*Journal of the Marine Biological Association of the United Kingdom*

**cambridge.org/mbi**

**Research Article**

**Cite this article:** Darvishnia Z, Sari A, Attaran-Fariman G, Seyfabadi J (2024). Spatiotemporal fluctuations in surface copepods community structure in Chabahar Bay, Gulf of Oman, Iran. *Journal of the Marine Biological Association of the United Kingdom* **104**, e114, 1–17. https://doi.org/10.1017/S002531542400105X

Received: 14 September 2024
Revised: 3 October 2024
Accepted: 7 October 2024

**Keywords:**
Chabahar Bay; diversity; environmental parameters; monsoon; surface copepods

**Corresponding author:**
Gilan Attaran-Fariman;
Email: Gilan.attaran@gmail.com

© The Author(s), 2024. Published by Cambridge University Press on behalf of Marine Biological Association of the United Kingdom

# Spatiotemporal fluctuations in surface copepods community structure in Chabahar Bay, Gulf of Oman, Iran

Zahra Darvishnia[1], Alireza Sari[2], Gilan Attaran-Fariman[3] and Jafar Seyfabadi[1]

[1]Department of Marine Biology, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Noor, Iran; [2]School of Biology and Centre of Excellence in Phylogeny, College of Science, University of Tehran, Tehran, Iran and [3]Department of Marine Biology, Faculty of Marine Sciences, Chabahar Maritime University, Chabahar, Iran

## Abstract

In the present study, the spatiotemporal distribution and community structure of surface copepods were investigated in Chabahar Bay, Gulf of Oman, through a year-long sampling programme divided into four distinct periods: post-monsoon (POM), northeast monsoon, pre-monsoon (PRM), and southwest monsoon (SWM). Sampling was conducted at five locations using a horizontal plankton net with a 100 μm mesh size, from the midnight to dawn period. Environmental parameters (temperature, salinity, pH, and total dissolved solids) were also recorded, revealing significant differences ($P < 0.0005$) across seasons and locations. A total of 38 copepod genera, belonging to five orders and 22 families, were identified, accounting for 66% of the total zooplankton population, while the remaining 34% consisted of non-copepod organisms. The highest and lowest mean abundances of copepods were recorded during the PRM and POM periods, respectively. Excluding copepod larvae, Cyclopoida and Calanoida exhibited the highest annual mean abundances, while Monstrilloida had the lowest. Results show the highest annual mean abundance belongs to the genera *Oithona* with 167,382 ± 11,089 ind. $m^{-3}$, *Temora* with 52,250 ± 3691 ind. $m^{-3}$, *Paracalanus* with 40,041 ± 2256 ind. $m^{-3}$, *Acartia* with 34,822 ± 3876 ind. $m^{-3}$, *Euterpina* with 34,313 ± 1542 ind. $m^{-3}$, and *Oncea* with 34,033 ± 2951 ind. $m^{-3}$. However, the lowest value of 794 ± 259 ind. $m^{-3}$ belonged to the genus *Cymbasoma*. The highest mean diversity index ($H'$) was observed in SWM and POM, while the highest mean species richness index ($D$) was observed in POM and SWM, and the highest mean Pielou's evenness ($J'$) was observed in SWM and POM.

## Introduction

As the most diverse members of the marine zooplankton are found in a wide range of environmental parameters, copepods play a significant role in the planktonic food web (Razouls *et al.*, 2019; Al-Mamun *et al.*, 2020; Walter and Boxshall, 2020). Despite their small size, they play a significant role in keeping water quality by controlling the growth of phytoplankton (Paturej and Kruk, 2011). Population fluctuations of plankton depend on several environmental factors, including the monsoon as a prevailing wind and surface current (Srichandan *et al.*, 2015).

The Chabahar Bay (Iran) is a small semi-tropical bay on the northeast coast of Gulf of Oman. Two distinct summer and winter monsoons and two inter-monsoonal periods (pre-monsoon [PRM] and post-monsoon [POM]), characteristic of the Asian monsoons (Wilson, 2000), affect the Arabian Sea and Gulf of Oman, including the coasts of Oman, Iran, Pakistan, and west coasts of India. Although the monsoons show a lower impact on the coasts of Iran (Caulfield, 1990), it is associated with physical and chemical changes in the water.

The effects of environmental parameters on various aspects of zooplankton (Nour El-Din and AL-Khayat, 2001; Smith and Madhupratap, 2005; Rezai *et al.*, 2014; Al-Mamun *et al.*, 2020; Amidi *et al.*, 2022) and copepods have been widely studied in various parts of Indian Ocean, including estuaries (Madhupratap, 1987; Paul *et al.*, 2019), various coastal regions of the Indian sub-continent (Saravanakumar *et al.*, 2007; Nawaz *et al.*, 2023), the Persian Gulf (Al-Yamani and Prusova, 2003; Al-Yamani and Khvorov, 2007; Ali *et al.*, 2009), Arabian Sea and Gulf of Oman (Kazmi, 2004; D'souza and Gauns, 2018; Smith *et al.*, 2020), and exclusively Chabahar Bay (Fallahi *et al.*, 2003; Peyghan *et al.*, 2011; Fazeli *et al.*, 2013, 2015; Hedayati *et al.*, 2017; Nazari *et al.*, 2018a, 2018b). Going through the above literature, none of these has focused on the diversity and species richness of surface copepods in relation to the environmental factors, particularly in the Chabahar Bay, which has been dealt with in the current study, accordingly. In the present study, the changes of environmental parameters in different seasons on the distribution, density, abundance, and structure of the communities of surface copepods in Chabahar Bay have been investigated, and it is assumed that the environmental parameters, particularly temperature fluctuations, salinity, and pH, are the key factors in the distribution, abundance, and density of copepods.

Considered as a free zone, Chabahar Port is expected to develop further that may cause pollution. In addition to the lack of monitoring surveys in the Chabahar Bay, there is a need to gather environmental and biological data in this water body. This study aims to investigate the effects of regional development to provide ecological and taxonomic data for monitoring studies further.

## Materials and methods

### *Study area*

The Gulf of Oman is warm and mainly affected by the tropical climate due to its location in the north of the Tropic of Cancer. The Gulf of Oman is along the western side of the Arabian Sea in the northwestern part of the Indian Ocean. The surface waters of the Indian Ocean with relatively low salinity of the Gulf of Oman enter the Persian Gulf through the Strait of Hormuz. The surface waters of the Gulf of Oman are dominated by the oceanic water of the Indian Ocean, which flows along the coast of Iran mixed with some cool water transported during the northeast monsoon (NEM) from December to March. During June–September, upwelling continues along the southern coast of Oman (Arabian Sea), leading to a decrease in water temperature in the Gulf of Oman during summer. Chabahar Bay, located in southeast of Iran, has a moderate tropical climate with high relative humidity. The connection of Iran's waters to the Indian Ocean through the Gulf of Oman exposes the region to the monsoon winds of the Indian Ocean (Al-Hashmi *et al.*, 2019).

The zooplankton samples were collected during four periods, including December 2021 (POM), January 2022 (NEM), May 2022 (PRM), and September 2022 (southwest monsoon [SWM]). The sampling was conducted from the mid-night to dawn. Five stations (Figure 1) were selected in the Chabahar Bay based on costal activities such as vicinity to international port (st.1), local port (st.2), Tis fishing port (st.3), centre of Chabahar Bay as a less-disturbed location (st.4), and old fishing and goods port in the city coastal area (st.5). The geographical location of each was GPS marked (Table 1).

**Table 1.** Coordinates of each sampling locality in Chabahar Bay

| Stations | Coordinates |
|---|---|
| St.1 (Shahid Beheshti Port) | 25°18′56″N, 60°36′05″E |
| St.2 (Shahid Kalantari Port) | 25°18′44″N, 60°36′11″E |
| St.3 (Tis fishing Port) | 25°22′21″N, 60°34′05″E |
| St.4 (Chabahar Bay centre) | 25°19′22″N, 60°35′44″E |
| St.5 (7th Tir Port) | 25°17′47″N, 60°37′31″E |

### *Sampling method*

The zooplankton samples were collected from the surface waters of Chabahar Bay using a Hydrobios® plankton net (30 cm aperture, 1.2 m total length, and 100 μm mesh size) equipped with a calibrated flowmeter for calculating the volume of filtered seawater. The net was towed horizontally at the water surface in five localities in the Chabahar Bay. All zooplankton samples (kept in 60 polyethylene containers of 300 $cm^3$) were immediately fixed and preserved in a 4% solution of formaldehyde in seawater and then their volumes were adjusted to 300 ml (Omori and Ikeda, 1984).

The environmental parameters including water surface temperature, salinity, pH, total dissolved solids (TDS), and dissolved oxygen (DO) were obtained *in situ* using a hand-held multiparameter probe Lutron® WA-2017SD for temperature, and ATi® R-pH instrument for other factors. At each station, water samples were collected in chlorophyll-*a* concentration. This was measured in a laboratory using a spectrophotometer UPLAB® at absorption wavelengths of 630, 647, and 664 nm following Jeffrey and Humphrey (1975).

In the laboratory, three replicates of 1 ml plankton samples in preserving fluid from each locality and season were transferred into a counting cell instrument and copepod/zooplankton individuals were sorted and then counted under a compound microscope ZEISS and a stereomicroscope WILD M3. Only adult copepods were identified and named to the genus level. The zooplankton abundances were expressed as the number of individuals per cubic metre (ind. $m^{-3}$) following Postel *et al.* (2000). Identification of copepods was verified using available keys (Conway *et al.*, 2006; Al-Yamani *et al.*, 2011; Prusova *et al.*, 2011; Conway, 2012; Richardson *et al.*, 2013). In the present study, the taxonomic nomenclature is adopted from the World Register of Marine Species (2024). The copepod diversity indices were calculated using the Shannon–Wiener diversity index '*H*′' (Shannon and Wiener, 1949), Margalef's species richness '*D*' (Margalef, 1968), and Pielou's evenness '*J*′' (Pielou, 1969).

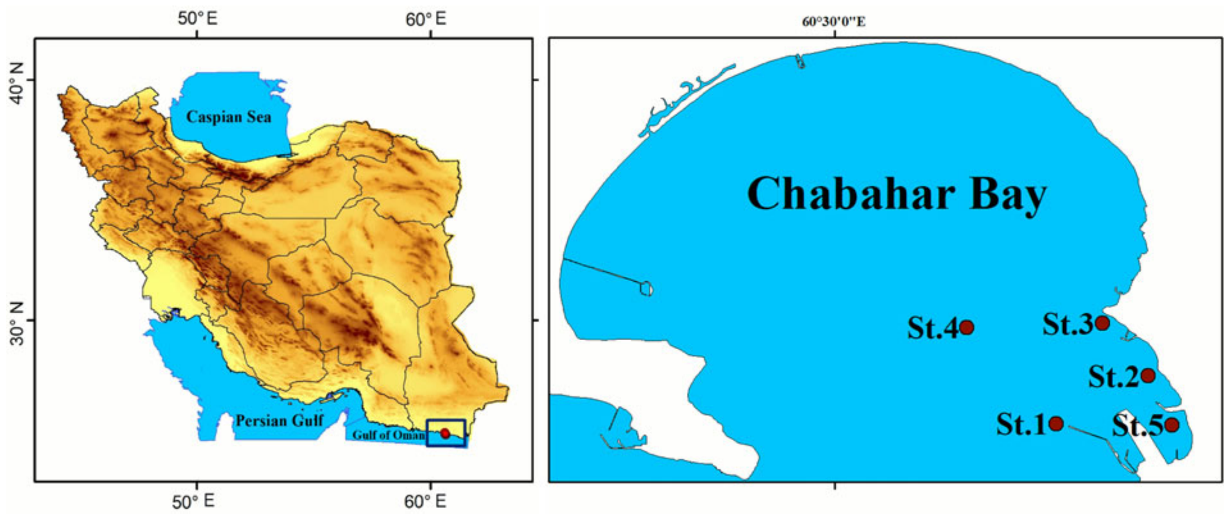


**Figure 1.** Sampling localities in Chabahar Bay, Gulf of Oman.

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

### Statistical analyses

To examine the normality of data, the Kolmogrov-Smirnov test was used. Then parametric tests were applied, as the data were normally distributed. Analysis of variance (ANOVA) using multiple comparison Tukey's *b* test was applied to find significant differences among mean annual abundances of copepod communities in and between each station and season using IBM SPSS Statistics software (Ver. 27). To determine the relationship between environmental parameters in different seasons and five sampling stations in the Chabahar Bay, principal component analysis (PCA) was performed. Temporal and spatial differentiation of the copepod communities among seasons and stations were visualized through non-metric multidimensional scaling (nMDS) and cluster analyses, which grouped copepod genera and assessed the similarities and differences between the stations and seasons of the year. Based on square root transformed genera abundances, the analysis used the Bray–Curtis similarity matrix to group season and stations. A similarity percentage contribution (SIMPER) analysis was performed for the observed differences of genera in different seasons and stations. The PCA, nMDS, cluster, and SIMPER analyses were performed using the PRIMER v6 statistical package (Clarke and Gorley, 2006).

