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Temporal and Diel Variability of Mesozooplankton Abundance in the Central Red Sea with Emphasis on the Calanoid Copepod *Centropages* spp.

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Abstract. The temporal and diel variability in mesozooplankton abundance were studied between January and December 2018 at a station in front of Obhur Creek, central Red Sea. Temperature and salinity reflected the hot and saline conditions of the Red Sea. Inorganic nutrients and phytoplankton biomass (chlorophyll *a*) depicted the oligotrophic characteristics of the region with occasional increase. Phytoplankton displayed low numerical densities (average 246.80±306.98×10^3 cells m^{-3}) except for the high value in May (1082.34×10^3 cells m^{-3}). Diatoms dominated the total phytoplankton (70.6%) most of the year, while dinoflagellates during summer. The mesozooplankton average abundance varied temporally between 1523±1377 in February and 23171±9704 individuals m^{-3} in December, while diel values fluctuated between 2694±3482 and 9009±6851 individuals m^{-3}. The seasonal abundance was the higher in cold period; while the high diel abundance appeared mainly from the evening and midnight collections. Copepods were the dominant group, contributing 79.5 % to total zooplankton. Cladocerans, chaetognaths, appendicularians and crab larvae were represented considerable percentages of total zooplankton (4.8, 1.7, 1.5 and 2.8%, respectively). All of these groups exhibited clear seasonal and diel variations. The dominant calanoid copepod *Centropages* spp. attained its high abundance during the spring and autumn, but it recorded the highest diel from the evening and midnight. It is evident from this study that the distribution of zooplankton in the central Red sea is mainly dependent on the cumulative effect of both temperature and solar radiation, while the *Centropages* spp. have a particular affinity towards the moderate temperature indicating its native behavior.

Keywords: Zooplankton, Monthly variations, Diel variations, Abundance, Red Sea.

1. Introduction

Zooplankton community has a key ecological role in the marine ecosystem (Pochon *et al*., 2013; Lomartire *et al*., 2021). It serves as a link between phytoplankton and higher trophic levels and serves as a base for commercial crustaceans and fish as well as their significant role in nutrient cycling and energy transport (Lenz, 2000). Moreover, zooplankton have a crucial role in the marine biogeochemical cycles, food webs and the biological carbon pump that regulates the atmospheric carbon dioxide levels through diel vertical migration (Parekh *et al*., 2006; Cavan *et al*., 2017). The spatial and temporal distribution of zooplankton communities fluctuate in response to environmental changes in marine ecosystems, such as variations in temperature and salinity (Gili *et al*., 1989; Purushothama *et al*., 2011). In general, changes in seasonal zooplankton species composition in relation to long-term ocean trends is an approach for tracking the impact of global change on different communities of marine ecosystems. In comparison with temperate waters, tropical and subtropical oligotrophic waters, such as the Red Sea, data on zooplankton monthly variability is lacking (Cornils *et al.*, 2005; Kürten *et al.*, 2015; El-Sherbiny *et al.*, 2019). It is well documented that in the marine environment plankton in general and zooplankton in particular undertake diel vertical migrations (DVM), where its density increases in the surface layers during nighttime and decreases during daytime (Last *et al.*, 2016; Cohen *et al.*, 2015). Such DVMs can vary daily, seasonally and ontogenetically as well as within the species (Uye *et al.*, 1990). The DVM have a crucial role in maintaining the ocean's carbon cycle and aiding in carbon sequestration (Schnetzer and Steinberg, 2002; Brierley, 2014). The main reason for the zooplankton to exhibit DVM appears to avoid predation by higher organisms, mainly the fish (Hays 2003, Ringelberg 2009).

There are literally minimal studies that focused on the temporal variability of zooplankton in the Red Sea (e.g. Echelman and Fishelson, 1990; Cornils *et al.*, 2005; 2007; Aamer *et al.*, 2006; Dorgham *et al.*, 2012; El-Sherbiny *et al.*, 2020). Almost all of these studies concentrated on the northern part of the region, while a few were focused on the spatial variability of zooplankton groups on a latitudinal gradient (e.g. Schneider *et al.*, 1987; Schnack-Schiel *et al.*, 2006; Kürten *et al.*, 2015, 2016; Al-Aidaroos *et al.*, 2016, 2017; Karati *et al.*, 2019, 2022). Very little information is available on the diel variations of zooplankton communities in the Red Sea and are either mostly restricted to offshore water or dealing with specific zooplankton groups (Weikert, 1980; Echelman and Fishelson, 1990; Böttger-Schnack, 1995; Karati *et al.*, 2019, 2022).

Within this context, the present study aimed at describing the temporal and the diel variability of zooplankton from the central Red Sea. It also focused on other physical, chemical and biological parameters that govern the distribution of different zooplankton groups. The major aim was to determine the defining factors that significantly affect the abundance and diel vertical migration of zooplankton. On a first of its kind, the present study detailed the seasonal and diel variability of native calanoid copepod *Centropages* spp. from the coastal waters of the central Red sea. It produced important findings that can be the first illustrate related to the research of zooplankton dynamics in the Red Sea.

2. Materials and Methods

2.1 Study Area

This study was conducted monthly from January to December 2018 at a coastal station near the entrance of Obhur Creek (21°42'24.25"N, 39°5'9.57"E), central Red Sea, Saudi Arabia (Fig. 1). It is about 0.5 kilometers away from the coast of Jeddah and has a depth of about 100 meters. Jeddah is a fast-growing metropolitan city in the world and due to its rapid urbanization, where the coastal water is hugely affected by different anthropogenic influences. The selected site is an ideal place to study the impact of such man-made pollution issues to aquatic communities.

