398	0.101	0.791*						
Oxygen	-0.497	0.061	0.477	0.843*					
Nitrate	-0.410	0.078	0.825*	0.988*	0.810*				
Nitrite	-0.411	0.083	0.849*	0.951*	0.763*	0.985*			
Phosphate	-0.055	0.378	0.304	0.435	0.309	0.475	0.509		
Ammonia	-0.294	0.272	0.708*	0.876*	0.689*	0.875*	0.854*	0.300	
Chlorophyll	-0.360	0.406	-0.206	0.021	0.359	0.027	0.070	0.149	0.157

In Gadani, Shannon diversity index and Margalef diversity index in station I was highest in North east monsoon as compare to other seasons. Pielou's evenness index was highest in station III in North east monsoon. Maximum number of species was recorded in station I in South west monsoon as compared to other seasons (Table III).

In Sandspit, lowest abundance of zooplankton was recorded in October in Station 1 i.e., 530.75 individuals/m^3 and high abundance was recorded in December in station 2 i.e., 441323 individuals/m^3. Variation in the zooplankton abundance was observed in the two stations in four seasons (Fig. 4). Annual percentage abundance of zooplankton species shows variations at two stations in Sandspit (Fig. 3).

Pearson correlation coefficient was applied to observe the relationships between zooplankton communities with Hydrographical parameters and nutrients. Zooplankton abundance was positively correlated with temperature, Salinity, pH and Ammonia and inverse correlation was observed with dissolve oxygen, chlorophyll *a*, nitrate, nitrite and phosphate at station 1 (Table IV). However, zooplankton abundance was positively correlated with salinity, dissolve oxygen, nitrate and ammonia and inverse correlation was observed with temperature, pH, chlorophyll *a,* nitrite and phosphate at station 2 (Table IV).

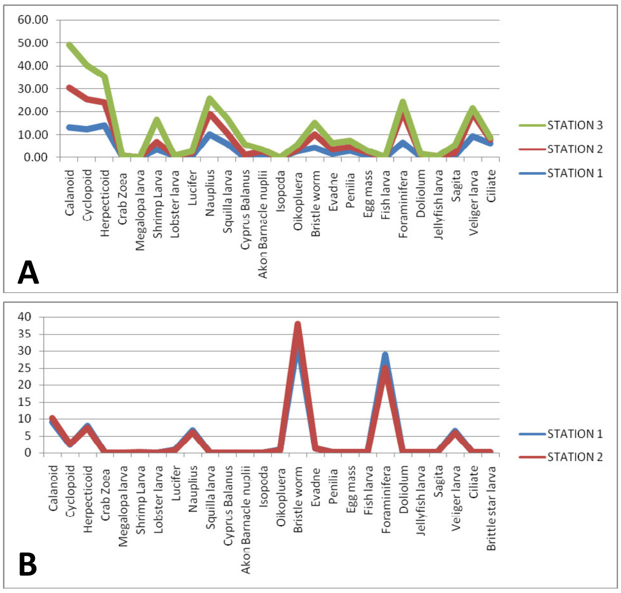

Fig. 3. Percentage abundance of zooplankton species in 2016-2017 at stations 1, 2, 3 of Gadani ship breaking area (A) and station 1 and 2 of sandspit (B).

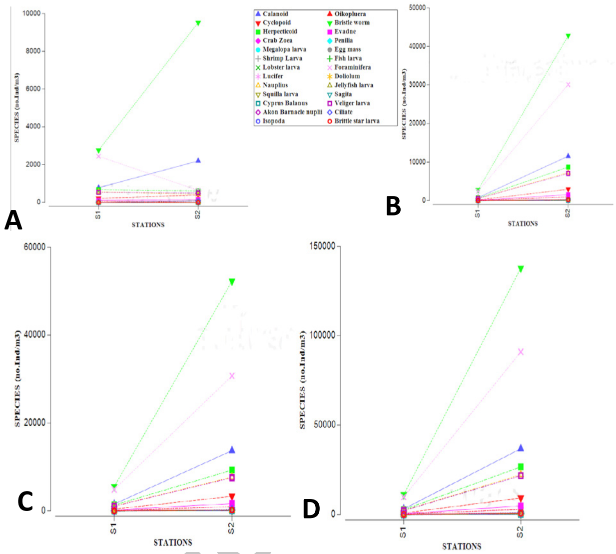

Fig. 4. Abundance of species (individuals/m³) in (A) autumn inter monsoon (October and November), (B) north east monsoon (December, January and February), (C) spring inter monsoon (March and April), (D) south west monsoon (May to September) in Sandspit.