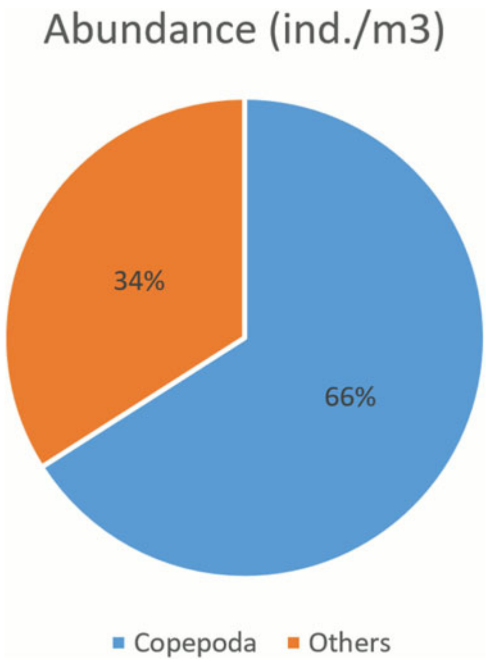


**Figure 2.** Copepod community relative abundance (%) and other zooplankton groups in Chabahar Bay.

## Results

### Environmental factors

The environmental parameters (mean ± SE) in the Chabahar Bay in different seasons are presented in Table 2. The results revealed that the greatest average temperature was recorded in SWM (24.40 ± 0.13°C) and POM (24.40 ± 0.21°C) while the lowest was observed in NEM (22.60 ± 0.13°C) ($N = 15$; $F = 31.294$; $P < 0.0005$). The highest mean value of salinity was recorded in PRM (38.00 ± 0.00 psu) and the lowest was recorded in SWM (36.25 ± 0.07 psu) ($N = 15$; $F = 76.99$; $P < 0.0005$). The highest and lowest mean pH values were recorded as 8.17 ± 0.004 and 7.44 ± 0.12 in NEM and SWM, respectively ($N = 15$; $F = 21.07$; $P < 0.0005$). The highest and lowest mean DO values were recorded in NEM and SWM as 6.76 ± 0.13 and 3.60 ± 0.10 mg $l^{-1}$, respectively ($N = 15$; $F = 84.08$; $P < 0.0005$). The highest and lowest mean TDS values were recorded in SWM and NEM as 56.93 ± 0.40 and 53.45 ± 0.46 mg $l^{-1}$, respectively ($N = 15$; $F = 20.90$; $P < 0.0005$). The highest and lowest mean values of chlorophyll-*a* were recorded in POM and NEM as 0.89 ± 0.12 and 0.08 ± 0.01 μg $ml^{-1}$, respectively ($N = 15$; $F = 43.53$; $P < 0.0005$). The results of ANOVA of environmental parameters in different seasons show that there is no significant difference between the average temperatures in SWM and POM, but there is a significant difference with other seasons ($P < 0.0005$). There is significant difference between the average salinity in pre-monsoon with other seasons ($P < 0.0005$). There is a significant difference between the average pH in NEM and other seasons ($P < 0.0005$). There is a significant difference between the average DO in NEM and other seasons ($P < 0.0005$). There is no significant difference between the average TDS in SWM, PRM, and POM, but there is a significant difference with NEM ($P < 0.0005$). Also, there is a significant difference between the average chlorophyll-*a* in POM and other seasons ($P < 0.0005$).

### Zooplankton community composition

In the present study, 38 copepod genera were identified which belonged to five orders and 22 families. The results of the current survey revealed that the total population of zooplankton community was remarkably diverse and comprised of 66% copepods and 34% non-copepods (Figure 2).

### Abundance of copepods

The comparison of analyses of variances of mean copepod abundance showed the highest value as 393,005 ± 21,324 ind. $m^{-3}$ in PRM ($N = 469$; $F = 104.394$; $P < 0.0005$). While in POM, the mean abundance of copepods was recorded as 38,792 ± 2339 ind. $m^{-3}$ ($N = 561$; $F = 104.394$; $P < 0.0005$). In addition, the results of the ANOVA (Table 3) showed that there is a significant difference between the mean abundance of copepods in PRM and other seasons ($P < 0.0005$) (Table S1, Supplementary material).

The comparison of ANOVA of the five studied copepod orders showed that, regardless of copepod larvae, the highest annual mean abundance of copepods belongs to the Cyclopoida

**Table 2.** Environmental parameter values (mean ± SE) in Chabahar Bay during the current survey

| Season | Temperature (°C) | Salinity (psu) | pH | DO (mg $l^{-1}$) | TDS (mg $l^{-1}$) | Chlorophyll-*a* (μg $ml^{-1}$) |
|---|---|---|---|---|---|---|
| POM | 24.40 ± 0.21$^{a}$ | 37.37 ± 0.12$^{b}$ | 7.85 ± 0.023$^{b}$ | 4.32 ± 0.25$^{b}$ | 56.09 ± 0.14$^{a}$ | 0.89 ± 0.12$^{a}$ |
| NEM | 22.60 ± 0.13$^{c}$ | 36.56 ± 0.10$^{c}$ | 8.17 ± 0.004$^{a}$ | 6.76 ± 0.12$^{a}$ | 53.45 ± 0.46$^{b}$ | 0.08 ± 0.01$^{b}$ |
| PRM | 23.40 ± 0.13$^{b}$ | 38.00 ± 0.00$^{a}$ | 7.92 ± 0.023$^{b}$ | 3.98 ± 0.06$^{b,c}$ | 56.58 ± 0.29$^{a}$ | 0.09 ± 0.01$^{b}$ |
| SWM | 24.40 ± 0.13$^{a}$ | 36.25 ± 0.07$^{d}$ | 7.44 ± 0.12$^{c}$ | 3.60 ± 0.10$^{c}$ | 56.93 ± 0.40$^{a}$ | 0.10 ± 0.01$^{b}$ |

Unmatched letters in each column show a significant difference.

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

**Table 3.** Mean abundance (ind. $m^{-3}$) of copepods in different seasons in Chabahar Bay

| Season | *N* | Mean ± SE | Maximum | Minimum | Sum (ind. $m^{-3}$) | % of total sum |
|---|---|---|---|---|---|---|
| POM | 561 | 38,792 ± 2339 | 42,622 | 34,551 | 116,377 | 4.7 |
| NEM | 595 | 213,324 ± 13,700 | 236,841 | 189,388 | 639,972 | 25.8 |
| PRM | 469 | 393,005 ± 21,324 | 420,532 | 351,032 | 1,179,016 | 47.5 |
| SWM | 528 | 182,571 ± 12,788 | 203,581 | 159,435 | 547,712 | 22.1 |
| Total | 2153 | 206,923 ± 38,480 | 420,532 | 34,551 | 2,483,077 | 100 |

*N*, number of individual of copepods.

291,266 ± 20,554 ind. $m^{-3}$ ($N = 835$; $F = 77.782$; $P < 0.0005$) and Calanoida 261,497 ± 21,970 ind. $m^{-3}$ ($N = 1003$; $F = 77.782$; $P < 0.0005$), while, the lowest mean abundance 794 ± 259 ind. $m^{-3}$ ($N = 3$; $F = 77.782$; $P < 0.0005$) belongs to the Monstrilloida (Figure 3). The results of the ANOVA showed that there is no significant difference between the mean abundance of Cyclopoida and Calanoida, but there is a significant difference with other orders ($P < 0.0005$) (Table S2, Supplementary material).

The results of ANOVA among copepod orders in different seasons indicated that, regardless of copepod larvae, in POM the Calanoida with 16,005 ± 731 ind. $m^{-3}$ ($N = 231$; $F = 97.948$; $P < 0.0005$) and Cyclopoida with 15,517 ± 1481 ind. $m^{-3}$ ($N = 258$; $F = 97.948$; $P < 0.0005$) presented the highest mean abundance. Similarly, in the NEM, Cyclopoida with 85,808 ± 5900 ind. $m^{-3}$ ($N = 245$; $F = 105.772$; $P < 0.0005$), in PRM, Cyclopoida with 141,205 ± 10,495 ind. $m^{-3}$ ($N = 173$; $F = 58.717$; $P < 0.0005$), and in SWM, Calanoida with 75,993 ± 7441 ind. $m^{-3}$ ($N = 267$; $F = 51.872$; $P < 0.0005$) demonstrated greater mean values (Figure 4). The results of the ANOVA showed that there is no significant difference between the mean abundance of Calanoida and Cyclopoida in POM, but there is a significant difference with other orders in this season ($P < 0.0005$). Also, there is a significant difference between the mean abundance of the Cyclopoida and other orders in the NEM and PRM. In the SWM, there is a significant difference between the mean abundance of the Calanoida and other orders ($P < 0.0005$) (Table S3, Supplementary material).

The comparison of differences in the mean abundance of copepod orders in different stations revealed that regardless of the copepod larvae, in the st.1 Cyclopoida with 120,643 ± 9952 ind. $m^{-3}$ ($N = 204$; $F = 67.128$; $P < 0.0005$) and Calanoida with 109,568 ± 6963 ind. $m^{-3}$ ($N = 285$; $F = 67.128$; $P < 0.0005$), in the st.2 Cyclopoida with 51,055 ± 4721 ind. $m^{-3}$ ($N = 173$; $F = 28.729$; $P < 0.0005$), in the st.3 Cyclopoida with 54,943 ± 4377 ind. $m^{-3}$ ($N = 180$; $F = 70.129$; $P < 0.0005$) and Calanoida with 46,404 ± 2700 ind. $m^{-3}$ ($N = 222$; $F = 70.129$; $P < 0.0005$) were dominant. While, in the st.4 Calanoida with 32,307 ± 3931 ind. $m^{-3}$ ($N = 172$; $F = 39.016$; $P < 0.0005$) and Cyclopoida with 24,812 ± 1101 ind. $m^{-3}$ ($N = 125$; $F = 39.016$; $P < 0.0005$) and in st.5 Calanoida with 43,193 ± 3960 ind. $m^{-3}$ ($N = 176$; $F = 74.739$; $P < 0.0005$) and Cyclopoida with 39,814 ± 2040 ind. $m^{-3}$ ($N = 153$; $F = 74.739$; $P < 0.0005$) represented the highest mean abundance (Figure 5). The results of the ANOVA showed that in st.1 and st.3, there is no significant difference between the mean abundance of Cyclopoida and Calanoida, but there is a significant difference with other orders in these two stations ($P < 0.0005$). In st.2, there is a significant difference between the mean abundance of Cyclopoida and other orders ($P < 0.0005$). In st.4 and st.5, there is no significant difference between the mean abundance of Calanoida and Cyclopoida, but there is a significant difference with other orders in these two stations ($P < 0.0005$) (Table S4, Supplementary material).

The comparison of means among copepod family members using ANOVA showed that, regardless of copepod larvae, the highest annual mean abundances were belonged to Oithonidae with 167,382 ± 11,089 ind. $m^{-3}$ ($N = 344$; $F = 147.324$; $P < 0.0005$), Paracalanidae 73,777 ± 4487 ind. $m^{-3}$ ($N = 273$; $F = 147.324$; $P < 0.0005$), Corycaeidae 59,823 ± 4229 ind. $m^{-3}$ ($N =$

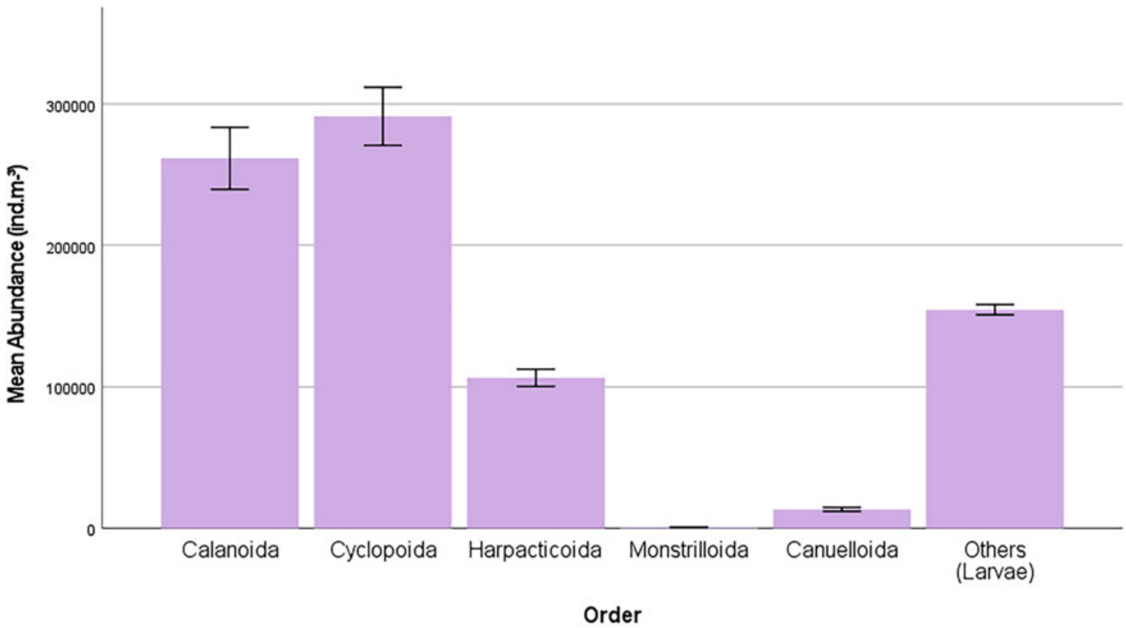


**Figure 3.** Annual mean abundances (±SE) of different orders of copepods in Chabahar Bay.

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

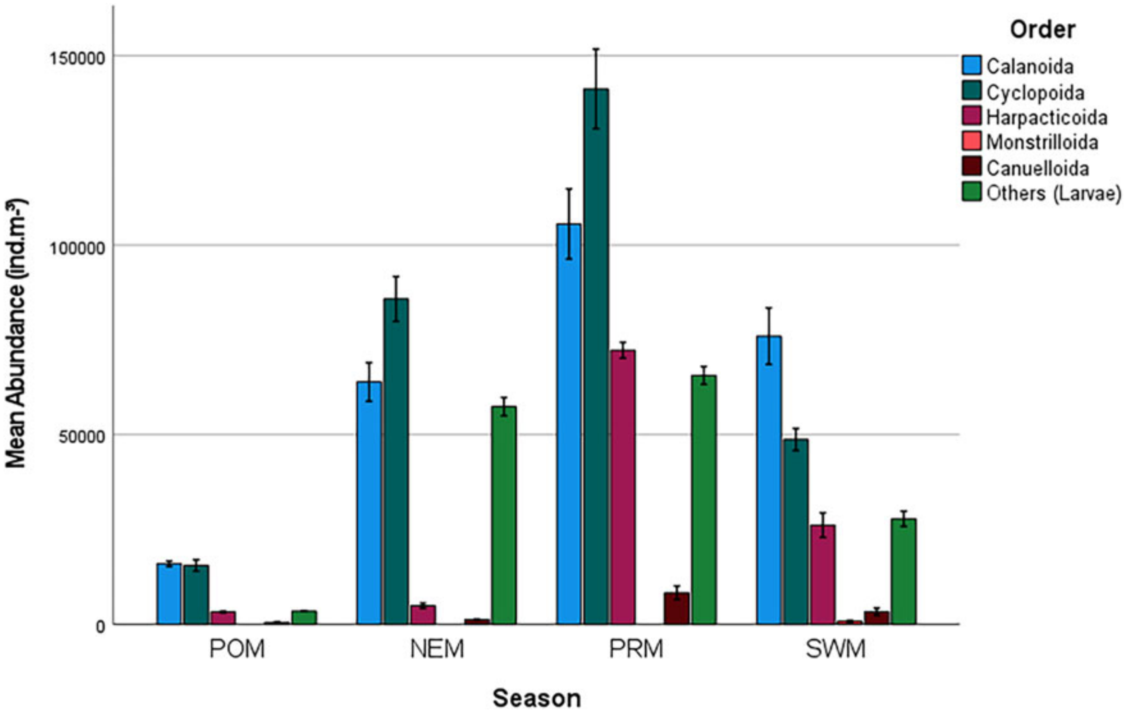


**Figure 4.** Mean abundance ± SE of different orders of copepods in different seasons in Chabahar Bay. POM, post-monsoon; NEM, northeast monsoon; PRM, pre-monsoon; SWM, southwest monsoon.