2.2 Field Sampling and Analysis

The physical parameters (temperature and salinity) were measured (4 times per day: at sunrise, mid-day, sunset and mid-night) with the help of a pre-calibrated multi-parameter water quality probe (Horiba U50). Seawater samples of around 10 liters were collected during the noontime using a Niskin sampler in clean polythene carbuoys for analytical purposes. For the estimation of phytoplankton biomass (chlorophyll *a*) an amount of 4-5 liters of seawater were filtered through Whatman GF/F filter paper of 0.7µm pore size and stored at -20°C until further analysis. After the filtration, a few drops of Magnesium carbonate ($MgCO_3$) were added to the filter paper in order to prevent the disintegration of chlorophyll molecules. All the filter papers were then wrapped in aluminum foil, properly labeled and kept in a deep freezer (-20°C). For the estimation of inorganic nutrients, 500 ml of the seawater sample was filtered through a 0.2µm GTTP membrane filter and collected in a Nalgene plastic bottle, which was later, stored at -20°C until further analysis. Both the chlorophyll and the nutrient samples were analyzed by using a UV spectrophotometer (Shimadzu) following the protocols of Parsons *et al.* (1984) and Strickland and Parsons (1972) respectively. For the estimation of phytoplankton abundance and community composition, one surface sample per day, mainly during the noontime was collected using a Hydrobios phytoplankton hand net of mesh size 20 µm. The net was equipped with a flowmeter, in order to determine the volume of water filtered (VWF), and towed for 5 minutes at a minimum boat speed and the collected samples were preserved immediately with Lugol’s iodine solution along with a few drops of concentrated formaldehyde solution (Kürten *et al.*, 2015) in an amber colored glass bottle. All the preserved samples were then prescreened using 500 µm mesh prior to the microscopic analysis to avoid the large sized particles especially zooplankton larvae. Phytoplankton triplicate counts were carried out in a Sedgewick Rafter counting chamber using an inverted microscope (Leica DMI 3000B) according to the standard procedures of LeGresley and McDermott (2010). The different phytoplankton species obtained were identified according to the well-known references (Taylor 1976; Tomas 1997; Gómez 2013).

Surface zooplankton was collected on a time interval of 6 hours [in the early morning (before sunrise), at midday (12 PM), at sunset and midnight (12 AM)] using Hydrobios WP2 net of mesh size 150 µm. A digital flow meter with backstop running was fixed on the mouth of the net to calculate the volume of water filtered (VWF). The collected samples were immediately preserved with 4% formaldehyde solution. A Folsom splitter was used in order to divide the zooplankton sample into ample aliquots for the analysis. The zooplankton standing stock was estimated from the average count of three aliquots from each sample in the Bogorov counting tray using a stereo zoom microscope (Wild Heerbrugg M3B) and expressed in number in cubic meter.

3. Statistical Analysis

The obtained data were treated statistically using software like SPSS 23, PAST 3 and PRIMER 6, while the plotting of scientific data was performed with the help of ORIGIN 6.0 software. In order to find out the relation between the different physical, chemical and biological parameters, Pearson’s coefficient of correlation (r) was determined. One-way analysis of variance (ANOVA) was applied to find the variation of different parameters based on the seasons.

4. Results

The maximum water temperature was recorded during September (33.8°C), while the minimum was observed during February (24.0°C). Maximum diel variation was observed during January (SD±1.5°C), while the minimum was recorded during October (SD± 0.03°C) (Fig. 2A). During the period of study, the highest salinity (39.39) occurred in October, while the lowest value of 38.74 occurred in February (Fig. 2B). The diel variation was negligible during the study period with a standard deviation ranging from 0.02 (December) to 0.07 (October).

The nitrate displayed clear monthly variation, attaining the highest value in January and July and the lowest in May-June with a yearly average of 0.34±0.02 µmol L^{-1} (Fig. 3A). In contrast, nitrite recorded the maximum value in October and the minimum in July with an average concentration of 0.03±0.01 µmol L^{-1} (Fig. 3B). Ammonia concentration (average 1.03±0.94 µmol L^{-1}) showed different temporal pattern sustaining pronouncedly low values from January to July as compared to those from August to December with a distinct peak in October (Fig. 3C). Phosphate was pronouncedly lower from Jun to December than from January to May with an overall average of 0.07±0.065 µmol L^{-1} (Fig. 3D). Silicate showed irregular temporal variation with the highest values (2.12 µmol L^{-1}) in May and the lowest (0.61 µmol L^{-1}) in September (average 0.07±0.065 µmol L^{-1}) (Fig. 3E). The phytoplankton biomass in terms of chlorophyll *a* fluctuated between 0.05 mg m^{-3} in January and 1.04 mg m^{-3} with an average value of 0.35±0.25 mg m^{-3} (Fig. 3F). The total phytoplankton abundance showed four peaks coincided with those of chlorophyll *a*, recording a distinguished peak during summer. The total density varied between 14.48 × 10^{3} cells m^{-3} (January) and 1082.34 × 10^{3} cells m^{-3} (May) with an average value of 246.8±306.98 × 10^{3} cells m^{-3} (Fig. 4A). Figure (4B) illustrates the role of different phytoplankton groups in the total count; centric diatoms (CD) exhibited different contribution to the total phytoplankton density from 1.4 % (May) to 67.5 % (February), while the contribution of pennate diatoms (PD) varied from 4.6 % (July) to 92.8 % (May). The dinoflagellates (D), formed between 4.7 % (May) and 60.8 % (August), and the cyanophytes (C) appeared to play mostly small role from 1.1 % (May) to 42.4 % (July).