Table III. Seasonal abundance of zooplankton (cells/L) recorded from Gadani and Sandspit.

Seasons	Stations	No. of species	Total no. of Ind.	Margalef diversity index	Pielou's evenness index	Shannon diversity index
Autumn inter monsoon	Station 1	16	6546	1.707	0.8162	2.263
	Station 2	14	6511	1.48	0.8037	2.121
	Station 3	16	10155	1.626	0.7767	2.153
North east monsoon	Station 1	18	7678	1.9	0.8465	2.447
	Station 2	17	7041	1.806	0.7242	2.052
	Station 3	15	8457	1.548	0.8499	2.302
Spring inter monsoon	Station 1	13	4529	1.425	0.7652	1.963
	Station 2	15	4954	1.646	0.8085	2.19
	Station 3	14	18399	1.324	0.8366	2.208
South west monsoon	Station 1	19	21867	1.801	0.8047	2.369
	Station 2	18	18293	1.732	0.7737	2.236
	Station 3	15	14932	1.457	0.8214	2.224
Autumn inter monsoon	Station 1	10	8209	0.9986	0.7599	1.75
	Station 2	11	14649	1.043	0.5328	1.278
North east monsoon	Station 1	26	8560	2.761	0.5882	1.917
	Station 2	26	116315	2.143	0.5676	1. 849
Spring inter monsoon	Station 1	26	16769	2.57	0.5662	1.845
	Station 2	26	130964	2.122	0.5574	1.816
South west monsoon	Station 1	26	33889	2.397	0.5777	1.882
	Station 2	26	363593	1.953	0.5641	1.838

Table IV. Correlation (Pearson) of total abundance of zooplankton with water parameters in Sandspit at station I and II.

	Abundance St. 1	Temp	Salinity	pH	Oxygen	Nitrate	Nitrite	Phosphate	Ammonia
Sandspit station I									
Temperature	0.103								
Salinity	0.144	0.158							
pH	0.396	-0.081	-0.107						
Oxygen	-0.127	-0.105	-0.109	0.096					
Nitrate	-0.643	-0.020	0.421	-0.383	0.135				
Nitrite	-0.308	-0.036	-0.054	0.380	0.089	0.478			
Phosphate	-0.439	-0.168	-0.297	0.449	-0.171	-0.096	0.288		
Ammonia	0.057	0.244	0.436	-0.126	0.007	0.540	0.059	-0.450	
Chlorophyll	-0.341	0.470	0.118	-0.611	0.238	0.441	-0.076	-0.336	0.301
Sandspit station II									
Temperature	-0.195								
Salinity	0.513	0.158							
pH	-0.102	-0.081	-0.107						
Oxygen	0.120	-0.105	-0.109	0.096					
Nitrate	0.129	-0.020	0.421	-0.383	0.135				
Nitrite	-0.175	-0.036	-0.054	0.380	0.089	0.478			
Phosphate	-0.142	-0.168	-0.297	0.449	-0.171	-0.096	0.288		
Ammonia	0.033	0.244	0.436	-0.126	0.007	0.540	0.059	-0.450	
Chlorophyll	-0.008	0.470	0.118	-0.611	0.238	0.441	-0.076	-0.336	0.301

Table V. Percentage abundance of zooplankton species in Sandspit and Gadani.

S.	Species	Sandspit %	Gadani %
1	Calanoid	9.66	16.39
2	Cyclopoid	2.53	13.44
3	Herpecticoid	7.65	11.86
4	Crab larva Zoea	0.03	0.29
5	Megalopa larva	0.04	0.06
6	Shrimp larva	0.11	5.51
7	Lobster larva	0.06	0.29
8	Lucifer	0.83	0.95
9	Nauplius	6.45	8.64
10	Squilla larva	0.08	5.69
11	Cyprus Balanus	0.09	1.92
12	Acorn Barnacle nauplii	0.10	1.26
13	Isopoda	0.11	0.03
14	Oikopluera	0.88	1.87
15	Doliolum	0.17	0.58
16	Bristle worm	35.31	5.03
17	Evadne	1.36	2.17
18	Penilia	0.14	2.45
19	Egg mass	0.19	1.00
20	Fish larva	0.15	0.11
21	Jellyfish larva	0.18	0.18
22	Veliger larva	6.23	7.26
23	Brittle star larva	0.21	0.00
24	Sagitta	0.19	1.90
25	Foraminifera	27.01	8.14
26	Ciliates	0.24	2.98

Table continued on next column............