228; $F = 147.324$; $P < 0.0005$), and Temoridae 52,250 ± 3691 ind. $m^{-3}$ ($N = 166$; $F = 147.324$; $P < 0.0005$). However, the lowest abundance values with 794 ± 259 ind. $m^{-3}$ belonged to the Monstrillidae ($N = 3$; $F = 147.324$; $P < 0.0005$) (Figure S1, Supplementary material). The results of the ANOVA showed that there is no significant difference between the mean abundance of the Paracalanidae and Corycaeidae, as well as the Corycaeidae and Temoridae, but there is a significant difference between other families ($P < 0.0005$) (Table S5, Supplementary material).

The results of ANOVA in different seasons, by combining the all stations data, showed that regardless of copepod larvae, in POM, the Paracalanidae with 9099 ± 529 ind. $m^{-3}$ ($N = 73$; $F = 93.391$; $P < 0.0005$; Figure S2A, Supplementary material), in NEM, Oithonidae with 52,061 ± 3817 ind. $m^{-3}$ ($N = 101$; $F = 178.836$; $P < 0.0005$; Figure S2B, Supplementary material), in PRM, Oithonidae with 89,836 ± 4540 ind. $m^{-3}$ ($N = 85$; $F = 140.772$; $P < 0.0005$; Figure S2C, Supplementary material) and in SWM, Temoridae with 21,068 ± 1962 ind. $m^{-3}$ ($N = 48$; $F = 37.264$; $P < 0.0005$), Oithonidae with 20,105 ± 2318 ind. $m^{-3}$ ($N$

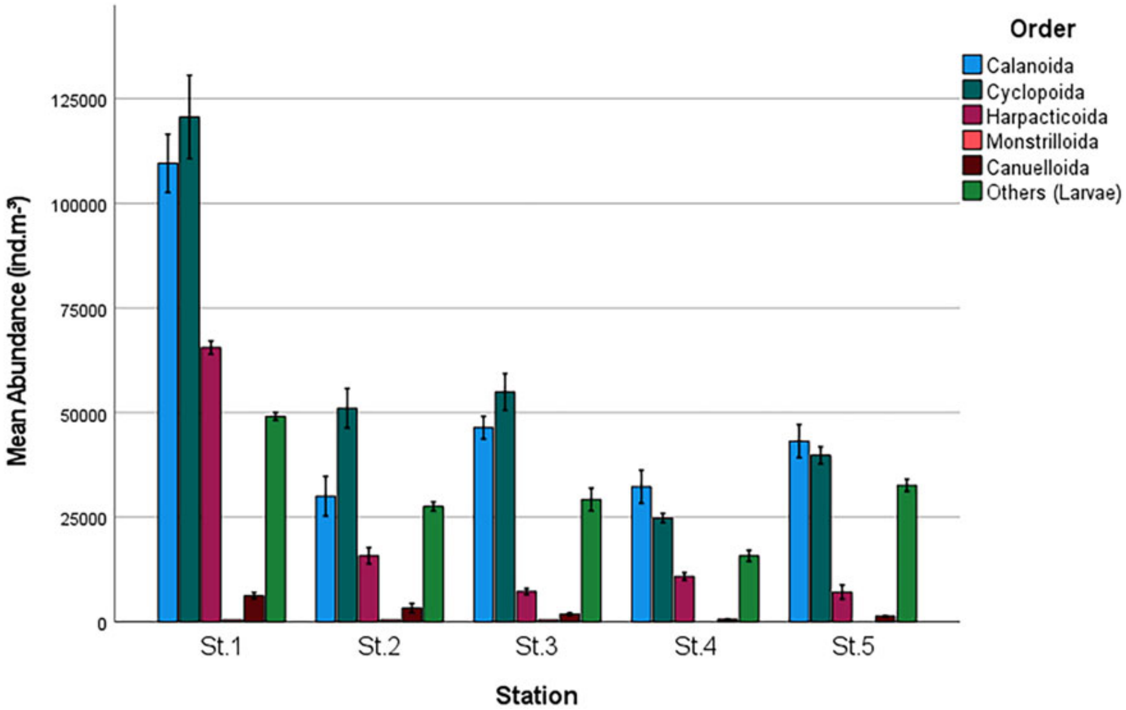


**Figure 5.** Mean abundance ± SE of different orders of copepods in different stations in Chabahar Bay.

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

= 60; $F = 37.264$; $P < 0.0005$) (Figure S2D, Supplementary material) presented the highest mean abundance. The results of the ANOVA showed that there is no significant difference between the mean abundance of Temoridae and Oithonidae in SWM but there is a significant difference with others ($P < 0.0005$). Also, there is a significant difference between the mean abundance of dominant families with others ($P < 0.0005$) (Table S6, Supplementary material).

The comparison of the mean abundance of copepod families in different stations showed that, regardless of copepod larvae, the Oithonidae presented the highest values as follows: in st.1 (Figure S3A, Supplementary material) with 73,641 ± 4759 ind. $m^{-3}$ ($N = 74$; $F = 111.479$; $P < 0.0005$), in st.2 (Figure S3B, Supplementary material) with 25,234 ± 1276 ind. $m^{-3}$ ($N = 70$; $F = 76.227$; $P < 0.0005$), in st.3 (Figure S3C, Supplementary material) with 31,083 ± 3301 ind. $m^{-3}$ ($N = 78$; $F = 65.196$; $P < 0.0005$), in st.4 (Figure S3D, Supplementary material) with 11,697 ± 839 ind. $m^{-3}$ ($N = 48$; $F = 38.591$; $P < 0.0005$), and in st.5 (Figure S3E, Supplementary material) with 25,727 ± 1376 ind. $m^{-3}$ ($N = 74$; $F = 119.607$; $P < 0.0005$). Also, the results of the ANOVA showed that there is a significant difference between the mean abundance of the Oithonidae with other families in stations ($P < 0.0005$) (Table S7, Supplementary material).

Comparison of ANOVA of means among different genera of copepods showed that, regardless of copepod larvae, the greatest annual mean abundance (Figure 6) belongs to the genera *Oithona* with 167,382 ± 11,089 ind. $m^{-3}$ ($N = 344$; $F = 202.964$; $P < 0.0005$), *Temora* with 52,250 ± 3691 ind. $m^{-3}$ ($N = 166$; $F = 202.964$; $P < 0.0005$), *Paracalanus* with 40,041 ± 2256 ind. $m^{-3}$ ($N = 142$; $F = 202.964$; $P < 0.0005$), *Acartia* with 34,822 ± 3876 ind. $m^{-3}$ ($N = 115$; $F = 202.964$; $P < 0.0005$), *Euterpina* with 34,313 ± 1542 ind. $m^{-3}$ ($N = 54$; $F = 202.964$; $P < 0.0005$), and *Oncea* with 34,033 ± 2951 ind. $m^{-3}$ ($N = 137$; $F = 202.964$; $P < 0.0005$). While the lowest value with 794 ± 259 ind. $m^{-3}$ ($N = 3$ $F = 202.964$; $P < 0.0005$) belonged to the genus *Cymbasoma*. The results of the ANOVA showed there is a significant difference between the mean abundance of *Oithona* and *Temora* with other genera ($P < 0.0005$). There is no significant difference between the mean abundance of *Paracalanus*, *Acartia*, *Euterpina*, and *Oncea* genera, but there is a significant difference with other genera ($P < 0.0005$) (Table S8, Supplementary material).

The results of ANOVA, by combining all the stations data in different seasons, showed that regardless of copepod larvae in POM the genus *Paracalanus* with 6135 ± 42 ind. $m^{-3}$ ($N = 42$; $F = 68.861$; $P < 0.0005$), *Oithona* with 5380 ± 553 ind. $m^{-3}$ ($N = 98$; $F = 68.861$; $P < 0.0005$) (Table 4) showed the highest mean abundance. In the NEM, the highest mean abundance belonged to the genus *Oithona* with 52,061 ± 3817 ind. $m^{-3}$ ($N = 101$; $F = 186.097$; $P < 0.0005$). The genus *Oithona* with 89,836 ± 4540 ind. $m^{-3}$ ($N = 85$; $F = 169.026$; $P < 0.0005$) had the highest mean abundance in PRM, and in SWM, genus *Temora* with 21,068 ± 1962 ind. $m^{-3}$ ($N = 48$; $F = 42.293$; $P < 0.0005$) and *Oithona* with 20,105 ± 2318 ind. $m^{-3}$ ($N = 60$; $F = 42.293$; $P < 0.0005$) represented the highest mean abundance. The results of ANOVA test showed that there is no significant difference between the mean abundance of *Paracalanus* and *Oithona* in POM but there is a significant difference with other genera in this season ($P < 0.0005$). In NEM and PRM, there is a significant difference between the genus *Oithona* and other genera ($P < 0.0005$). Also, in SWM, there is no significant difference between *Temora* and *Oithona* genera, but there is a significant difference with other genera in this season ($P < 0.0005$) (Table S9, Supplementary material).

The comparison of differences of the mean abundance of copepod genera in different stations, ANOVA analyses showed that, regardless of copepod larvae, the genus *Oithona* in st.1 (Table 5) with 73,641 ± 4759 ind. $m^{-3}$ ($N = 74$; $F = 136.545$; $P < 0.0005$), in st.2 with 25,234 ± 1276 ind. $m^{-3}$ ($N = 70$; $F = 81.877$; $P < 0.0005$), in st.3 with 31,083 ± 3301 ind. $m^{-3}$ ($N = 78$; $F = 70.048$; $P < 0.0005$), in st.4 with 11,697 ± 839 ind. $m^{-3}$ ($N = 48$; $F = 40.276$; $P < 0.0005$), and in st.5 with 25,727 ± 1376 ind. $m^{-3}$ ($N = 74$; $F = 132.005$; $P < 0.0005$) presented the highest mean abundances. The results of ANOVA showed that there are significant differences between the mean abundance of the genus *Oithona* and other genera of copepods in different stations ($P < 0.0005$) (Table S10, Supplementary material).

### Biodiversity indices

In the study of biodiversity indices, the results showed that the highest mean Shannon–Wiener diversity index ($H'$) values were observed in SWM (2.80 ± 0.04) and POM (2.65 ± 0.06), while the lowest values were calculated in NEM (2.33 ± 0.05) and PRM (2.39 ± 0.09) ($N = 15$; $F = 10.94$; $P < 0.0005$). The highest mean Margalef species richness indices ($D$) were observed in POM (2.23 ± 0.11) and SWM (2.09 ± 0.08). The lowest value (1.63 ± 0.14) was recorded in PRM ($N = 15$; $F = 5.64$; $P < 0.002$).

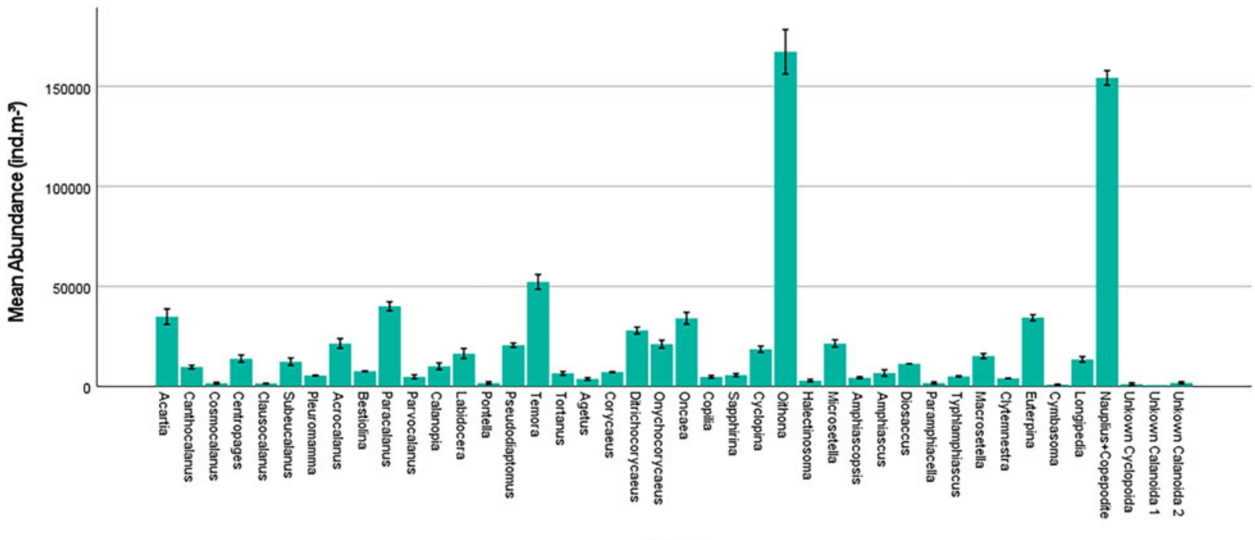


**Figure 6.** Annual mean abundance ± SE of different copepod families in Chabahar Bay.

**Table 4.** Annual mean abundance ± SE (ind. m$^{-3}$) of different genera of copepods in different seasons in Chabahar Bay