The zooplankton community was represented mainly by copepods (79.5%), besides other less abundant groups like cladocerans (4.8%), chaetognaths (1.7%), appendicularians (1.5%) and amphipods (0.6%) (Fig. 5). Meroplanktonic forms were dominated by molluscs larvae (7.3 %) and less so by decapod larvae (2.7%) and ichthyoplankton (1.5%) (Fig. 5). The total zooplankton count showed wide monthly and diel fluctuations with an overall average of 5820 individuals m^{-3}. The lowest daily average (1523.2±1376.5 individuals m^{-3}) was observed in February, while the highest average (23170.7±9703.4 individuals m^{-3}) appeared in December. The highest diel abundance (average: 9009±6850.9 individuals m^{-3}) was recorded at 6 PM followed by the midnight collection (7962.9±9477.8 individuals m^{-3}). The abundance in the early morning and noon were mostly lower (Fig. 6A).

As the predominant zooplankton group, copepods displayed one distinguished peak in December (average 19288 individuals m^{-3}), as compared to the lowest average in February (1217 individuals m^{-3}). Figure (6B) illustrates that the pattern of diel variation of copepods was similar to that of the total zooplankton where higher abundance appeared at the evening (6644±5044.2 individuals m^{-3}) and midnight (6645.1±8554.7 individuals m^{-3}) collections than the early morning (1988.2±2240.3 individuals m^{-3}) and noon (3226.65±6458.8 individuals m^{-3}) collections (Fig. 6B). Cladocerans were less abundant with monthly maximum count (894 individuals m^{-3}) in June (Fig. 6C). The diel pattern reported high abundance in the evening (566.2±882.7 individuals m^{-3}) as compared to that (59.8±86.2 individuals m^{-3}) occurred in the early morning. In contrast to other zooplankton groups, the cladocerans exhibited slightly higher densities during the noontime collection throughout the study. Chaetognaths were the next important group in the total holoplankton community, forming 1.7% of the total zooplankton, attaining the maximum count (246 individuals m^{-3}) in October and the minimum in February (Fig. 6D). Evening collection accounted for the highest diel abundance (217.7±235.3 individuals m^{-3}), while the noontime collection contributed pronouncedly less diel abundance (33.7±54.1 individuals m^{-3}) (Fig. 6D). Appendicularians formed 1.5% of the total zooplankton with an average count of 88 individuals m^{-3}. It showed its highest densities in July and October (267 and 206 individuals m^{-3} respectively) and the lowest (4 individuals m^{-3}) in September (Fig. 6E). The daily average density of the appendicularians ranged between 3.9±4.8 individuals m^{-3} (September) and 205.7±168.2 individuals m^{-3} (July), occurring at the noon and evening collections respectively (Fig. 6E). The adult decapods showed a daily average between 4.0±2.8 individuals m^{-3} in January and 545±1044.9 individuals m^{-3} in June (Fig. 6F), with the highest diel count at 6 pm (223.4±595.7 individuals m^{-3}), and the lowest

(4.9±7.7 individuals m^{-3}) at the noontime (Fig. 6F). Ostracods were intermittently found in the area, displaying limited contribution (0.3%) to the total zooplankton with a daily average between 0.30±0.60 individuals m^{-3} in August and 100.4 ±41.9 individuals m^{-3} in December. It showed higher densities at the evening and midnight collections (Fig. 7A). The bivalve larvae were the dominant molluscs larvae (321 individuals m^{-3}), having a widely fluctuated count between 2.9±5.8 individuals m^{-3} during May and 2613 ± 1844.9 individuals m^{-3} during December (Fig. 7B). This caused a high increase in total zooplankton count during December. As shown in Fig. (7B), the bivalve larvae displayed almost equal presence except during the noon time The gastropod larvae were the other dominant molluscs with a maximum of 553±717.3 individuals m^{-3} in December and the high densities (228.08 ± 441.33 individuals m^{-3}) almost at the evening (Fig. 7C). Crab larvae were the major decapod during the study period, recoding two peaks in May (194 individuals m^{-3}) and in September-October (198-145 individuals m^{-3}), and higher abundance at the evening and midnight (Fig. 7D). Fish eggs constituted 0.1% of the total zooplankton and attained the highest abundance (256.2±150.4 individuals m^{-3}) in April. The diel distribution of the fish larvae seems to be similar almost at all the collection times with considerable high densities in early morning and mid night in April and May respectively (Fig. 7F).

The *Centropages* spp. was one of the dominant calanoid copepod present during the study period, displaying temporal and diel variations. Four small increases were observed in March, May, October and December with average abundance of 138, 183, 152 and 152 individuals m^{-3}, respectively (Fig. 8). High average abundance was observed at the evening (135±106.9= individuals m^{-3}) and midnight (140±87.8 individuals m^{-3}). In contrast, the high density in May (239.7 individuals m^{-3}) appeared at the noontime and was comparable to the highest density (331.1 individuals m^{-3}) recorded during the study (Fig. 8).