In Sandspit Shannon diversity index and Margalef diversity index in station I was highest in North east monsoon as compare to other seasons. Pielou's evenness index was highest in station I in autumn inter monsoon. Minimum number of species was recorded in station I in autumn inter monsoon as compared to other seasons (Table III).

There is variation in the percentage abundance of zooplankton species in Sandspit and Gadani (Table V). The highest percent abundance was of Bristle worm 35.31 no.Ind/m^3 in Sandspit than Foraminifera 27.01 no.Ind/

m^3 and third abundance was of Calanoid Copepod 9.66 no.Ind/m^3 However, the highest percent abundance was of Calanoid Copepod 16.39 no.Ind/m^3 in Gadani than Cyclopoid 13.44 no.Ind/m^3 and third abundance was of Herpecticoid 11.86 no.Ind/m^3.

DISCUSSION

The present study was conducted in Gadani, situated along the Baluchistan coast and Sandspit, located on the Sind coast within the Northern Arabian Sea. This region experiences significant influences from both the south west monsoon (summer monsoon) and north-east monsoon (winter monsoon). During summer, the south west monsoon leads to upwelling, bringing nutrient rich cooler waters parallel to the coast into the euphotic zone, creating a strong connection between biological and physical processes. This upwelling phenomenon brings nutrient rich water to the surface that influence phytoplankton growth thus increasing chlorophyll *a* content and high gross primary productivity of the region (Banse, 1987; Kumar *et al*., 2001).

In the current study, data on the seasonal abundance and distribution of zooplankton with physico-chemical parameters are studied. In the south west monsoon, the peak abundance of zooplankton was noticed due to high chlorophyll *a* content in Gadani and Sandspit. Our result corresponds with Soriede *et al*. (2010), who reported high abundance of zooplankton can be related to the high content of chlorophyll *a* in the area. In the south west monsoon, the temperature was recorded high in both sites (Gadani and Sandspit) as compared to other seasons. Temperature is an important factor that regulates biochemical attributes of marine environment. The disparity in temperature may be due to variations of seasonal impact. In winter, when the temperature was low, the dissolved oxygen value was high, whereas dissolve oxygen was low in summer when temperature was high. In high temperature the organisms demand for oxygen increases results in low dissolved oxygen retaining capacity of water (Hussain *et al*., 2013).

Salinity has a great effect on the ecological processes of marine environment and is a factor affecting the biodiversity of zooplanktons (Zadereev *et al*., 2022), an increase in salinity results in loss of biodiversity (Schallenberg *et al*., 2003). In Sandspit salinity is positively correlated with zooplankton abundance but in Gadani it is negatively correlated. The pH is also an important variable in assessment of water quality because it has a great impact on chemical and biological processes. The pH value was 7.4-8.6 in the Gadani ship breaking area whereas in Sandspit sites it was 7.7-8.6. The pH value showed negative correlation with zooplankton density in Gadani and Sandspit however, pH value showed positive correlation with zooplankton density in Sandspit in station 1. High pH value is directly proportional with water productivity. The pH value greater than 7 but less than 8.5 is best for productivity while pH value less than 4 is harmful for marine life (Abowei, 2010).

The zooplankton abundance and diversity show variations with different season and varied from station to station. The peak abundance is in south west monsoon than in spring inter monsoon, autumn inter monsoon and north east monsoon at coastal waters of Gadani ship breaking area. Whereas in Sandspit the peak abundance of zooplankton is in south west monsoon than in spring inter monsoon, north east monsoon and autumn inter monsoon. In Gadani copepod dominate the zooplankton group, highest percentage was recorded of Calanoid 16.39% than Cyclopoid 13.44% and Herpecticoid 11.86%. Copepods were the most abundant group in Gadani 41.6% than 19.8% in Sandspit of total zooplankton group. Copepod abundance may be due to high temperature and high rate of productivity. In Gadani in all zooplankton groups, Calanoid copepod shows highest in number. The Calanoid copepod shows the peak abundance in autumn inter monsoon and spring inter monsoon whereas, Foraminifera shows abundance in south west monsoon and Veliger larva in north east monsoon. Copepods are the most adaptable and abundant group in marine waters, can tolerate wide range of fluctuations in different physico-chemical parameters and are dominant group. They are the most important secondary producers in coastal and marine ecosystems, forming an important link between phytoplankton, microzooplankton and higher tropic levels such as fish (Beyst *et al*., 2001). Copepods are herbivorous, some are omnivorous and carnivorous. They are widely distributed in world Ocean and contribute 80% of the biomass (Sampey *et al*., 2007). Copepods have sturdy exoskeleton and the longest and toughest appendages which assist them to swim faster than other zooplankton. The three orders of copepod differ in their feeding habitats. The cyclopoid copepods are generally carnivorous and feeds on other zooplankton and fish larvae, they also feed on detritus, bacteria and algae. The calanoid copepods are omnivorous feed on rotifers, ciliates, algae, detritus and bacteria. Their food is dependent on age, sex, season and food availability. The herpacticoid are primarily benthic and third group of copepod. Herpacticoid physical shape and diverse feeding habits help them to tolerate severe environment as compared to Cladocera (Kalff, 2016). Cladocerans and copepods serve as the bioindicator to determine the health of the aquatic ecosystem (Jha and Barat, 2003).