| | Season | | | |
|---|---|---|---|---|
| Genus | POM | NEM | PRM | SWM |
| *Acartia* | 991 ± 166 | 5862 ± 727 | 21,363 ± 2317 | 6606 ± 926 |
| *Canthocalanus* | 459 ± 112 | 3810 ± 391 | 4828 ± 619 | 797 ± 268 |
| *Cosmocalanus* | 315 ± 39 | 236 ± 0 | – | 1175 ± 332 |
| *Centropages* | 745 ± 43 | 1934 ± 50 | 5200 ± 644 | 5976 ± 1374 |
| *Clausocalanus* | 340 ± 161 | 1056 ± 65 | – | – |
| *Subeucalanus* | 593 ± 180 | 1980 ± 148 | 5719 ± 809 | 4037 ± 812 |
| *Pleuromamma* | – | – | 1066 ± 267 | 4346 ± 468 |
| *Acrocalanus* | 2141 ± 154 | 6367 ± 650 | 8230 ± 1035 | 4693 ± 729 |
| *Bestiolina* | 574 ± 84 | 2386 ± 418 | 3886 ± 466 | 714 ± 179 |
| *Paracalanus* | 6135 ± 342 | 10,505 ± 963 | 15,863 ± 808 | 7538 ± 576 |
| *Parvocalanus* | 249 ± 36 | 1838 ± 579 | 1333 ± 533 | 1327 ± 219 |
| *Calanopia* | 514 ± 137 | 3100 ± 304 | 3536 ± 1509 | 2873 ± 470 |
| *Labidocera* | 698 ± 38 | 2770 ± 519 | 5409 ± 2621 | 7504 ± 23 |
| *Pontella* | – | – | – | 1663 ± 614 |
| *Pseudodiaptomus* | 68 ± 0 | 12,413 ± 1048 | 5544 ± 1008 | 2563 ± 192 |
| *Temora* | 1889 ± 187 | 7998 ± 768 | 21,294 ± 1199 | 21,068 ± 1962 |
| *Tortanus* | 159 ± 15 | 1824 ± 330 | 2307 ± 372 | 2169 ± 299 |
| *Agetus* | 279 ± 51 | 1478 ± 252 | 1333 ± 533 | 921 ± 307 |
| *Corycaeus* | 824 ± 57 | 1883 ± 300 | 3297 ± 233 | 1086 ± 306 |
| *Ditrichocorycaeus* | 2004 ± 135 | 6967 ± 193 | 12,749 ± 1419 | 6225 ± 625 |
| *Onychocorycaeus* | 1776 ± 92 | 5934 ± 189 | 7788 ± 1634 | 5587 ± 194 |
| *Oncaea* | 2679 ± 402 | 10,114 ± 746 | 14,472 ± 1678 | 6768 ± 855 |
| *Copilia* | 1164 ± 203 | 1569 ± 60 | – | 2516 ± 171 |
| *Sapphirina* | 644 ± 150 | 2208 ± 245 | 1648 ± 232 | 1707 ± 480 |
| *Cyclopina* | 767 ± 99 | 4117 ± 423 | 9461 ± 1094 | 4174 ± 216 |
| *Oithona* | 5380 ± 553 | 52,061 ± 3817 | 89,836 ± 4540 | 20,105 ± 2318 |
| *Halectinosoma* | – | – | 2665 ± 533 | 529 ± 0 |
| *Microsetella* | 1143 ± 76 | 1739 ± 127 | 12,853 ± 1524 | 5696 ± 1033 |
| *Amphiascopsis* | – | – | 1333 ± 533 | 2967 ± 971 |
| *Amphiascus* | – | – | 3213 ± 807 | 3433 ± 990 |
| *Diosaccus* | 106 ± 0 | – | 6996 ± 657 | 4283 ± 651 |
| *Paramphiacella* | – | – | 1333 ± 266 | 1057 ± 0 |
| *Typhlamphiascus* | – | – | 4836 ± 419 | 529 ± 0 |
| *Macrosetella* | 742 ± 96 | – | 10,796 ± 1009 | 3583 ± 338 |
| *Clytemnestra* | 90 ± 22 | – | 2932 ± 267 | 924 ± 204 |
| *Euterpina* | 1269 ± 89 | 3174 ± 555 | 25,311 ± 201 | 4559 ± 949 |
| *Cymbasoma* | – | – | – | 794 ± 259 |
| *Longipedia* | 519 ± 93 | 1277 ± 123 | 8315 ± 1800 | 3339 ± 934 |
| Nauplius + Copepodite | 3472 ± 101 | 57,405 ± 2397 | 65,640 ± 2337 | 27,824 ± 2015 |
| Unknown Calanoida1 | – | – | – | 525 ± 10 |
| Unknown Calanoida2 | 135 ± 0 | – | – | 535 ± 0 |
| Unknown Cyclopoida | – | – | 1862 ± 0 | 1588 ± 530 |

POM, post-monsoon; NEM, northeast monsoon; PRM, pre-monsoon; SWM, southwest monsoon.

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

**Table 5.** Annual mean abundance ± SE (ind. $m^{-3}$) of different genera of copepods in five stations in Chabahar Bay

| Genus | Station | | | | |
|---|---|---|---|---|---|
| | St.1 | St.2 | St.3 | St.4 | St.5 |
| *Acartia* | 20,396 ± 2522 | 2457 ± 717 | 4926 ± 404 | 1988 ± 386 | 5055 ± 640 |
| *Canthocalanus* | 3833 ± 262 | 945 ± 335 | 2374 ± 562 | 1162 ± 361 | 1313 ± 215 |
| *Cosmocalanus* | 755 ± 85 | 63 ± 0 | 106 ± 0 | 897 ± 205 | – |
| *Centropages* | 6225 ± 495 | 1467 ± 188 | 2906 ± 208 | 1431 ± 541 | 1827 ± 675 |
| *Clausocalanus* | 203 ± 68 | 95 ± 32 | 760 ± 109 | 119 ± 40 | 358 ± 172 |
| *Subeucalanus* | 6269 ± 790 | 811 ± 259 | 836 ± 107 | 2427 ± 695 | 1986 ± 407 |
| *Pleuromamma* | 1780 ± 235 | 793 ± 264 | 524 ± 0 | 2249 ± 409 | 758 ± 253 |
| *Acrocalanus* | 9203 ± 1005 | 3027 ± 290 | 3576 ± 436 | 2956 ± 726 | 2668 ± 124 |
| *Bestiolina* | 3082 ± 470 | 444 ± 148 | 2475 ± 200 | 199 ± 40 | 1574 ± 180 |
| *Paracalanus* | 14,761 ± 637 | 4934 ± 721 | 8573 ± 833 | 4464 ± 367 | 7308 ± 685 |
| *Parvocalanus* | 2518 ± 564 | 243 ± 116 | 649 ± 113 | 1417 ± 473 | 473 ± 59 |
| *Calanopia* | 5250 ± 635 | 1184 ± 120 | 1520 ± 262 | 714 ± 152 | 2032 ± 569 |
| *Labidocera* | 6965 ± 2158 | 2347 ± 494 | 3616 ± 216 | 1437 ± 248 | 2015 ± 156 |
| *Pontella* | – | – | 1049 ± 0 | 1227 ± 0 | – |
| *Pseudodiaptomus* | 7227 ± 285 | 2679 ± 529 | 5252 ± 55 | 1993 ± 257 | 3438 ± 575 |
| *Temora* | 19,015 ± 1048 | 7476 ± 1069 | 5881 ± 580 | 7999 ± 1129 | 11,879 ± 1518 |
| *Tortanus* | 1914 ± 488 | 529 ± 0 | 1904 ± 235 | 1024 ± 168 | 1440 ± 113 |
| *Agetus* | 2030 ± 545 | – | 1057 ± 27 | 921 ± 307 | 355 ± 102 |
| *Corycaeus* | 3375 ± 451 | 1072 ± 385 | 2038 ± 77 | 310 ± 192 | 295 ± 59 |
| *Ditrichocorycaeus* | 10,567 ± 1558 | 7370 ± 654 | 4094 ± 177 | 2903 ± 254 | 3011 ± 247 |
| *Onychocorycaeus* | 8858 ± 1499 | 5064 ± 666 | 3062 ± 227 | 2251 ± 593 | 1850 ± 365 |
| *Oncaea* | 10,459 ± 349 | 7605 ± 1451 | 9427 ± 461 | 2839 ± 208 | 3703 ± 652 |
| *Copilia* | 1610 ± 373 | 670 ± 243 | 1151 ± 566 | 488 ± 166 | 807 ± 146 |
| *Sapphirina* | 2233 ± 276 | 380 ± 212 | 1633 ± 421 | 1055 ± 157 | 506 ± 26 |
| *Cyclopina* | 7247 ± 871 | 3660 ± 457 | 1749 ± 164 | 2504 ± 655 | 3360 ± 723 |
| *Oithona* | 73,641 ± 4759 | 25,234 ± 1276 | 31,083 ± 3301 | 11,697 ± 839 | 25,727 ± 1376 |
| *Halectinosoma* | 2665 ± 533 | 529 ± 0 | – | – | – |
| *Microsetella* | 12,608 ± 730 | 2421 ± 530 | 2180 ± 256 | 2296 ± 409 | 1926 ± 475 |
| *Amphiascopsis* | 1333 ± 533 | 1586 ± 0 | 1573 ± 303 | – | 505 ± 0 |
| *Amphiascus* | 2932 ± 705 | 3100 ± 833 | – | 921 ± 307 | – |
| *Diosaccus* | 8005 ± 309 | – | 509 ± 35 | 2094 ± 205 | 706 ± 201 |
| *Paramphiacella* | 1333 ± 266 | 1057 ± 0 | – | – | – |
| *Typhlamphiascus* | 4531 ± 267 | 529 ± 0 | 318 ± 31 | 458 ± 1 | – |
| *Macrosetella* | 10,069 ± 648 | 1850 ± 447 | – | 1454 ± 116 | 1430 ± 180 |
| *Clytemnestra* | 3200 ± 368 | – | – | 1227 ± 0 | 1010 ± 0 |
| *Euterpina* | 18,886 ± 494 | 6680 ± 539 | 2674 ± 395 | 3692 ± 215 | 2382 ± 883 |
| *Cymbasoma* | 535 ± 0 | 529 ± 0 | 524 ± 0 | – | – |
| *Longipedia* | 6265 ± 770 | 3315 ± 1080 | 1858 ± 337 | 646 ± 98 | 1365 ± 184 |
| Nauplius + Copepodite | 49,088 ± 900 | 27,579 ± 1057 | 29,242 ± 2708 | 15,786 ± 1338 | 32,646 ± 1460 |
| Unknown Calanoida1 | 935 ± 400 | – | – | – | – |
| Unknown Calanoida2 | 535 ± 0 | 1410 ± 466 | – | – | – |
| Unknown Cyclopoida | 313 ± 178 | – | – | 458 ± 0 | 555 ± 50 |

The highest mean Pielou's evenness ($J'$) were calculated (Table 6) in SWM (0.90 ± 0.01) and POM (0.88 ± 0.01). The lowest value was calculated in NEM (0.76 ± 0.01) ($N = 15$; $F = 37.22$; $P <$ 0.0005). The results of ANOVA showed that there is no significant difference between the mean Shannon–Wiener diversity index in SWM and POM, but there is a significant difference with NEM

**Table 6.** Biodiversity indices (mean ± SE) of copepods in different seasons at Chabahar Bay

| Season | S | *H′* | | | *D* | | | *J′* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean ± SE | Maximum | Minimum | Mean ± SE | Maximum | Minimum | Mean ± SE | Maximum | Minimum |
| POM | 32 | $2.65 \pm 0.06^{a}$ | 2.98 | 2.18 | $2.23 \pm 0.11^{a}$ | 2.75 | 1.39 | $0.88 \pm 0.01^{a}$ | 0.93 | 0.84 |
| NEM | 28 | $2.33 \pm 0.05^{b}$ | 2.64 | 1.82 | $1.89 \pm 0.07^{ab}$ | 2.25 | 1.41 | $0.76 \pm 0.01^{c}$ | 0.81 | 0.66 |
| PRM | 35 | $2.39 \pm 0.09^{b}$ | 2.98 | 1.76 | $1.63 \pm 0.14^{b}$ | 2.71 | 0.96 | $0.83 \pm 0.01^{b}$ | 0.92 | 0.73 |
| SWM | 41 | $2.80 \pm 0.04^{a}$ | 3.07 | 2.48 | $2.09 \pm 0.08^{a}$ | 2.55 | 1.56 | $0.90 \pm 0.01^{a}$ | 0.94 | 0.85 |

S, total genera; *H′*, Shannon–Wiener diversity index; *D*, Margalef's species richness; *J′*, Pielou's evenness.
Unmatched letters in each column indicate a significant difference.

and PRM ($P < 0.0005$). There is no significant difference between the means of Margalef species richness indices in POM and SWM, but there is a significant difference in PRM ($P < 0.002$). There is no significant difference between the mean Pielou's evenness in POM and SWM, but there is a significant difference in PRM and NEM ($P < 0.0005$) (Table S11, Supplementary material).

### *Relationship between environmental parameters and copepod communities*

The PCA revealed that the first two axes explained 65.8% of the total variation in environmental parameters, including temperature, salinity, DO, pH, TDS, and chlorophyll-*a*. The PCA results indicate that salinity was the most influential factor at the first station during the POM period, while chlorophyll-*a* had the greatest impact at the second and third stations. Both salinity and chlorophyll-*a* were the most significant factors at the fourth and fifth stations during POM. During the NEM, DO exerted a greater influence at all stations. In the PRM and SWM, salinity and TDS were the most important factors in the five stations, respectively (Figure 7).

The relationship between environmental parameters and the most abundant copepod genera (*Oithona*, *Temora*, *Paracalanus*, *Acartia*, *Euterpina*, and *Oncea*) in different seasons is shown in Figure 8. The first two axes of the PCA express 85.2% of the overall changes in environmental parameters (temperature, salinity, DO, pH, TDS, and chlorophyll-*a*) in relation to these genera. The PCA results indicate that, during the PRM, salinity had the greatest influence on these genera.

Cluster analysis and nMDS were employed to examine the similarity of copepod community abundance across different stations and seasons, as depicted in Figure 9. The cluster analysis revealed the highest degree of similarity (82.58%) between st.1 and st.4 during the NEM. Additionally, the nMDS analysis yielded a stress level of 0.06, indicating an excellent correspondence between the stations across different seasons.