5. Statistical Analysis

Most of the parameters showed significant temporal variation during the study period. This was evident from the One-Way Analysis of Variance (One-way Anova). Temperature and salinity showed highly significant temporal variation with $F = 135.189$, $P < 0.05$ and $F = 63.41$, $P < 0.05$, respectively. The densities of total zooplankton and copepods showed similar significant variations ($F = 5.576$ and 5.113, $P < 0.05$). Other minor zooplankton groups showed significant variation between months like the ostracods, bivalve larvae, fish larvae and fish eggs ($P < 0.05$). Moreover, statistically highly significant diel variability was observed in the distribution of different zooplankton groups such as Chaetognatha ($F= 4.136$, $P < 0.05$), Appendicularia ($F= 4.095$, $P < 0.05$), crab larvae ($F = 5.166$, $P < 0.05$) and the *Centropages* spp. ($F = 6.607$, $P < 0.05$). The Pearson correlation analysis revealed weak correlation between the physico-chemical parameters and different zooplankton groups. However, the abundance of *Centropages* spp. was highly correlated with silicate ($r = 0.605$), total phytoplankton ($r = 0.654$), and pennate diatoms ($r = 0.629$). Furthermore, a positive correlation was detected between fish egg and gastropod larvae ($r=0.939$) as well as between fish larvae and pennate diatoms ($r= 0.598$).

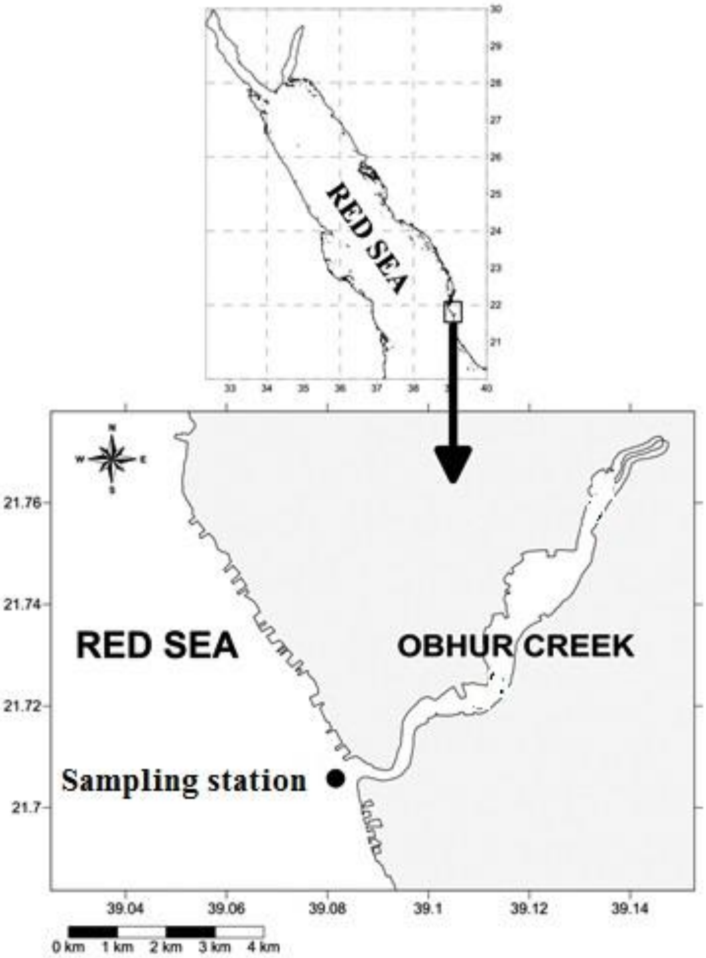

Fig. 1. Map showing the sampling station near Obhur Creek, Central Red Sea.

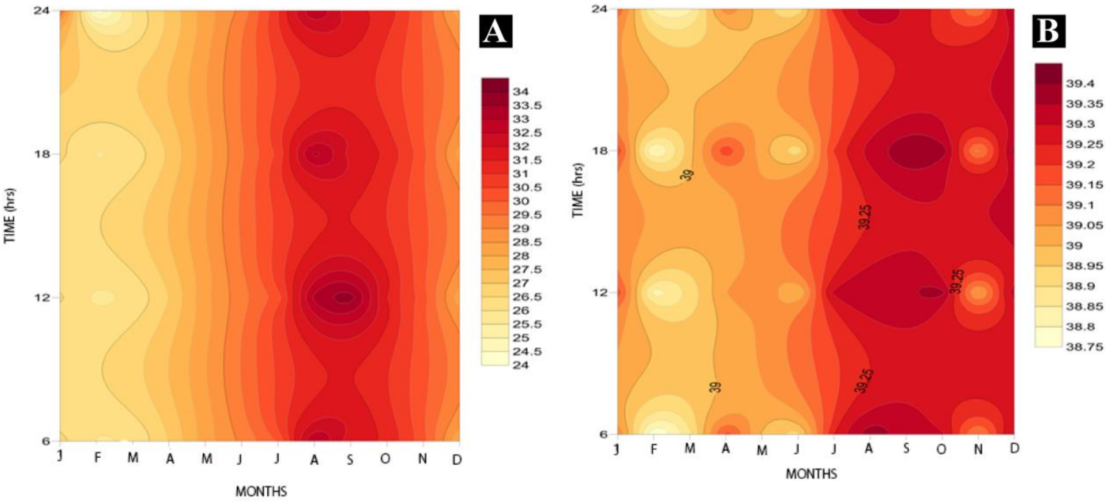

Fig. 2. Monthly variations in temperature (°C) and salinity (B) in the study area.