Studies on the effect of pollution on zooplankton is scarce (Zaitsev, 1992). However, efforts have been made to initiate categories of zooplankton on the basis of their tolerance to pollution (Soetaert and Van Rijswijk, 1993). Changes in zooplankton diversity, abundance and populations seem to be correlated with factors related with pollution. Anoxic conditions may be the factor for decrease of zooplankton population and diversity in polluted environment (Park and Marshall, 2000) and particulate matter concentrations may affect the death rate of copepods (Castel and Feurtet, 1992). The present study reveals that the environmental conditions of coastal waters of Gadani ship breaking area is polluted and there is less zooplankton but in offshore waters high abundance and diversity of copepod is present.

Increase in nutrient may alter zooplankton species diversity and marine pollution due to anthropogenic activities induces algal bloom affecting population of zooplankton present in the surrounding environment and they exhibit rapid changes in their populations (Park and Marshall, 2000; Jakhar, 2013). Coastal environments are highly productive areas owing to food supplies Cebrian and Valiela (1999). The zooplankton abundance and composition generally varied due to the seasonal variations and their habitat like coastal and mangrove ecosystem. In the present study the abundance of zooplankton was greater in open-ocean as compare to near shore waters. In Sandspit total abundance per year of zooplankton in Station II was 727186.8 individuals/m^3 as compare to Station I was 67777 individuals/m^3. Whereas in Gadani total abundance per year of zooplankton in station III was maximum 51942 individuals/m^3, in station II was 36798 individuals/m^3 and in station I was 40620 individuals/m^3. In ship breaking area (station I) there is less abundance of zooplankton as compared to offshore (station III). This may be due to the organic and inorganic materials dissolved in the water that support zooplankton growth. Similar results also reported by Bhuiyan *et al*. (1982), Ali *et al*. (1985), Zafar (2000) and Khan *et al*. (2015).

CONCLUSION

This study provides recent and up-to-date data on diversity and abundance of zooplankton in two distinct sites: The Gadani ecosystem on the Balochistan coast (a polluted site) and Sandspit on the Sind coast (a non-polluted) within the Northern Arabian Sea. It shows the significance of physico-chemical parameters and nutrient levels as pivotal factors that influence the production of phytoplankton and zooplankton essential for sustainable fisheries. Moreover, the study highlights the impact of seasons on the physiological and chemical condition of marine waters that determine composition and distribution of zooplankton species. Further studies of the seasonal zooplankton abundance and diversity in the inshore and offshore waters of the Pakistan coast are required to understand the dynamics of the zooplankton to sustain fisheries in this area.

DECLARATIONS

Acknowledgement

The authors would like to thank Higher Education Commission (HEC) for providing financial support of the project No. 20-2768, National Research Program for Universities (NRPU) to carry out the present research and the facility provided by Centre of Excellence in Marine Biology is well appreciated.

Funding

The authors would like to thank Higher Education Commission (HEC) for providing financial support of the project No. 20-2768, National Research Program for Universities (NRPU) to carry out the present research and the facility provided by Centre of Excellence in Marine Biology is well appreciated.

Statement of conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Abowei, J.F.N., 2010. Salinity, dissolved oxygen, pH and surface water temperature conditions in Nkoro River, Niger Delta, Nigeria. *Adv. J. Fd. Sci. Tech*., **2**: 16-21.

Ali, A., Sukanta, S. and Mahmood, N., 1985. Seasonal abundance of plankton in Moheskhali channel, Bay of Bengal. In: *Proceedings of SAARC seminar on protection of environmental from degradation, Dhaka, Bangladesh*, pp. 128-140.