SIMPER analysis based on genera abundance data showed that the similarity between stations is mainly caused by the *Paracalanus* (contribution: 22.23%), *Copilia* (contribution:

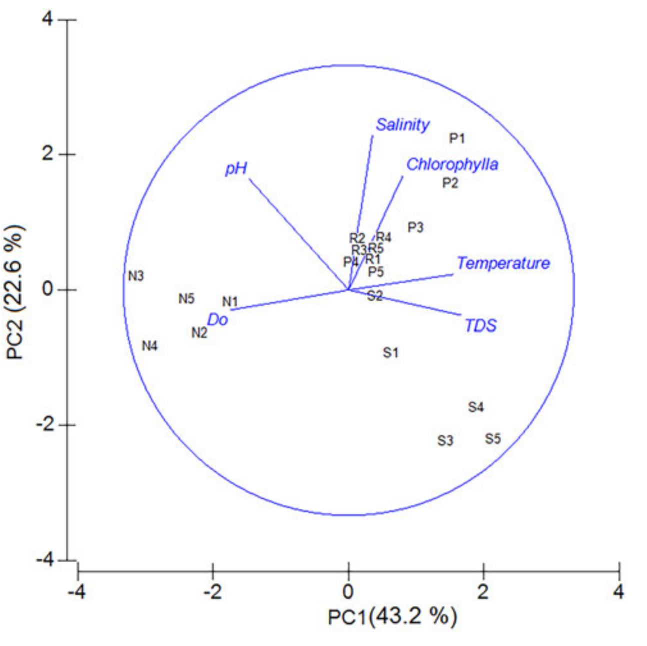


**Figure 7.** PCA results based on environmental parameters in different seasons and stations in Chabahar Bay. P, post-monsoon; N, northeast monsoon; R, pre-monsoon; S, southwest monsoon. 1, st.1; 2, st.2; 3, st.3; 4, st.4; 5, st.5.

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

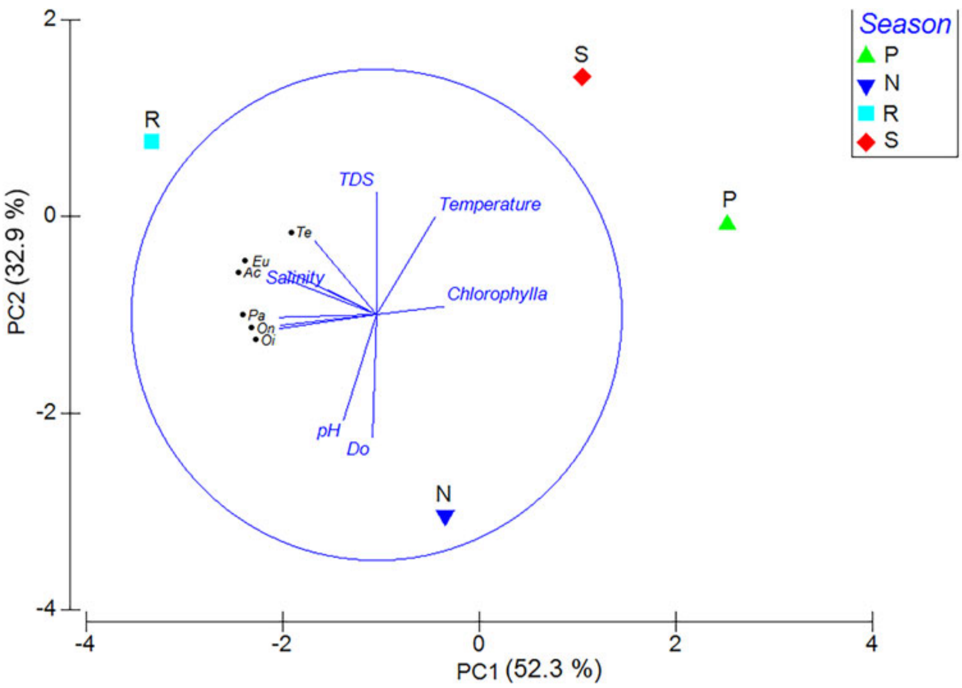


**Figure 8.** PCA based on the relationship between environmental parameters and the most abundant studied genera in different seasons in Chabahar Bay. P, post-monsoon; N, northeast monsoon; R, pre-monsoon; S, southwest monsoon. *Ac*, *Acartia*; *Pa*, *Paracalanus*; *Te*, *Temora*; *On*, *Oncea*; *Oi*, *Oithona*; *Eu Euterpina*.

11.18%), *Bestiolina* (contribution: 9.34%), and *Agetus* (contribution: 6.32%) in POM (1.27% average similarity). The similarity between the stations is due to the *Clausocalanus* (contribution: 24.54%), *Oncaea* (contribution: 12.95%), *Pseudodiaptomus* (contribution: 9.16%), and *Copilia* (contribution: 8.39%) in NEM (14.26% average similarity). The similarity between stations is because of *Typhlamphiascus* (contribution: 3.78%), *Microsetella* (contribution: 3.78%), *Acartia* (contribution: 3.72%), and *Paramphiacella* (contribution: 3.72%) in PRM (73.29% average similarity). The similarity between stations is due to the genera *Cosmocalanus* (contribution: 9.89%), *Pontella* (contribution: 9.26%), *Cymbasoma* (contribution: 6.31%), and *Amphiascopsis* (contribution: 5.72%) in SWM (35.42% average similarity) (Table 7).

## Discussion

### *Environmental factors*

The water quality of the Chabahar Bay has been affected by several factors in recent decades as a result of anthropogenic activities (Burt *et al.*, 2016; Agah *et al.*, 2021). By measuring the environmental parameters at the sampling site, differences in the abundance of zooplanktons are observed (Kang *et al.*, 2010). Previous studies showed that physical and chemical factors such as temperature and salinity are related to changes in the abundance of zooplanktons. The effect of these factors on the abundance and diversity of zooplanktons has been demonstrated in several studies (ROPME, 2003, 2004; Tajevidi *et al.*, 2015).

Temperature fluctuations as a fundamental feature of water conditions are important in regulating many physiological processes of marine organisms and therefore it is one of the most important characteristics of water quality in aquaculture (IEPA, 2001), as it controls water metabolism, and it determines the aquatic habitat area (Ding and Elmore, 2015). Due to the change in pH, salinity, and DO values in the waters of seashores, both in terms of time and geography, it is not possible to provide fixed guideline values for temperature (Agah *et al.*, 2021).

In the current study, the highest mean temperatures were recorded in SWM (24.40 ± 0.13°C) and POM (24.40 ± 0.21°C), while the lowest mean temperature was recorded in NEM (22.60 ± 0.13°C). In the previous studies conducted in the Chabahar Bay by Bordbar *et al.* (2024), the lowest (16°C) and highest (34°C) water surface temperature values were recorded in February and June, respectively. In another study, Ershadifar *et al.* (2021) recorded the elevated temperature (33°C) in the SWM due to the weak thermal stratification caused by the monsoon waves and the high turbulence of the water. This thermal stratification occurs during POM and later disappears in NEM as a result of lower water surface temperature owing to vertical mixing.

In a study of Agah *et al.* (2021), the average temperature values were between 25.5 and 26.6°C in the Chabahar Bay in PRM and POM, respectively. Also, the results showed that the surface water temperature changes in PRM and POM inside the Chabahar Bay were relatively higher than other stations, which can be attributed to the less water exchange in the mouth of the semi-closed bay. According to the report of NOAA Coral Reef Watch (2019), the minimum and maximum annual changes in sea surface temperature in Chabahar Bay in 2017 were observed in February (22.8°C) and June (30.3°C) with an average of 25.7°C.

According to the results of the current study, the highest mean value of salinity was found in PRM (38.00 ± 0.00 psu) and the lowest in SWM (36.25 ± 0.07 psu). According to Ershadifar *et al.* (2021), salinities fluctuate in Chabahar Bay, especially in hot seasons, which is affected by evaporation rate due to shallow depth, semi-closed environment, and limited water flow. In several studies, the measured salinity in Chabahar Bay was between 36.7 and 36.9 psu (Fazeli *et al.*, 2010), 36.6 and 36.7 psu (Agah *et al.*, 2021), and in the Omani waters (Emara, 2010) in February and March at 36.7 psu.

The pH is an important indicator of water quality. The ideal pH for biological productivity is between 6.8 and 8.5 (CCME, 2003), and pH values less than 4 are harmful to aquatic life (Abowei, 2010). Seasonal changes in atmospheric carbon dioxide and phytoplankton activities can affect pH changes in different

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

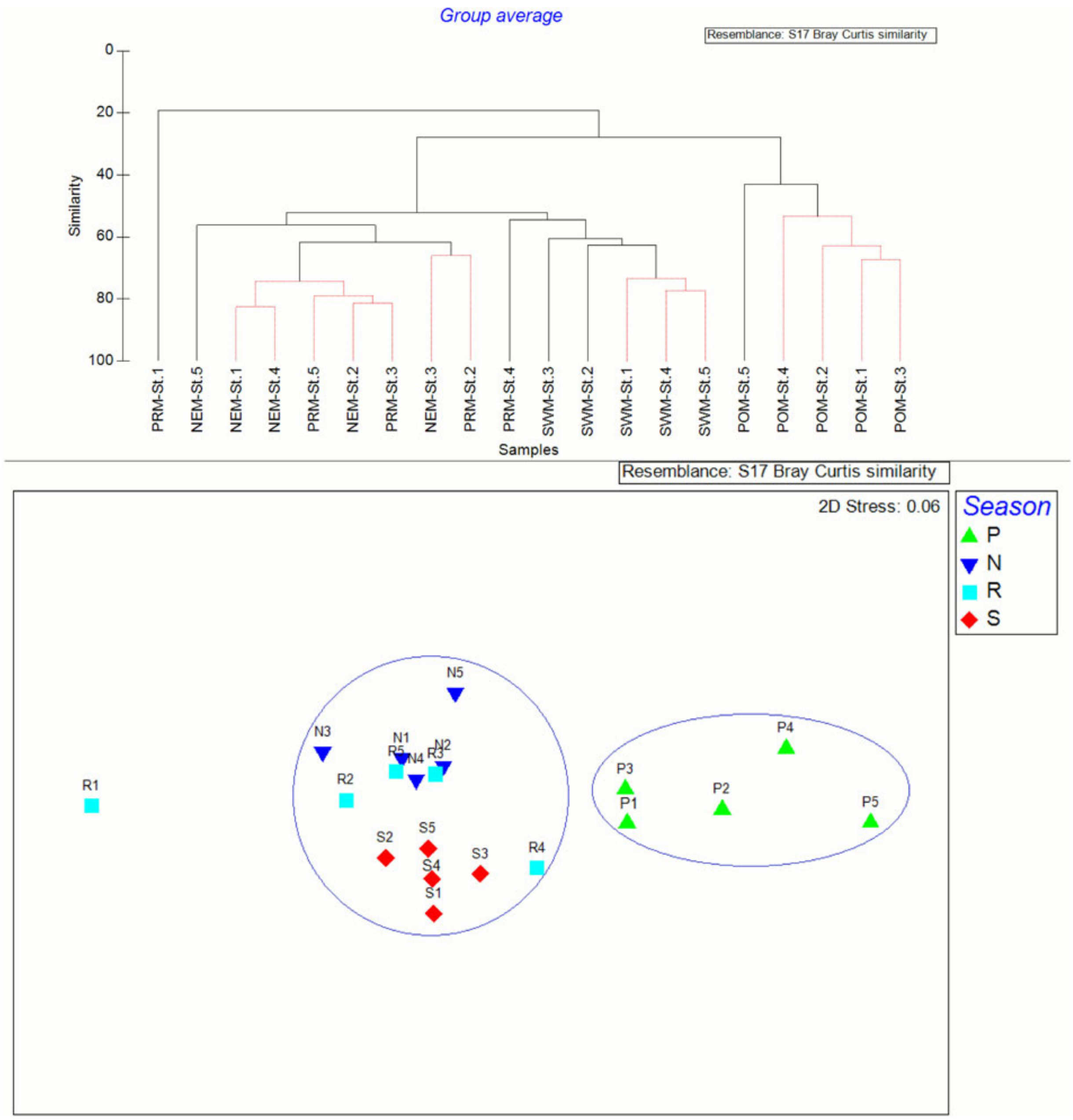


**Figure 9.** Cluster analysis (A) and nMDS ordination plot (B) illustrating the spatial differentiation of copepod communities in different seasons and stations in Chabahar Bay. P, post-monsoon; N, northeast monsoon; R, pre-monsoon; S, southwest monsoon.

seasons (Agah *et al*., 2021). The highest and lowest mean pH values in the present study were recorded in the NEM and SWM as 8.17 ± 0.004 and 7.44 ± 0.12, respectively. Similarly, Ershadifar *et al*. (2021) reported that the lowest pH values were recorded in SWM which agree with the current study findings. In a study by Agah *et al*. (2021), the average pH value POM in Chabahar Bay was 8.18. Also, in a study by Fazeli *et al*. (2013), the highest (8.4) and lowest (8.2) pH values were reported in Chabahar Bay in NEM and SWM, respectively.

Low levels of DO are known as one of the main factors for the survival of fauna and flora in aquatic environments (Friedrich *et al*., 2014). The highest and lowest mean DO values were recorded in NEM and SWM as 6.76 ± 0.13 and 3.60 ± 0.10 mg $l^{-1}$, respectively. Ershadifar *et al*. (2021) showed that DO values exhibit an increasing trend from spring to autumn. In the autumn, as stated by Naqvi (2006), with a decrease in temperature and the later weakening of thermal stratification, the blooming of phytoplankton occurs and accordingly the amount of DO increases. In the summer because of seasonal stratification, according to Al-Azri *et al*. (2010), it leads to a decrease in oxygen concentration and hypoxic conditions in different areas of the Gulf of Oman. A study of Abedi *et al*. (2022) showed the negative effect of hypoxia conditions in the summer on the abundance of mesozooplanktons in the Gulf of Oman.

In a study of Agah *et al*. (2021), the amount of DO in the water surface of Chabahar Bay was between 6.6 and 6.13 mg $l^{-1}$ in POM, which was considered to be moderate to maintain aquatic biodiversity. In general, organic waste and other inputs of nutrients from wastewater, industrial, and agricultural discharges can lead to a decrease in oxygen levels in some marine areas (Khan and Mohammad, 2014).