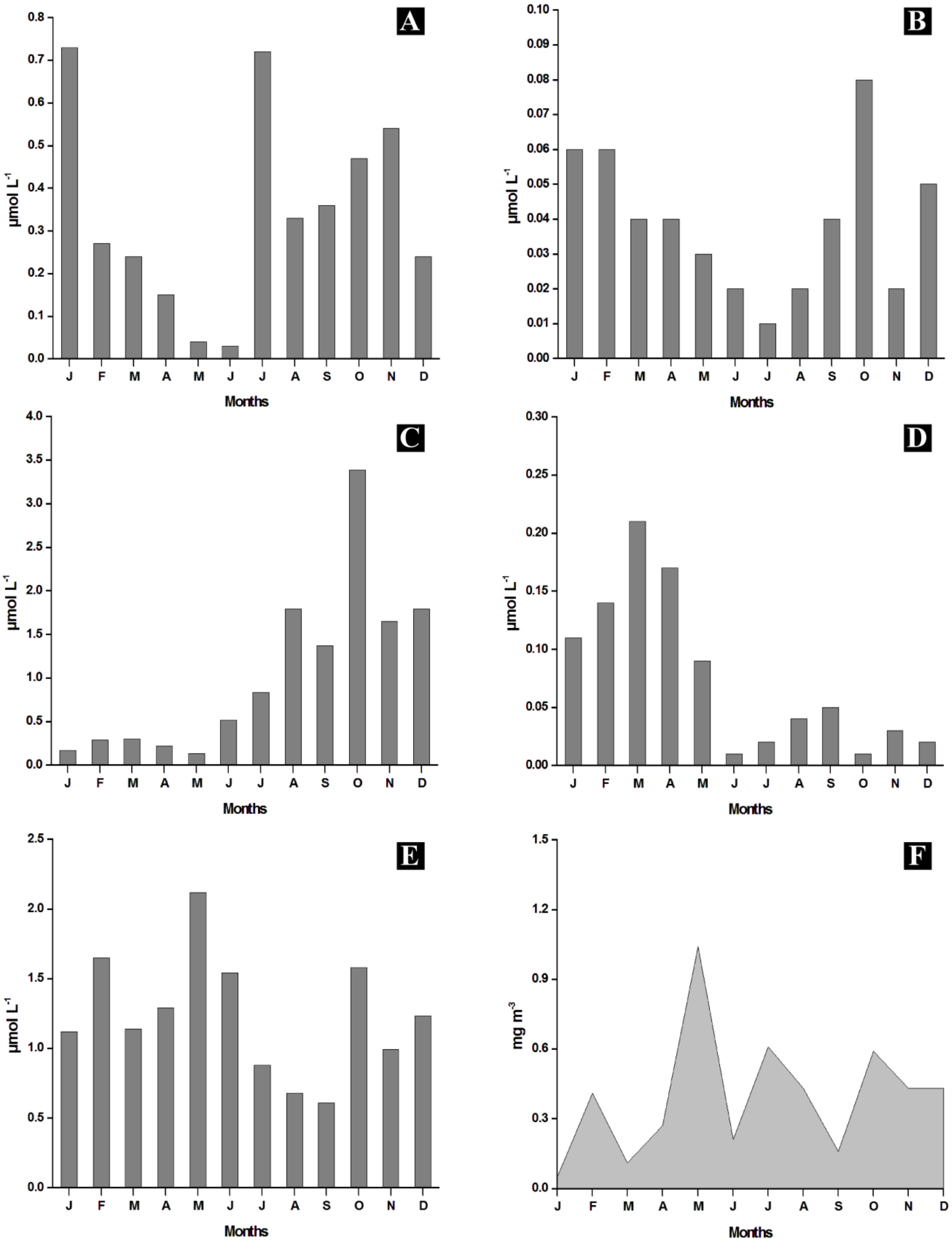

Fig. 3. Monthly variations in the concentrations of nitrate (A), nitrite (B), ammonia (C), phosphate (D), silicate (E) and chlorophyll *a* (F) in the study area.