Bagheri, S., Sabkara, J., Yousefzad, E. and Zahmatkesh, Y., 2017. Ecological study of zooplankton communities in the Persian Gulf Martyrs Lake (Chitgar-Tehran) and the first report of the freshwater jellyfish *Craspedacusta*sp. (Cnidaria, Limnomedusae) in Iran. *Iran. J. Fish Sci.,* **25**: 113-128.

Baliarsingh, S.K., Srichandan, S., Sahu, B.K., Sahu K.C., Lotliker, A.A. and Kumar, T.S., 2014. Zooplankton community distribution offshore transects of some Indian estuaries of east coast: A taxonomic investigation during a summer cruise. *Ind. J. Geo Mar. Sci.,* **43**: 21-32.

Banse, K., 1987. Seasonality of phytoplankton chlorophyll in the central and northern Arabian Sea. *Deep-Sea Res.,* **34**: 713-723. https://doi.org/10.1016/0198-0149(87)90032-X

Beaugrand, G., Brander, K.M., Lindley, J.A., Soussi, S. and Reid, P.C., 2003. Plankton effect on cod recruitment in the North Sea. *Nature,* **426**: 661-664. https://doi.org/10.1038/nature02164

Beaugrand, G., Reid, P.C., Ibañez, F., Lindley, J.A. and Edwards, M., 2002. Reorganization of North Atlantic marine copepod biodiversity and climate. *Science,* **296**: 1692-1694. https://doi.org/10.1126/science.1071329

Beyst, B., Buysse, D., Dewicke, A. and Mees, J., 2001. Surf zone hyperbenthos of Belgian sandy beaches: Seasonal patterns. *Est. Coast. Shelf. Sci.,* **53**: 877-895. https://doi.org/10.1006/ecss.2001.0808

Bhuiyan, A.L., Mohi, S.A., Khair, S.A. and Das, N.G., 1982. Macro-zooplanktons of the continental shelf of the Bay of Bengal. *Chitt. Univ. St.,* **6**: 51-59.

Calbet, A., Landry, M.R. and Scheinberg, R.D., 2000. Copepod grazing in a subtropical bay: Species-specific responses to a midsummer increase in nanoplankton standing stock, *Mar. Ecol. Progr. Ser.,* **193**: 75-84. https://doi.org/10.3354/meps193075

Castel, J. and Feurtet, A., 1992. Fecundity and mortality rates of the copepod *Eurytemora affinis* in the Gironde Estuary. In: *Proceedings of marine eutrophication and population dynbamics* (eds. G. Colombo, I. Ferrari, V.U. Ceccherelli and R. Rossi). 25th Europian Marine Biology Symposium, Ferrara, September 1990. pp. 143–149.

Cebrián, J. and Valiela, I., 1999. Seasonal patterns in phytoplankton biomass in coastal ecosystems. *J. Plank. Res.,* **21**: 429–444. https://doi.org/10.1093/plankt/21.3.429

Chen, J., Zhao, K., Cao, Y., Wu, B., Pang, W., You, Q. and Wang, Q., 2020. Zooplankton community structure and its relationship with environmental factors in Poyang Lake. *Acta Ecol. Sin*., **40**: 6644.

Cocheret, Moriniere, E., Nagelkerken, I., Meij, H. and van der Velde, G., 2004. What attracts juvenile coral reef fish to mangroves: Habitat complexity or shade? *Mar. Biol.,* **144**: 139-145. https://doi.org/10.1007/s00227-003-1167-8

Dean, H.K., 2004. Marine biodiversity of Costa Rica: Class polychaeta (Annelida). *Rev. Biol. Trop.,* **52**: 131-181.

Dias, R.J.P., Wieloch, A.H. and D'agosto, M., 2008. The influence of environmental characteristics on the distribution of ciliates (Protozoa, Ciliophora) in an urban stream of southeast Brazil. *Rev. Brasil. Biol.,* **68**: 287-295. https://doi.org/10.1590/S1519-69842008000200009

Eisner, L.B., Napp, J.M., Mier, K.L., Pinchuk, A.I. and Andrews, A.G., 2014. Climate-mediated changes in zooplankton community structure for the eastern Bering Sea. *Deep-Sea Res., Pt. II*., **109**: 157-171. https://doi.org/10.1016/j.dsr2.2014.03.004

Fiksen, O., Jorgensen, C., Kristiansen, T., Vikebo, F. and Huse, G., 2007. Linking behavioural ecology and oceanography: Larval behaviour determines growth, mortality and dispersal. *Mar. Ecol. Progr. Ser*., **347**: 195–205. https://doi.org/10.3354/meps06978

Gajbhiye, S.N., 2002. Zooplankton study methods, importance and significant observations. In: *The national seminar on creeks, estuaries and mangroves - pollution and conservation, Thane* (ed. G. Quardros). pp. 21-27.