According to previous studies (Mohanty *et al*., 2010; Al-Mamun *et al*., 2020), the seasonal and spatial changes of environmental factors such as TDS and DO have a key role in the seasonal cycle of zooplanktons, especially the composition and distribution of copepods. In the current study, the highest and

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

**Table 7.** SIMPER analysis: contribution (%) of the most representative genera to similarity between seasons

| Season | Genera | Average similarity (%) | Contribution (%) |
|---|---|---|---|
| POM | *Paracalanus* | 1.27 | 22.23 |
| | *Copilia* | | 11.18 |
| | *Bestiolina* | | 9.34 |
| | *Agetus* | | 6.32 |
| NEM | *Clausocalanus* | 14.26 | 24.54 |
| | *Oncaea* | | 12.95 |
| | *Pseudodiaptomus* | | 9.16 |
| | *Copilia* | | 8.39 |
| PRM | *Typhlamphiascus* | 73.29 | 3.78 |
| | *Microsetella* | | 3.78 |
| | *Acartia* | | 3.72 |
| | *Paramphiacella* | | 3.72 |
| SWM | *Cosmocalanus* | 35.42 | 9.89 |
| | *Pontella* | | 9.26 |
| | *Cymbasoma* | | 6.31 |
| | *Amphiascopsis* | | 5.72 |

lowest mean TDS values were recorded in SWM and NEM as $56.93 \pm 0.40$ and $53.45 \pm 0.46$ mg $l^{-1}$, respectively. This is in agreement with the measured data of TDS in summer (37.06–36.6) and winter (35.7–32.64) by Amidi *et al.* (2022) in the northwestern and eastern Indian Ocean.

The highest and lowest mean values of chlorophyll-*a* were recorded as $0.89 \pm 0.12$ and $0.08 \pm 0.00$ µg $ml^{-1}$ in POM and NEM, respectively. In a study by Ershadifar *et al.* (2021), high levels (1.90–3.77) of chlorophyll-*a* in PRM and POM correspond to algal bloom, which is consistent with the findings of the current study. Also, in a study of Agah *et al.* (2021), the highest chlorophyll-*a* value was recorded at the level of 0.64 µg $ml^{-1}$. In some studies (Al-Azri *et al.*, 2010; Piontkovski *et al.*, 2011; Polikarpov *et al.*, 2016; Bordbar *et al.*, 2024) the high chlorophyll levels in the autumn correspond to the runoff after the SWM. In the analysis of the results of satellite data in the western parts of Gulf of Oman in 1997–2008, it was shown that the highest concentration of chlorophyll-*a* was in February during NEM and in July–September during SWM. In PRM, as shown by Piontkovski *et al.* (2011), due to the lower density of phytoplankton, the concentration of chlorophyll-*a* was low.

## Zooplankton community composition

In the current study, the seasonal diversity and spatiotemporal fluctuations of surface copepods of Chabahar Bay were investigated. As this study focuses exclusively on surface copepods, consequently certain zooplankton and copepod species may be underrepresented, and their distribution patterns cannot be comprehensively explored in this paper.

This resulted in the identification of five orders, 22 families, and 38 genera of copepods. Here, we reported higher diversity, compared to Fazeli *et al.* (2015) in which 20 genera were identified. This is possibly related to sampling at dark with more localities in the current study. In the current study, 66% of the total zooplankton community belonged to copepods and 34% to non- copepods. This is nearly similar to previous studies by Loqmani *et al.* (2019) in Chabahar Bay.

## Abundance of copepods

According to the results of the current study, the highest mean abundance of copepods was obtained in PRM. In another study at the Persian Gulf (Mohsenizadeh *et al.*, 2016), the peak abundance of copepods was seen in spring and winter in Nayband Bay. In a study of Dos Santos *et al.* (2023), the peak abundance of copepods in the northeastern Atlantic Ocean was also shown in spring. According to Al-Busaidi and Claereboudt (2023), variation in the number of copepods is possibly under the influence of factors such as plankton net mesh size, netting technique (vertical, horizontal, or oblique), nature of sampling sites (open water, semi-enclosed bay, or estuarine system), number of sampling sites, boat speed, and the number of samples.

In the current study, among the 38 genera of recorded copepods, 11 families and 17 genera belonged to Calanoida, five families and nine genera to Cyclopoida, four families and ten genera to Harpacticoida, one family and one genus to Monstrilloida, and one family and one genus to Canuelloida. In a study of Al-Busaidi and Claereboudt (2023) in the Gulf of Oman, the total number of copepod species was 50, of which 38 species belonged to Calanoida. While in the Arabian Sea, there were 57 copepod species, of which 44 (43%) were calanoids. Here in Chabahar Bay, 66 species of copepods were identified by Fazeli *et al.* (2015), of which 34 were calanoid species. In a previous study (Fazeli *et al.*, 2013), 48 copepods were recorded in Chabahar Bay, of which 32 species belonged to calanoids.

In Blanco-Bercial *et al.*'s (2014) study, the Calanoida, Cyclopoida, and Harpacticoida are known as dominant taxa. Here, the annual copepod diversity included the highest frequency of Cyclopoida (35.2%), Calanoida (31.6%), Harpacticoida (12.9%), and less abundant Canuelloida (1.6%). Conversely, the least abundant taxon was Monstrilloida (0.1%). In a study by Mohsenizadeh *et al.* (2016), zooplankton fluctuations in Nayband Bay were attributed to the seasonal cycle of rainfall. They also reported that Cyclopoida with 24% of total abundance was the dominant copepod group.

In the current study, the family Monstrillidae showed the lowest mean abundance among the studied families. In a study by Suárez-Morales and Grygier (2021), it was shown that the Monstrillidae is abundant and diverse in coastal habitats; similarly Suárez-Morales (2001) reported a high abundance of this group in Caribbean coral reefs. At a Brazilian estuary, Leite *et al.* (2010) demonstrated that the peak abundance of Monstrilloids was in the dry season, while these were absent in the rainy season.

The genera *Oithona* and *Euterpina* are typical members of the Arabian Sea zooplankton. Their presence seems to be associated with low oxygen areas (see Jyothibabu *et al.*, 2018). In the current study, the genus *Oithona* was the most abundant taxon. The annual total abundance was 20.2% of total copepods. Also, in the NEM and PRM, these contributed with the highest mean abundance which agrees with previous a study by Al-Busaidi and Claereboudt in (2023). In their study, the abundance of *Oithona* in the Arabian Sea increased sharply with the onset of the SWM and continued towards the POM. In a study of Abedi *et al.* (2023), it was shown that the genus *Oithona* is abundant in the Persian Gulf and the Gulf of Oman in the summer and spring in a wider range of temperature and salinity. In Smith and Madhupratap's (2005) study, regardless of the location, the NEM is associated with an increase in the abundance of cyclopoid, especially for the members of the genus *Oithona*.

The dominancy of the genus *Oithona* probably depends on more than one factor. Small species have a low metabolism, thus require limited energy (Kiørboe and Hirst, 2014). Also, as Castellani *et al.* (2005) stated, lower metabolic requirements may increase the chances of survival and reproduction of the genus *Oithona* and results in a higher abundance. The ability of *Oithona* to survive

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

when water conditions are unfavourable, may explain the abundance of members of this genus in marine environments worldwide (Turner, 2004; Zamora-Terol and Saiz, 2013). The members of the genus *Oithona* act as the main grazers of phytoplanktons, key components of the microbial loop, and prey for ichthyoplanktons and other larger pelagic carnivores. In their study, Abedi *et al.* (2023) demonstrated that the members of the genus *Oithona* are considered as bioindicator in the Persian Gulf and the Gulf of Oman.

In addition to the high annual frequency of *Oithona*, the other genera namely, *Temora*, *Paracalanus* (Calanoida), and *Euterpina* (Harpacticoida) show the highest mean abundance. This may be due to the high tolerance of *Oithona* to temperature and salinity changes (Nishida, 1985), the adaptive reproductive natures of *Euterpina* (Mantha *et al.*, 2012), and the opportunistic behaviours of *Temora* (Madhupratap, 1987). Similar to the present study, in a previous study by Mwaluma *et al.* (2003), the genera *Paracalanus* and *Temora* were the most dominant copepod genera in Mida Creek in the Eastern Indian Ocean and according to Nakajima *et al.* (2008), *Paracalanus*, *Oithona*, *Microsetella*, and *Oncaea* were dominant genera in Malaysia.

In the present study, the genus *Temora* was the most abundant calanoid in Chabahar Bay. This is similar to and agrees with previous observations in the Gulf of Oman (see Al-Azri *et al.*, 2010; Fazeli and Zare, 2011; Piontkovski *et al.*, 2014; Fazeli *et al.*, 2015) and the Arabian Sea (Jemi and Hatha, 2019). This planktonic and epipelagic genus is widely distributed in tropical, subtropical, temperate waters (Tseng *et al.*, 2011) and lagoons (Almeida *et al.*, 2012) in high abundance. As stated by Chang *et al.* (2014), this may be due to their feeding behaviour, when preferred diatoms become scarce and consequently these copepods shift to consume a variety of food items including heterotrophic nano-flagellates and tolerate periods with limited phytoplankton.

In the current study, the Canuelloida contributed with 1.6% of the copepod community. Their least abundance in the planktonic community, as stated by Wells (1980), may indicate that they mostly feed near the substrate.

In the current study, among the five study stations, the highest mean abundance of copepods was observed in the order: st.1 > st.3 > st.2 > st.5 > st.4. In their study, Keshavarzi *et al.* (2015) showed that some stations such as Shahid Kalantari Port, Tis fishing Port, and 7th Tir Port are affected by anthropogenic activities. The Shahid Beheshti, Shahid Kalantari, Tis, and 7th Tir Ports are located in the Chabahar Bay, and due to limited water circulation as a semi-closed bay, they trap shipping activity wastes. They also mentioned that most of the polluted stations, such as the 7th Tir Port, are located in the southeast of Chabahar Bay, and the pollution decreases northwesterly in the bay. Consequently, Keshavarzi *et al.* (2015) concluded that the areas such as 7th Tir Port is under higher potential risks for Chabahar Bay biota.

In a study by Loqmani *et al.* (2019), the results of the one-way ANOVA showed no significant difference in terms of zooplankton density in different stations of each season. In their later study, Loqmani *et al.* (2020) stated that the partial difference in the measured zooplankton density in different stations could be due to difference in the sampling time or presence of a warmer or cooler waterbody at the same time in the region.

### Biodiversity indices

The three biodiversity indices showed moderate diversity of copepods ($H'$: 2.33–2.80) similar to previous studies from the Arabian Sea (Padmavati *et al.*, 1998; D'souza and Gauns, 2018) and Bay of Bengal (Fernandes, 2008). The number of species varies depending on the stability of the environment (Margalef, 1958; Deevey, 1971). According to the results of the present study, similar to Fazeli *et al.* (2013), the lowest biodiversity index value was obtained in the NEM. Also, the highest and lowest species richness values were observed in the POM and PRM, respectively. According to Goswami *et al.* (1992), in terms of location, the mean abundance and diversity of zooplankton showed an inverse correlation with the abundance of zooplankton and accordingly they found higher diversity in stations far from the coast due to the stable and prevailing environmental conditions which allow the plankton community to diversify.

Compared to the Gulf of Oman, diversity indices in the Persian Gulf are low (Ghanbarifardi and Malek, 2009). Probably, the SWM and NEM in the Arabian Sea are the reason for the higher diversity indices in the Gulf of Oman. Upwelling of nutrient-rich deep waters of the Arabian Sea continues during the SWM along the southern coast of Oman at the Arabian Sea (Wiggert *et al.*, 2005). During the POM, based on Fazeli *et al.* (2013), the species richness of mesozooplanktons gradually starts to increase.

### Relationship between environmental parameters and copepod communities

In the current study, PCA results showed that environmental parameters such as pH, DO, temperature, salinity, and chlorophyll-*a* have a significant influence on semi-closed bays such as Chabahar Bay. Similarly, in a study of Amidi *et al.* (2022), the results of the PCA showed that electrical conductivity, temperature, salinity, and TDS had the greatest impact on stations in the Persian Gulf and the Indian Ocean. In a study of Ershadifar *et al.* (2021), the first two axes of the PCA test explained 85.6% of the variation in physicochemical parameters and chlorophyll in Chabahar Bay, with the first axis explained 63.9% of environmental changes, showing a positive correlation between temperature and salinity. The second axis explained 21.7% of changes, where temperature had a strong positive correlation and pH had a strong negative correlation. Abo-Taleb *et al.* (2020) conducted a study in the northwest Red Sea, where PCA results showed that in colder seasons, there was a close correlation between DO and depth, while in warmer seasons, temperature and salinity were closely correlated. The first two axes of the PCA explained 29.9% of environmental parameter changes in cold seasons and 29.6% in hot seasons.

Copepod species are generally divided into three categories: thermophilic species, eurythermal species such as *Acartia* spp., *Centropages* spp., and halophilic tropical species (Zuo *et al.*, 2006). In a study by Abedi *et al.* (2023) in the Gulf of Oman, canonical correspondence analysis (CCA) revealed that mesozooplankton abundance in summer and spring was significantly correlated with salinity, DO, and water temperature. Based on these results, the mesozooplankton communities in the Gulf of Oman are primarily influenced by the combined effects of temperature, salinity, and DO, which significantly impact their distribution during these seasons.

In a study of Nandy and Mandal (2020), CCA results indicated that temperature, pH, DO, salinity, and nutrients are the key environmental parameters in relation to spatial–temporal changes of zooplankton distribution. The results of this test across the four seasons of the study, a clear spatial distribution pattern of zooplankton populations was observed along the salinity gradient, suggesting that salinity plays a crucial role in explaining zooplankton dynamics, particularly on a spatial scale. Dorgham *et al.* (2019) found in high salinity areas, species such as *Oithona nana*, *O. plumifera*, *Euterpina acutifrons*, and *Paracalanus parvus* were the most abundant species and had a relatively higher contribution. Pervious research has highlighted the significant influence of sea surface salinity, DO, and sea surface temperature on the diversity, distribution, and dominance of copepod species

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

(Radhakrishnan *et al.*, 2020). The effect of salinity and temperature on the presence of some high saline species such as *Oncaea* along the northeastern Arabian Sea is controlled by ocean currents (Radhakrishnan *et al.*, 2020). Chew and Chong's (2011) study in Malaysia revealed that species such as *Oithona simplex* are correlated with higher salinity. Due to its ability to adapt to a wide range of salinity and temperature, *Paracalanus crassirostris* is the dominant species of the copepod community in the west coast of Peninsular Malaysia. It appears that salinity and chlorophyll-*a* are the two main factors controlling the diversity of copepods. Marques *et al.* (2009) also demonstrated that the salinity of different water masses is closely related to the distribution pattern of zooplanktons. Yoshida *et al.* (2006) showed that *Acartia pacifica* prefers water with higher salinity and lower temperature. Similarly, Santhanam and Perumal (2003) observed a positive correlation between salinity and the population density of *Acartia* and *Oithona* in the Vellar estuary on the southeast coast of the Indian Ocean.