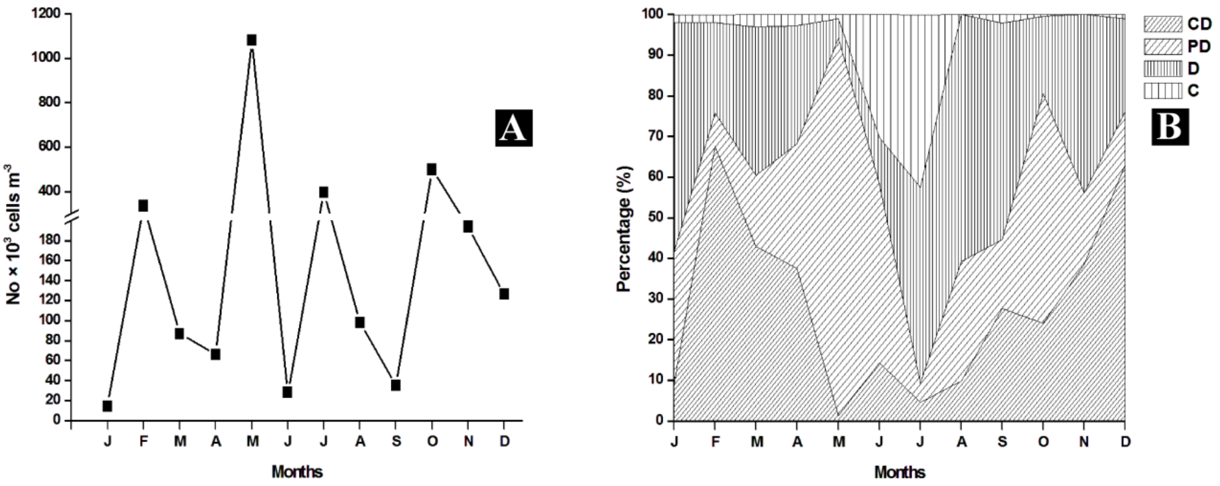

Fig. 4. Monthly variation in total phytoplankton densities (A) and contribution of different phytoplankton groups to total phytoplankton density in the study area (Abbreviations: C: cyanophytes, D: diatoms, CD: centric diatoms and PD: pennate diatoms).

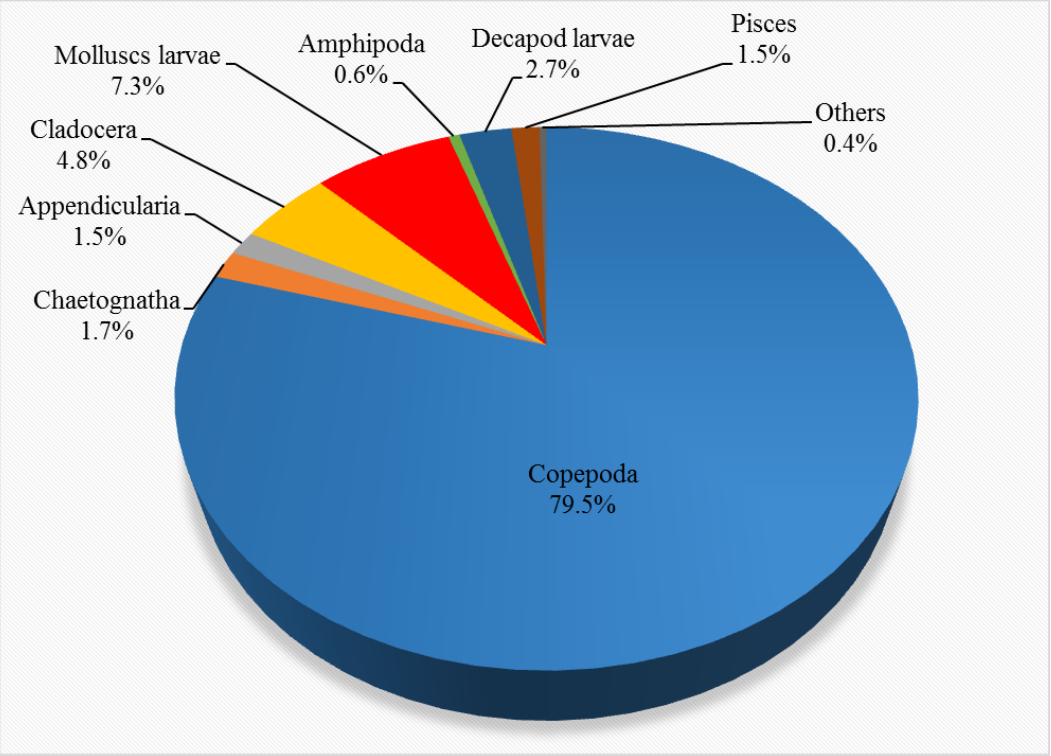

Fig. 5. Average contribution of different zooplankton groups at Obhur Creek during the period of study.