Gifford, D.J., 1991. The protozoan-metazoan trophic link in pelagic ecosystems. *J. Protozool.,* **38**: 81–86. https://doi.org/10.1111/j.1550-7408.1991.tb04806.x

Goswami, S.C., 2004. Zooplankton methodology, collection and identification. A field Indian Ocean. *Nat. Lon.,* **196**: 1224-1225.

Grolière, C.A., Chakli, R., Sparagano, O. and Pepin, D., 1990. Application de la colonisation d'un substratartificiel par les Ciliésàl' Étude de la qualité des eauxd'unerivière. *Eur. J. Protistol.,* **25**: 381-390. https://doi.org/10.1016/S0932-4739(11)80131-8

Hansen, B.W., Hygum, B.H. and Brozek, M., 2000. Food web interactions in a *Calanus finmarchicus* dominated pelagic ecosystem. *J. Plank. Res.,* **22**: 569-588. https://doi.org/10.1093/plankt/22.3.569

Hay, S., 2006. Marine ecology: Gelatinous bells may ring change in marine ecosystems. *Curr. Biol*., **16**: R679–R682. https://doi.org/10.1016/j.cub.2006.08.010

Hussain, A., Sulehria, A.Q., Ejaz, M. and Maqbool, A., 2013. Monthly variations in physico-chemical parameters of a flood plain reservoir on River Ravi near Balloki Headworks (Pakistan). *Biologia* (Pakistan), **59**: 371-377.

Jakhar, P., 2013. Role of phytoplankton and zooplankton as health indicators of aquatic ecosystem: A review. *Int. J. Innov. Res. Stud.,* **2**: 489–500.

Jha, P. and Barat, S., 2003. Hydrobiological study of lake Mirik in Darjeeling, Himalayas. *J. environ. Biol.,* **24**: 339-344.

Kalff, J., 2016. *Limnology: Inland water ecosystems*. 2nd Edn., Prentice Hall Publications, New Jersey, USA., pp. 592. http://wgbis.ces.iisc.ernet.in/energy/water/paper/Tr -115/ref.htm

Kane, J., 1993. Variability of zooplankton biomass and dominant species abundance on Georges Bank, 1977–1986. *Fish. Bull.,* **91**: 464–474

Khan, M.S.K., Uddin, S.A. and Haque, M.A., 2015. Abundance and composition of zooplankton at Sitakunda coast of Chittagong, Bangladesh. *Res. Agric. Live Fish*., **2**: 151–160. https://doi.org/10.3329/ralf.v2i1.23053

Kumar, S.P., Ramaiah, N., Gauns, M., Sarma, V.V.S.S., Muraleedharan, P.M., Raghukumar, S., Kumar, M.D. and Madhupratap, M., 2001. Physical forcing of biological productivity in the Northern Arabian Sea during the Northeast Monsoon. *Deep-Sea Res.*, **48**: 1115-1126. https://doi.org/10.1016/S0967-0645(00)00133-8

Lacerot, G., Kruk, C., Lürling, M. and Scheffer, M., 2013. The role of subtropical zooplankton as grazers of phytoplankton under different predation levels. *Freshw. Biol*., **58**: 494-503. https://doi.org/10.1111/fwb.12075

Lan, Y.C., Shih, C.T., Lee, M.A. and Shieh, H.Z., 2004. Special distribution of copepods in relation to water mass in the Taiwan Strait. *Zool. Stud.,* **43**: 332-343.

Lipej, L., Mozatic, P., Turk, V., Malej, A., 1997. The trophic role of the marine cladoceran *Penilia avirostris* in the Gulf of Trieste. *Hydrobiologia,* **360**: 197–203. https://doi.org/10.1007/978-94-011-4964-8_22

Murugan, N., Murugavel, P. and Kodarkar, M.S., 1998. *Cladocera: The biology, classification, identification and ecology*. Indian Association of Aquatic Biologists (IAAB), Hyderabad. http://wgbis.ces.iisc.ernet.in/energy/water/paper/Tr -115/ref.htm.