The cluster analysis of the stations over 1 year reveals a high similarity of 82%, indicating no significant differences between the stations. Given considering the high similarity, it is likely that the stations, all located within the same study area, exhibit changes in similarity primarily due to seasonal variations and environmental parameters.

In the current study, the 38 genera of copepods studied accounted for cumulative contribution of >90% of the total community. According to a study of Abedi *et al.* (2022), SIMPER analysis can be appropriate for describing the dissimilarity of the mesozooplankton community in different environments such as oxygen gradients in the nearly hypoxic and hypoxic layers of the Gulf of Oman. The nine dominant species of zooplanktons in the coastal waters of the northern Bay of Bengal, Bangladesh accounted for the cumulative contribution of >80% within the whole community (Al-Mamun *et al.*, 2020). The SIMPER results in Shi *et al.*'s (2019) study revealed that in the two periods of June–July and September–November, the average similarities were higher than 70%, which indicated similar copepod assemblages.

## Conclusion

The main objective of the current study was to investigate the spatial–temporal fluctuations of the community structure of surface copepods of Chabahar Bay in the Gulf of Oman. Five areas were investigated in four seasons (POM, NEM, PRM, and SWM) for the status of copepod communities and environmental parameters. The current study results indicated the diversity of copepod communities in different seasons of the Gulf of Oman. Among the 38 genera of copepods identified in the five stations, the most abundant belonged to the genus *Oithona*. Due to the different abundances of the copepods in different stations, the impact of human activities was visible in the studied stations. The results showed that environmental conditions determine the structure and distribution of zooplankton communities, especially copepods in Chabahar Bay. We recommend further survey on zooplankton communities, especially in relation to copepod biodiversity in different depths at the Gulf of Oman. This study provides essential baseline data for future large-scale research with regards to habitat and valuable information for ecological assessments and improved management of Chabahar Bay. Due to the increase of anthropogenic activities around this area, continuous monitoring of environmental parameters related to copepod communities will be necessary in the future.

**Supplementary material.** The supplementary material for this article can be found at https://doi.org/10.1017/S002531542400105X

**Data.** Data will be available on request.

**Acknowledgements.** The authors would like to express their gratitude to Aslam Rigi-Mirkazehi for his invaluable assistance with sample collection. We are also indebted to Dr Mehdi Ghodrati Shojaei for his expertise and guidance in statistical analysis. We are grateful to the University of Tehran and Chabahar Maritime University for providing research and laboratory facilities.

**Author contributions.** Z. D.: conceptualized the study, laboratory examination, data collection, analyses, and writing – manuscript draft. A. S.: conceptualized the study, project administration, collected samples, supervised the study, and writing – review and editing of manuscript. G. A.-F.: conceptualized the study and its design, collected data, and critically revised the manuscript. J. S.: conceptualized the study and revised the manuscript.

**Financial support.** This research was financially supported by the Department of Marine Biology, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Noor, Iran. This support is gratefully acknowledged as it facilitated the completion of the PhD thesis from which this work originated.

**Competing interests.** None.

## References

**Abedi E, Seyfabadi J, Saleh A and Sari A** (2022) Mesozooplankton community in near-hypoxic and hypoxic layers of the Persian Gulf and the Gulf of Oman. *Marine Pollution Bulletin* **184**, 114146. https://doi.org/10.1016/j.marpbul.2022.114146

**Abedi E, Seyfabadi J, Saleh A and Sari A** (2023) Mesozooplankton communities related to water masses in the Persian Gulf and the Gulf of Oman. *Marine Pollution Bulletin* **188**, 114571. https://doi.org/10.1016/j.marpolbul.2022.114146

**Abo-Taleb H, Ashour M, El-Shafei A, Alataway A and Maaty MM** (2020) Biodiversity of Calanoida Copepoda in different habitats of the north-western Red Sea (Hurghada Shelf). *Water* **12**, 656.

**Abowei J** (2010) Salinity, dissolved oxygen, pH and surface water temperature conditions in Nkoro River, Niger Delta, Nigeria. *Advance Journal of Food Science and Technology* **2**, 36–40.

**Agah H, Saleh A and Jalili M** (2021) Assessment of environmental parameters in pre- and post-monsoons at Chabahar Bay, Gulf of Oman. *Civil Engineering Infrastructures Journal* **54**, 111–127.

**Al-Azri AR, Piontkovski SA, Al-Hashmi KA, Goes JI and Do Gomes HR** (2010) Chlorophyll-*a* as a measure of seasonal coupling between phytoplankton and the monsoon periods in the Gulf of Oman. *Aquatic Ecology* **44**, 449–461.

**Al-Busaidi SS and Claereboudt MR** (2023) Seasonal variations of surface mesozooplankton community structure in the Sea of Oman and the Arabian Sea. *Journal of Agricultural and Marine Sciences* **28**, 30–46.

**Al-Hashmi KA, Piontkovski SA, Bruss G, Hamza W, Al-Junaibi M, Bryantseva Y and Popova E** (2019) Seasonal variations of plankton communities in coastal waters of Oman. *International Journal of Oceans and Oceanography* **13**, 395–426.

**Al-Mamun A, Akhtar A, Rahman MF, AftabUddin S and Modeo L** (2020) Temporal distribution of zooplankton communities in coastal waters of the northern Bay of Bengal, Bangladesh. *Regional Studies in Marine Science* **34**, 100993. https://doi.org/10.1016/j.rsma.2019.100993

**Al-Yamani FY and Khvorov SA** (2007) Spatio-temporal variation in larval decapod composition and abundance off Bubiyan Island of Kuwait. *International Journal of Oceans and Oceanography* **2**, 69–84.

**Al-Yamani FY and Prusova I** (2003) *Common Copepods of the Northwestern Arabian Gulf: Identification Guide.* Kuwait: Kuwait Institute for Scientific Research, 110p.

**Al-Yamani FY, Skryabin V, Gubanova A, Khvorov S and Prusova I** (2011) *Marine Zooplankton Practical Guide.* Kuwait: Kuwait Institute for Scientific Research, 399p.

**Ali M, Al-Yamani F and Khalaf TA** (2009) Observathion of *Acartia* (*Acartiella*) *faoensis* (Copepoda, Calanoida, Acartidae) near Bubiyan Island in the north of Kuwait. *Crustaceana* **82**, 1073–1077.

**Almeida L, Costa I and Eskinazi-Sant'Anna E** (2012) Composition and abundance of zooplankton community of an impacted estuarine lagoon in Northeast Brazil. *Brazilian Journal of Biology* **72**, 13–24.

**Amidi R, Fatemi SMR, Ghodousi J and Javid AH** (2022) Zooplankton abundance and diversity in the ballast water of ships, Shahid Rajaee Port, Persian Gulf, Hormozgan, Iran. *Iranian Journal of Fisheries Sciences* **21**, 331–354.

**Blanco-Bercial L, Cornils A, Copley N and Bucklin A** (2014) DNA barcoding of marine copepods: assessment of analytical approaches to species identification. *PLoS Currents* **6**. https://doi.org/10.1371/currents./tol.cdf8b74881f87e3b01d56b43791626d2

**Bordbar MH, Nasrolahi A, Lorenz M, Moghaddam S and Burchard H** (2024) The Persian Gulf and Oman Sea: climate variability and trends inferred from satellite observations. *Estuarine, Coastal and Shelf Science* **296**, 108588.

**Burt JA, Coles S, Lavieren H, Taylor O, Looker E and Samimi-Namin K** (2016) Oman's coral reefs: a unique ecosystem challenged by natural and man-related stresses and in need of conservation. *Marine Pollution Bulletin* **105**, 498–506.

**Castellani C, Robinson C, Smith T and Lampitt RS** (2005) Temperature affects respiration rate of *Oithona similis*. *Marine Ecology Progress Series* **285**, 129–135. https://doi.org/10.3354/meps285129

**Caulfield MP** (1990) The Persian Gulf Region, a climatological study. Department of the Navy Headquarters, United States. Marine Corps Washington, DC, 20380-0001.

**CCME (Canadian Council of Ministers of the Environment)** (2003) Canadian water quality guideline for the protection of aquatic life, Winnipeg, MB.

**Chang KH, Doi H, Nishibe Y, Nam GS and Nakano SI** (2014) Feeding behavior of the copepod *Temora turbinata*: clearance rate and prey preference on the diatom and microbial food web components in coastal area. *Journal of Ecology and Environment* **37**, 225–229.

**Chew LL and Chong VC** (2011) Copepod community structure and abundance in a tropical mangrove estuary, with comparisons to coastal waters. *Hydrobiologia* **666**, 127–143.

**Clarke KR and Gorley RN** (2006) PRIMER Version 6: User Manual/Tutorial. Plymouth, PRIMER-E, p. 192.

**Conway DV** (2012) *Marine zooplankton of southern Britain*. Part 2: *Arachnida, Pycnogonida, Cladocera, Facetotecta, Cirripedia and Copepoda* (ed. AWG John). Occasional Publications. Marine Biological Association of the United Kingdom, No 26, Plymouth, United Kingdom, 163pp.

**Conway DVP, White RG, Hugues-Dit-Ciles J, Gallienne CP and Robins DB** (2006) *Guide to the Coastal and Surface Zooplankton of the South-Western Indian Ocean*. Plymouth: Occasional publication of the Marine Biological Association of the United Kingdom, 367 pp.

**Deevey GB** (1971) The annual cycle in quantity and composition of the zooplankton of the Sargasso Sea off Bermuda. I. The upper 500 m. *Limnology and Oceanography* **16**, 219–240.

**Ding H and Elmore AJ** (2015) Spatio-temporal patterns in water surface temperature from Landsat time series data in the Chesapeake Bay, USA. *Remote Sensing of Environment* **168**, 335–348.

**Dorgham M, El-Tohamy W, Qin J, Abdel-Aziz N and El-Ghobashy A** (2019) Mesozooplankton in a stressed area of the Nile Delta Coast, Egypt. *Egyptian Journal of Aquatic Biology and Fisheries* **23**, 89–105.

**Dos Santos A, Marques R and Pires RF** (2023) Zooplankton biodiversity and temporal dynamics (2005–2015) in a coastal station in western Portugal (northeastern Atlantic Ocean). *PeerJ* **11**, e16387. http://doi.org/10.7717/peerj.16387

**D'souza AM and Gauns M** (2018) Spatial variability of copepod species distribution in the eastern Arabian Sea in pre-monsoon conditions. *Deep-Sea Research Part II. Topical Studies in Oceanography* **56**, 111–120.

**Emara HI** (2010) Nutrient salts, inorganic and organic carbon contents in the waters of the Persian Gulf and the Gulf of Oman. *Journal of the Persian Gulf (Marine Science)* **1**, 33–44.

**Ershadifar H, Ker K, Kochaknejad A, Qazilu A and Beskele GR** (2021) Investigating the effect of monsoon phenomenon on physicochemical parameters, nutrients and chlorophyll-*a* in Chabahar Bay. *Environmental Science Quarterly* **19**, 19–36.

**Fallahi M, Seraji F and Dehghan S** (2003) Hydrobiology of RSA-Plankton section. *Iranian Fisheries Organization Report*, 190pp.

**Fazeli N and Zare R** (2011) Effect of seasonal monsoons on calanoid copepod in Chabahar Bay Gulf of Oman. *Jordan Journal of Biological Sciences* **4**, 55–62.

**Fazeli N, Zare R, Nabavi SMB and Sanjani S** (2015) Monsoon effects on the copepod community structure in the Chabahar Bay, Oman Sea. *International Journal of Aquatic Biology* **3**, 245–257.

**Fazeli N, Marnani HR, Sanjani S, Zare R, Dehghana S and Jahani N** (2010) Seasonal variation of Copepoda in Chabahar Bay-Gulf of Oman. *Jordan Journal of Biological Sciences* **147**, 1–24.

**Fazeli N, Savari A, Nabavi SMB and Zare R** (2013) Seasonal variation of zooplankton abundance, composition and biomass in the Chabahar Bay, Oman Sea. *International Journal of Aquatic Biology* **1**, 294–305.

**Fernandes V** (2008) The effect of semi-permanent eddies on the distribution of mesozooplankton in the central Bay of Bengal. *Journal of Marine Research* **66**, 465–488.

**Friedrich J, Janssen F, Aleynik D, Bange HW, Boltacheva N, Çagatay MN, Dale AW, Etiope G, Erdem Z, Geraga M, Gilli A, Gomoiu MT, Hall POJ, Hansson D, Holtappels YHMM, Kirf K, Kononets M, Konovalov S, Lichtschlag A, Livingstone DM, Marinaro G, Mazlumyan S, Naeher S, North RP, Papatheodorou G, Pfannkuche O, Prien R, Rehder G, Schubert CJ, Soltwede T, Sommer S, Stahl H, Stanev EV, Teaca A, Tengberg A, Waldmann C, Wehrli B and Wenzhöfer F** (2014) Investigating hypoxia in aquatic environments: diverse approaches to addressing a complex phenomenon. *Biogeosciences (Online)* **11**, 1215–1259.

**Ghanbarifardi M and Malek M** (2009) Distribution, diversity, and abundance of rocky intertidal fishes in the Persian Gulf and Gulf of Oman, Iran. *Marine Biology Research* **5**, 496–502. https://doi.org/10.1080/17451000802441293

**Goswami SC, Sarupria JS and Bhargava RMS** (1992) Zooplankton standing stock assessment and fishery resources in the Indian Seas. In Desai BN (ed.), *Oceanography of the Indian Ocean*. New Delhi: Oxford and IBH Publ. Co. pp. 217–226.

**Hedayati A, Pouladi M, Vazirizadeh A, Qadermarzi A and Mehdipour N** (2017) Seasonal variations in abundance and diversity of copepods in Mond River estuary, Bushehr, Persian Gulf. *Biodiversitas Journal of Biological Diversity* **18**, 447–452.

**IEPA (Ireland Environmental Protection Agency)** (2001) *Parameters of Water Quality: Interpretation and Standards*. Johnstown: Environmental Protection Agency Johnstown, p. 133.

**Jeffrey ST and Humphrey GF** (1975) New spectrophotometric equations for determining chlorophylls a, b, c1 and c2 in higher plants, algae and natural phytoplankton. *Biochemie und physiologie der pflanzen* **167**, 191–194.