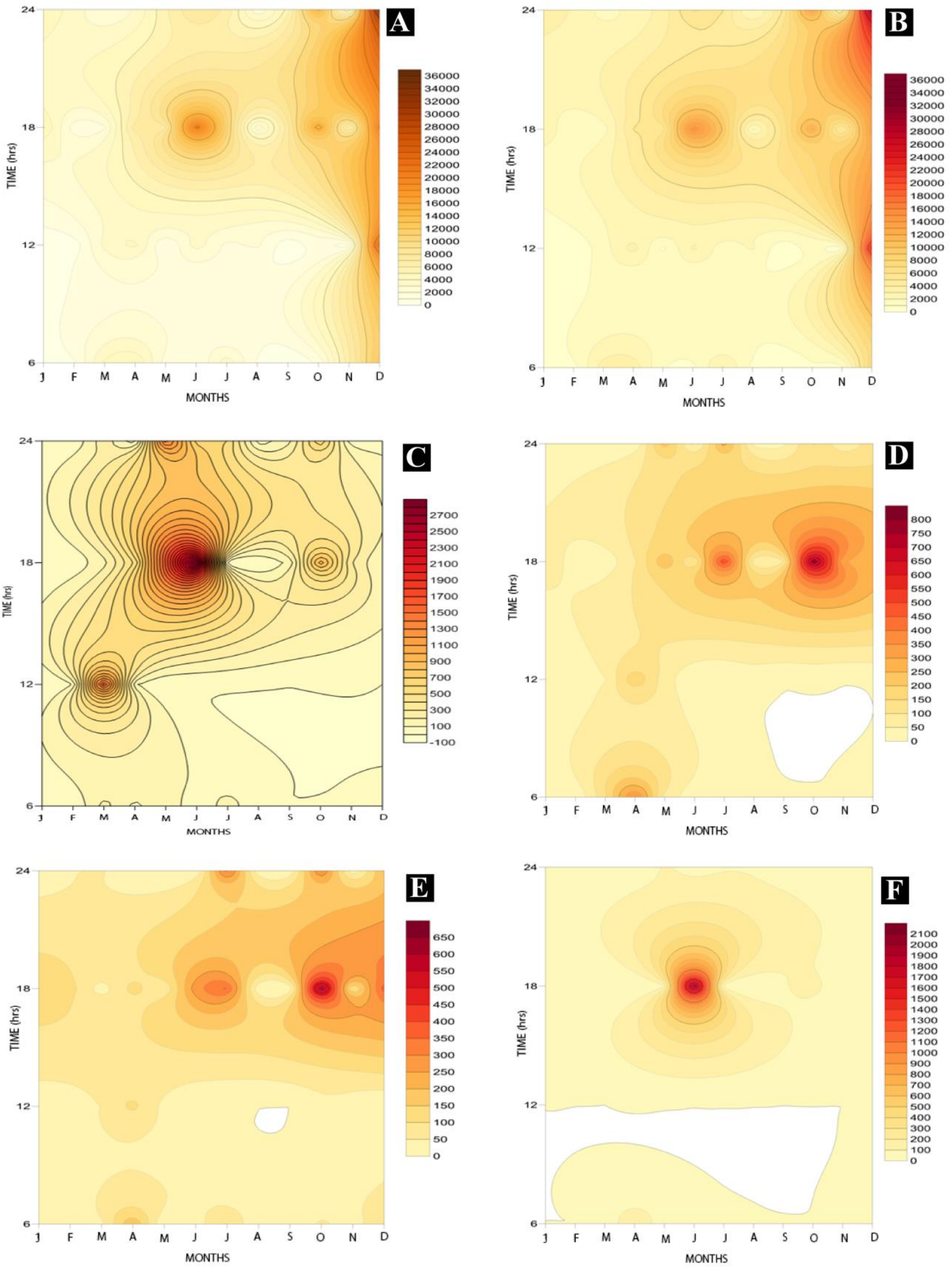

Fig. 6. Monthly variations in the count (individuals m^{-3}) of total zooplankton (A), copepods (B) cladocerans (C), chaetognaths (D), appendicularians (E) and decapods (F).