Nigam, R., Panchang, R. and Banerjee, P., 2005. Foraminifera in surface sediments of Mandovi River Estuary: Indicators for mining pollution and high sea stand in Goa. *Ind. J. Coast. Res*., **21**: 853–859. https://doi.org/10.2112/03-0061.1

Paffenhöfer, G.A. and Mazzocchi, M.G., 2003. Vertical distribution of subtropical epiplanktonic copepods. *J. Plank. Res*., **25**: 1139–1156. https://doi.org/10.1093/plankt/25.9.1139

Panchang, R., Nigam, R., Baig, N. and Naik, G.N., 2005. A foraminifera testimony for the reduced adverse effects of mining in Zuari estuary, Goa. *Int. J. environ. Stud*., **62**: 579-591. https://doi.org/10.1080/00207230500241801

Park, G.S. and Marshall, H.G., 2000. Estuarine relationships between zooplankton community structure and trophic gradients. *J. Plank. Res.,* **22**: 121-135. https://doi.org/10.1093/plankt/22.1.121

Purcell, J.E., 2005. Climate effects on formation of jellyfish and ctenophore blooms. *J. Mar. Biol. Assoc. U.K*., **85**: 461–476. https://doi.org/10.1017/S0025315405011409

Rahkola-Sorsa, M., 2008. *The structure of zooplankton community in large boreal lakes and assessment of zooplankton methodology*. PhD dissertation, University of Joensuu.

Raja, B.C.S., Jayaraju, N., Sreenivasulu, G., Suresh, U. and Reddy, A.N. 2016. Heavy metal pollution monitoring with foraminifera in the estuaries of Nellore coast, East coast of India. *Mar. Pollut. Bull*., **113**: 542–551. https://doi.org/10.1016/j.marpolbul.2016.08.051

Romano, E., Bergamin, L., Grazia, M., Gabriella, M., Ausili, A. and Gabellini, M., 2008. Industrial pollution at Bagnoli (Naples, Italy): Benthic foraminifera as a tool in integrated programs of environmental characterisation. *Mar. Pollut. Bull*., **56**: 439–457. https://doi.org/10.1016/j.marpolbul.2007.11.003

Sabates, A. and Olivar, M.P., 1996. Variation of larval fish distributions associated with variability in the location of a shelf-slope front. *Mar. Ecol. Progr. Ser*., **135**: 11–20. https://doi.org/10.3354/meps135011

Saleem, M., Aftab, J., Hasaney, S.I., Kahkishan, S., Haider, S.W. and Muzaffar, M., 2016. Toxicity levels, ecological risk assessment of heavy metals and distribution in the surface sediment of Hub River, Hub River estuary and Gadani Coast, Baluchistan, Pakistan. *J. Biol. Environ*. Sci., **8**: 219-232.

Sampey, A., McKinnon, A.D., Meekan, M.G., Mc Cormick, M.I., 2007. Glimpse into guts: Overview of the feeding of larvae of tropical shore. *Mar. Ecol. Progr. Ser*., **339**: 243-257. https://doi.org/10.3354/meps339243

Santos-Wisniewski, M., Rocha, O., Guntzel, A. and Matsumura-Tundisi, T., 2006. Aspects of the life cycle of *Chydorus pubescens Sars*, 1901 (Cladocera, Chydoridae). *Acta Limn. Brasil*., **18**: 305–310.

Schallenberg, M., Hall, C.J. and Burns, C.W., 2003. Consequences of climate-induced salinity increases on zooplankton abundance and diversity in coastal lakes. *Mar. Ecol. Prod. Ser*., **251**: 181-189. https://doi.org/10.3354/meps251181

Shannon, C.E. and Weaver, W., 1949. *The mathematical theory of communication*. University Illinois Press. Urbana, pp. 117.

Shin, S.S., Choi, S.Y., Seo, M.H., Lee, S.J., Soh, H.Y.

and Youn, S.H., 2022. Spatiotemporal distribution characteristics of copepods in the water masses of the Northeastern East China Sea. *J. Mar. Sci. Eng.,* **10**: 754. https://doi.org/10.3390/jmse10060754

Siddiqui, P.J., Farooq, S., Shafique, S., Burhan, Z. and Farooqi. Z., 2008. Conservation and management of biodiversity in Pakistan through the establishment of marine protected areas. *Ocean Coast Manage*., **51**: 377-382. https://doi.org/10.1016/j.ocecoaman.2008.01.006

Sieburth, J.M., Smetacek, V. and Lenza, J., 1978. Pelagic ecosystem structure: Heterotrophic compartments and their relationship to plankton size fractions. *Limn. Ocean*, **23**: 1256-1263. https://doi.org/10.4319/lo.1978.23.6.1256