**Jemi JN and Hatha AAM** (2019) Copepod community structure during upwelling and non-upwelling seasons in coastal waters off Cochin, southwest coast of India. *Acta Oceanologica Sinica* **38**, 111–117.

**Jyothibabu R, Balachandran KK, Jagadeesan L, Karnan C, Arunpandi N, Naqvi SWA and Pandiyarajan RS** (2018) Mud banks along the southwest coast of India are not too muddy for plankton. *Scientific Reports* **8**, 2544. https://doi.org/10.1016/j.ecolind.2018.04.069

**Kang JH, Hyun BG and Shin K** (2010) Phytoplankton viability in ballast water from international commercial ships berthed at ports in Korea. *Marine Pollution Bulletin* **60**, 230–237.

**Kazmi QB** (2004) Copepods from shore and offshore waters of Pakistan. *Journal of Marine Science and Technology* **12**, 223–228.

**Keshavarzi B, Ebrahimi P and Moore F** (2015) A GIS-based approach for detecting pollution sources and bioavailability of metals in coastal and marine sediments of Chabahar Bay, SE Iran. *Geochemistry* **75**, 185–195.

**Khan MN and Mohammad F** (2014) Eutrophication: challenges and solutions. *Eutrophication: Causes, Consequences and Control* **2**, 1–15. https://doi.org/10.13140/2.1.3673.8884

**Kiørboe T and Hirst AG** (2014) Shifts in mass scaling of respiration, feeding, and growth rates across life-form transitions in marine pelagic organisms. *The American Naturalist* **183**, E118–E130. https://doi.org/10.1086/675241

**Leite NR, Pereira LCC, Abrunhosa F, Pires MAB and Da Costa RM** (2010) Occurrence of *Cymbasoma longispinosum* Bourne, 1890 (Copepoda: Monstrilloida) in the Curuçá River estuary (Amazon Littoral). *Anais da Academia Brasileira de Ciências* **82**, 577–583.

**Loqmani M, Zabihi F and Attaran Fariman G** (2019) Investigating the effect of monsoon on the zooplankton biodiversity of the eastern coast of Chabahar (Makran Sea). *Animal Environment Journal* **11**, 327–334.

**Loqmani M, Attaran Fariman G and Zabihi F** (2020) Investigating the distribution and seasonal density of zooplanktons in the northern shores of Makran Sea. *Animal Environment Quarterly* **12**, 363–372.

**Madhupratap M** (1987) Status and strategy of zooplankton of tropical Indian estuaries: a review. *Bulletin of the Plankton Society of Japan* **34**, 65–81.

**Mantha G, Muthaiyan S, Narayana M, Kareem A, Hans-Uwe D, Kandasamy S and Jiang-Shiou H** (2012) Community structure of the Harpacticoida

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

(Crustacea: Copepoda) on the Coast of Chennai, India. *Zoological Studies* **51**, 463–475.

**Margalef DR** (1958) Information theory in ecology. *General Systems* **3**, 36–71.

**Margalef R** (1968) *Perspectives in Ecological Theory*. Chicago: The University of Chicago Press.

**Marques SC, Azeiteiro UM, Martinho F, Viegas I and Pardal MÂ** (2009) Evaluation of estuarine mesozooplankton dynamics at a fine temporal scale: the role of seasonal, lunar and diel cycles. *Journal of Plankton Research* **31**, 1249–1263.

**Mohanty AK, Sahu G, Singhasamanta B, Mahapatra D, Panigrahy RC, Satpathy KK and Sahu BK** (2010) Zooplankton diversity in the nearshore waters of Bay of Bengal, off Rushikulya Estuary. *IUP Journal of Environmental Sciences* **4**, 61–85.

**Mohsenizadeh F, Haghshenas A and Rabbaniha M** (2016) The survey on zooplankton community Naiband Bay. 5th National Congress on Agriculture, Aquatic Animals and Food. Iran. Bushehr. May 2016.

**Mwaluma J, Osore M, Kamau J and Wawiye P** (2003) Composition, abundance and seasonality of zooplankton in Mida Creek, Kenya. *Western Indian Ocean Journal of Marine Science* **2**, 147–155.

**Nakajima R, Yoshidia T, Othman BHR and Toda T** (2008) Dial variation in abundance, biomass and size composition of zooplankton community over a coral reef in Redang Island, Malaysia. *Journal of Plankton and Benthos Research* **3**, 216–226.

**Nandy T and Mandal S** (2020) Unravelling the spatio-temporal variation of zooplankton community from the river Matla in the Sundarbans estuarine system, India. *Oceanologia* **62**, 326–346.

**Naqvi S** (2006) Oxygen deficiency in the north Indian Ocean. *Gayana* **70**, 53–58.

**Nawaz MA, Sivakumar K and Baskar G** (2023) Seasonal dynamics of body size in calanoid copepods (Calanoida: Copepoda) from the stressed tropical coast of India, Chennai, Bay of Bengal. *Aquatic Ecology* **58**, 1–11.

**Nazari F, Mirshamsi O, Sari A, Aliabadian M and Arbizu PM** (2018a) Three new Canuellidae (Copepoda: Canuelloida) from Iran. *Zootaxa* **4446**, 401–441.

**Nazari F, Mirshamsi O, Sari A and Aliabadian M** (2018b) A first report of *Canuellina insignis* Gurrney, 1927 (Canuellidae: Copepoda) from the Persian Gulf and Gulf of Oman. *Iranian Journal of Animal Biosystematics* **14**, 131–136.

**Nishida S** (1985) Taxonomy and distribution of the family Oithonidae (Copepods, Cyclopoida) in the Pacific and Indian Oceans. Ocean Research Institute. University of Tokyo, Japan. No. 20. 167p.

**NOAA, Coral Reef Watch** (2019) Monthly and annual composites of 5 km satellite coral bleaching heat stress products (Version 3.1), 1985 to 2019. Dataset available at https://coralreefwatch.noaa.gov/satellite/hdf/index.php (accessed 19 October 2019).

**Nour El-Din NM and AL-Khayat JA** (2001) Impact of industrial discharges on the zooplankton community in the Mesaieed industrial area, Qatar (RSA). *International Journal of Environmental Studies* **58**, 173–184.

**Omori M and Ikeda T** (1984) *Methods in Marine Zooplankton Ecology*. New York: John Wiley & Sons, 332pp.

**Padmavati G, Haridas P, Nair KKC, Gopalakrishnan TC, Shiney P and Madhupratap M** (1998) Vertical distribution of mesozooplankton in the central and eastern Arabian Sea during the winter monsoon. *Journal of Plankton Research* **20**, 343–354.

**Paturej E and Kruk M** (2011) The impact of environmental factors on zooplankton communities in the Vistula Lagoon. *Oceanological and Hydrobiological Studies* **40**, 37–48.

**Paul S, Karan S, Ghosh S and Bhattacharya BD** (2019) Hourly variation of environment and copepod community of the Ganges River Estuary of India: perspectives on sampling estuarine zooplankton. *Estuarine, Coastal and Shelf Science* **230**, 106441. https://doi.org/10.1016/j.ecss.2019.106441

**Peyghan S, Savari A, Doustshenas B, Sakhaee N and Dehghan Madiseh S** (2011) New record of *Acartia (Acartiella) faoensis* Khalaf, 1991 (Copepoda: Calanoida: Acartidae) from Iranian waters of NW Persian Gulf. *Iranian Journal of Animal Biosystematics* **7**, 177–179.

**Pielou EC** (1969) *An Introduction to Mathematical Ecology*. New York, NY: Wiley-Interscience.

**Piontkovski S, Al-Azri A and Al-Hashmi K** (2011) Seasonal and interannual variability of chlorophyll-*a* in the Gulf of Oman compared to the open Arabian Sea regions. *International Journal of Remote Sensing* **32**, 7703–7715.

**Piontkovski SA, Al-Maawali A, Al-Manthri WAM, Al-Hashmi K and Popova EA** (2014) Zooplankton of Oman coastal waters. *Journal of Agricultural and Marine Sciences* **19**, 37–50.

**Polikarpov I, Saburova M and Al-Yamani F** (2016) Diversity and distribution of winter phytoplankton in the Arabian Gulf and the Sea of Oman. *Continental Shelf Research* **19**, 85–99.

**Postel L, Fock H and Hagen W** (2000) Biomass and abundance. In Harris RP, Wieb PH, Lenz J, Skjoldal HR and Huntley M (eds), *ICES Zooplankton Methodology Manual*. London: Academic Press, pp. 83–174.

**Prusova I, Smith SL and Popova E** (2011) *Calanoid Copepods of the Arabian Sea Region*. Muscat, Oman: Sultan Qaboos University, Academic Publication Board.

**Radhakrishnan R, Sunny SK, Sivasankaran BN and Mahadevan H** (2020) Surface cyclopoid copepod assemblages in relation to environmental conditions near undisturbed coral reefs of Minicoy, southeastern Arabian Sea, a part of the Indian Ocean. *Marine Ecology* **41**, e12619.

**Razouls C, de Bovée F, Kouwenberg J and Desreumaux N** (2019) Diversity and geographic distribution of marine planktonic copepods. Available at http://copepodes.obs-banyuls.fr/en (accessed 12 February 2019).

**Rezai H, Amini N and Kabiri K** (2014) Spatial and temporal distribution of zooplankton biomass in the northeast Persian Gulf. *Journal of the Persian Gulf* (*Marine Science*) **5**, 79–84.

**Richardson AJ, Davies C, Slotwinski A, Coman F, Tonks M, Rochester W, Murphy N, Beard J, McKinnon D, Conway D and Swadling K** (2013) *Australian marine zooplankton*: taxonomic sheets, 294p.

**ROPME** (2003) *Reginal Report of the State of the Marin Environment*. Kuwait: ROPME.

**ROPME** (2004) *Regional Report of the State of the Marin Environment*. Kuwait: ROPME.

**Santhanam P and Perumal P** (2003) Diversity of zooplankton in Parangipettai coastal waters, southeast coast of India. *Journal of the Marine Biological Association of India* **45**, 144–151.

**Saravanakumar A, Rajkumar M, Serebiah S and Thivakaran GA** (2007) Abundance and seasonal variations of zooplankton in the arid zone mangroves of Gulf of Kachchh-Gujarat, west coast of India. *Pakistan Journal of Biological Sciences* **10**, 3525–3532.

**Shannon C and Wiener E** (1949) *The Mathematical Theory of Communications*. Urbana: Urbana Illinois Press City, 117p.

**Shi Y, Yuan W, Zuo T, Wang J and Pakhomov EA** (2019) Seasonal variation in copepod abundance and community structure in the Laoshan Bay, China. *Regional Studies in Marine Science* **28**, 100577.

**Smith SL and Madhupratap M** (2005) Mesozooplankton of the Arabian Sea: patterns influenced by seasons, upwelling, and oxygen concentrations. *Progress in Oceanography* **65**, 214–239.

**Smith SL, Criales MM and Schack C** (2020) The large-bodied copepods off Masirah Island, Oman: an investigation of southwest monsoon onset and die-off. *Journal of Marine Systems* **204**, 103289. https://doi.org/10.1016/j.jmarsys.2019.103289

**Srichandan S, Sahu BK, Panda R, Baliarsingh SK, Sahu KC and Panigrahy RC** (2015) Zooplankton distribution in coastal water of the north-western Bay of Bengal, off Rushikulya estuary, east coast of India. *Indian Journal of Geo-Marine Sciences* **44**, 519–527.

**Suárez-Morales E** (2001) An aggregation of monstrilloid copepods in a western Caribbean reef area: ecological and conceptual implications. *Crustaceana* **74**, 689–696.

**Suárez-Morales E and Grygier MJ** (2021) Mediterranean and Black Sea Monstrilloid copepods (Copepoda: Monstrilloida): rediscovering the diversity of transient zooplankters. *Water* **13**, 1036. https://doi.org/10.3390/w13081036

**Tajevidi N, Manochehri H and Shapouri M** (2015) Identification of zooplankton communities in Asalouye Port and Qeshm Island. *Journal of Marine Biology, Islamic Azad University, Ahvaz Branch* **7**, 57–67.

**Tseng LC, Kumar R, Chen QC and Hwang JS** (2011) Faunal shift between two copepod congeners (*Temora discaudata* and *T. turbinata*) in the vicinity of two nuclear power plants in southern East China Sea: spatiotemporal patterns of population trajectories over a decade. *Hydrobiologia* **666**, 301–315.

**Turner JT** (2004) The importance of small planktonic copepods and their roles in pelagic marine food webs. *Zoological Studies* **43**, 255–266.

**Walter TC and Boxshall G** (2020) World of Copepods database. Caligidae Burmeister, 1835. Accessed through: World Register of Marine Species. Available from: https://www.marinespecies.org/aphia.php?p=taxdetails&id=135513 (accessed 16 June 2023).

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press

**Wells JBJ** (1980) A revision of the genus *Longipedia* Claus (Crustacea: Copepoda: Harpacticoida). *Zoological Journal of the Linnean Society* **70**, 103–189.

**Wiggert J, Hood R, Banse K and Kindle J** (2005) Monsoon-driven biogeochemical processes in the Arabian Sea. *Progress in Oceanography* **65**, 176–213. https://doi.org/10.1016/j.pocean.2005.03.008

**Wilson SC** (2000) *Northwest Arabian Sea and Gulf of Oman*. Amsterdam: Seas at the Millennium: Pergamon Press, pp. 17–34.

**WoRMS, Editorial Board** (2024) World Register of Marine Species. Available at https://www.marinespecies.org at VLIZ (accessed 29 August 2024). https://doi.org/10.14284/170

**Yoshida T, Toda T, Md Yusoff F and Othman BHR** (2006) Seasonal variation of zooplankton community in the coastal waters of the Straits of Malacca. *Coastal Marine Science* **30**, 320–327.

**Zamora-Terol S and Saiz E** (2013) Effects of food concentration on egg production and feeding rates of the cyclopoid copepod *Oithona davisae*. *Limnology and Oceanography* **58**, 376–387.

**Zuo T, Wang R, Chen YQ, Gao SW and Wang K** (2006) Autumn net copepod abundance and assemblages in relation to water masses on the continental shelf of the Yellow Sea and East China Sea. *Journal of Marine Systems* **59**, 159–172.

https://doi.org/10.1017/S002531542400105X Published online by Cambridge University Press