Soetaert, K. and Rijswijk, P.V., 1993. Spatial and temporal patterns in Wester schelde zooplankton. *Mar. Ecol. Pro. Ser.,* **97**: 47–59. https://doi.org/10.3354/meps097047

Søreide, J.E., Leu, E., Berge, J., Graeve, M. and Falk-Petersen, S., 2010. Timing of blooms, algal food quality and *Calanus glacialis* reproduction and growth in a changing Arctic. *Glob. Change Biol*., **16**: 3154–3163. https://doi.org/10.1111/j.1365-2486.2010.02175.x

Steinberg, D.K., Pilskain, C.H. and Silver, M.W., 1998. Contribution of zooplankton associated with detritus to sediment trap swimmer carbon in Monterey Bay, California, U.S.A, *Mar. Ecol. Pro. Ser.,* **164**: 157-166. https://doi.org/10.3354/meps164157

Stirling, G. and Wilsey, B., 2001. Empirical relationships between species richness, evenness, and proportional diversity. *Am. Natur*., **158**: 286–299. https://doi.org/10.1086/321317

Strickland, J.D.H. and Parsons, T.R., 1972. A practical handbook for seawater analysis. *Fish. Res. Board Can.,* pp. 167-311.

Sun, X., Zhang, H., Wang, Z., Huang, T. and Huang, H., 2022. Phytoplankton community response to environmental factors along a salinity gradient in a Seagoing River, Tianjin, China. *Microorganisms*, **11**: 75. https://doi.org/10.3390/microorganisms11010075

Tan, Y., Huang, L. and Chen, Q. and Huang, X., 2004. Seasonal variation in zooplankton composition and grazing impact on phytoplankton standing stock in the Pearl River Estuary, China, *Contin. Shelf Res.* **24**: 1949-1968. https://doi.org/10.1016/j.csr.2004.06.018

Tewari, A., Joshi, H.V., Trivedi, R.H., Sravankumar, V.G., Raghunathan, C., Khambhaty, Y., Kotiwar, O.S. and Mandal, S.K., 2001. The effect of ship scrapping industry and its associated wastes on the biomas production and biodiversity of biota in *in situ* condition at Alang. *Mar. Poll. Bull.,* **42**: 462-469. https://doi.org/10.1016/S0025-326X(00)00185-5

Tse, P., Hui, S.Y. and Wong, C.K., 2007. Species composition and seasonal abundance of Chaetognatha in the subtropical coastal waters of Hong Kong. *Estuar. Coast. Shelf. Sci*., **73**: 290–298. https://doi.org/10.1016/j.ecss.2007.01.011

Uye, S., 1994. Replacement of large copepods by small ones with eutrophication of embayments: Cause and consequence. *Hydrobiologia,* **292/293**: 513–519. https://doi.org/10.1007/BF00229979

Wroblewski, J.S., 1980. A simulation of the distribution of *Acartia clause* during the Oregon upwelling, August 1973. *J. Plank. Res.,* **2**: 43-68. https://doi.org/10.1093/plankt/2.1.43

Zadereev, E., Drobotov, A., Anishchenko, O., Kolmakova, A., Lopatina, T., Oskina, N. and Tolomeev, A., 2022. The structuring effects of salinity and nutrient status on zooplankton communities and trophic structure in Siberian Lakes. *Water*, **14**: 1468. https://doi.org/10.3390/w14091468

Zafar, M., 2000. *Study on Sergestid shrimp* Acetes *in the vicinity of Matamuhuri river confluence, Bangladesh*. Ph. D. thesis, University of Chittagong, Bangladesh, pp. 320.

Zaitsev, Y.P., 1992. Recent changes in the trophic structure of the Black Sea. *Fish. Ocean*, **2**: 180–189. https://doi.org/10.1111/j.1365-2419.1992.tb00036.x

Zhao, W., Dai, L., Chen, X., Wu, Y., Sun, Y. and Zhu, L., 2022. Characteristics of zooplankton community structure and its relationship with environmental factors in the south Yellow Sea. *Mar. Pollut. Bull*., **176**: 113471. https://doi.org/10.1016/j.marpolbul.2022.113471

Zingel, P., 2005. Vertical and seasonal dynamics of planktonic ciliates in a strongly stratified hypertrophic lake. *Hydrobiologia*, **547**: 163-174. https://doi.org/10.1007/s10750-005-4157-7