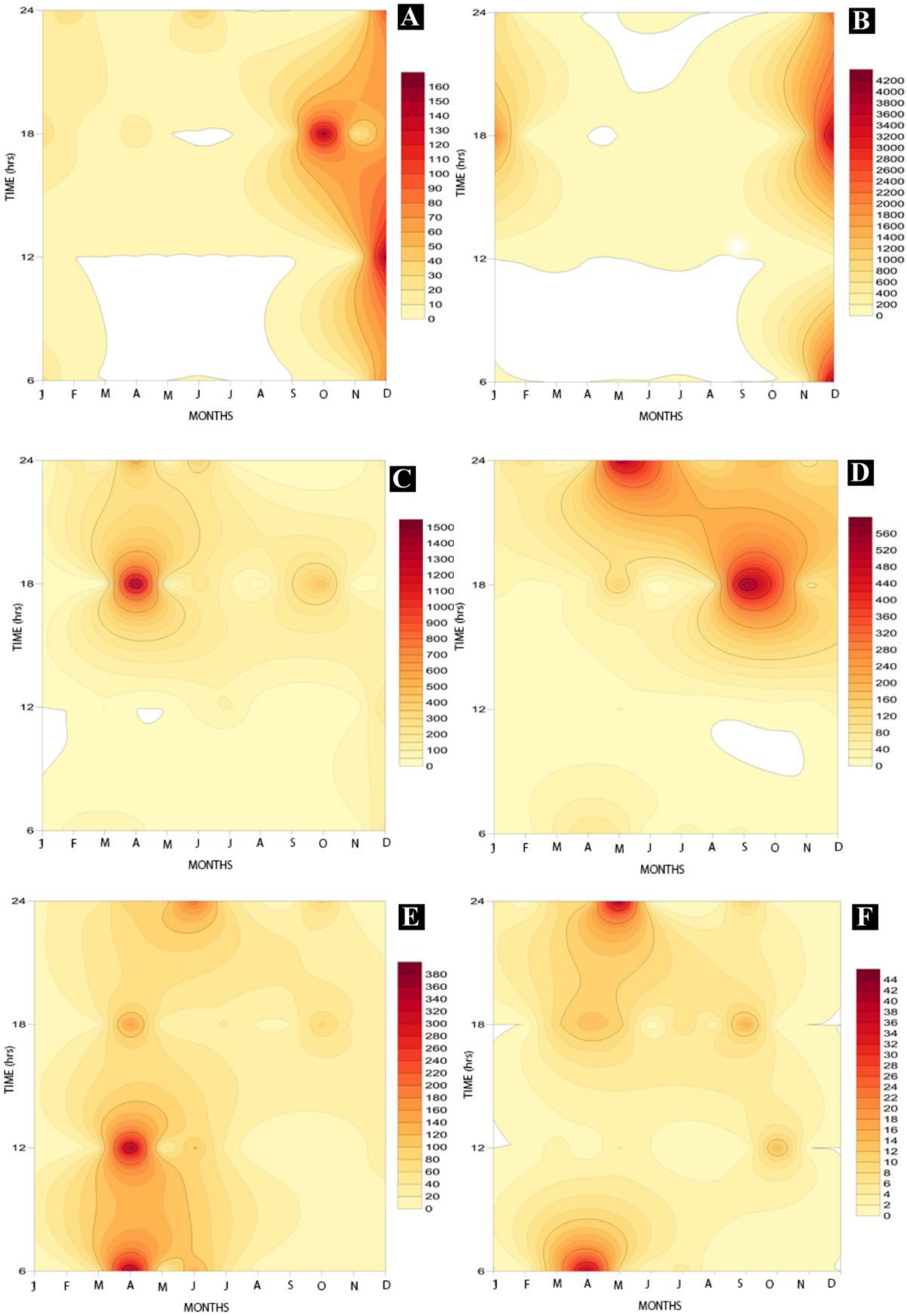

Fig. 7. Monthly count (individuals m^{-3}) of: ostracods (A), bivalve larvae (B), gastropod larvae (C), crab larvae (D), fish eggs (E) and fish larvae (F).

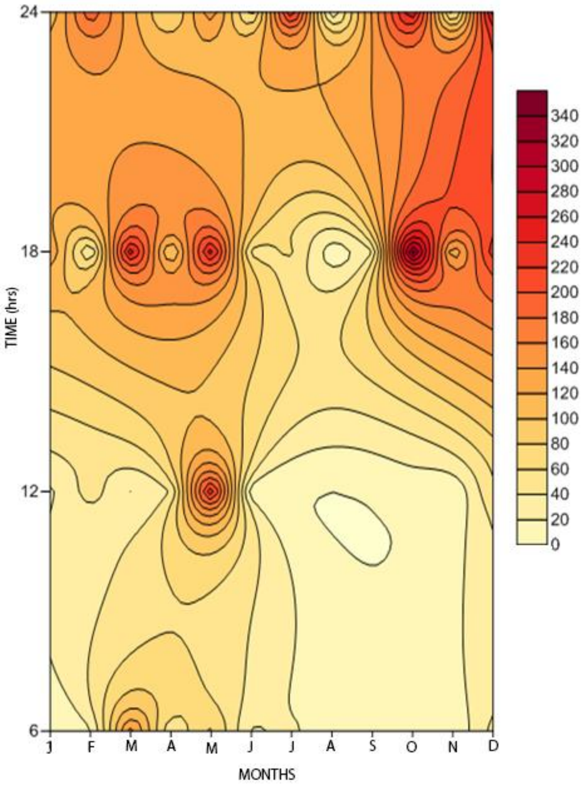

Fig. 8. Monthly variations in abundance of calanoid copepod *Centropages* spp. (individuals m^{-3}) in the study area.

6. Discussion

In marine ecosystems, physico-chemical characteristics can have great effects on the abundance and distribution of both phyto- and zooplankton (Hays *et al*., 2001). The obtained physical parameters were simply the reflection of a hot arid climate that prevalent throughout the Red Sea basin. The seasonal and diel temperature values during the present study were comparable with those reported by other studies in the region (Al-Amri *et al*., 2020; El-Sherbiny *et al*., 2021). Temperature had fewer roles in determining the temporal distribution of many zooplankton groups in the study as it is revealed by the insignificant correlation. Although the temperature has less influence on the distribution of marine organisms in the Red Sea (Qurban *et al*., 2014; Kürten *et al*., 2015; Devassy *et al*., 2017), the high temperature in the surface water during summer was accompanied by the presence of most adapted zooplankton groups in the water column (Al-Aidaroos *et al*., 2014, 2015; El-Sherbiny and Al-Aidaroos, 2021). It is well known that the average surface temperature of the Red Sea has increased substantially during the last few decades (Raitsos *et al*., 2011; Chaidez *et al*., 2017; Shaltout, 2019; Agulles *et al*., 2021), while the studies that deal with the effect of the such increase on marine zooplankton is little. During the present study, the high zooplankton abundance at the evening and night collections can be explained by the response of zooplankton to both the temperature and light intensity, particularly the high penetration of ultraviolet light (UV) which has a direct effect on the Red Sea zooplankton communities (Al-Aidaroos *et al*., 2014, 2015; Mantha *et al*., 2016; Overmans and Agustí, 2020). The lack of riverine inputs and the high evaporation rate makes the Red Sea waters one of the high saline ecosystems in the world (Morcos, 1970; Reiss and Hottinger, 1984; Sofianos *et al*., 2002). This may explain the strong positive correlation between salinity and temperature in our region, where the zooplankton count showed a significant positive correlation with salinity. Mezger *et al*. (2016) observed a similar positive correlation between planktonic foraminifera and salinity.

Although the levels of inorganic nutrients reflect the highly oligotrophic conditions of the study area, some of the nutrients have comparatively higher values, which could be brought from the fast growing metropolitan city. This coincides with the fact that the study area lies under the effect of sewage discharge and other anthropogenic activities (Al-Farawati, 2010; El-Sherbiny *et al*., 2021). The low inorganic nutrients recorded in the current study were frequently reported in the central Red Sea (e.g. Al-Farawati *et al.*, 2008; Pena Garcia *et al*., 2014; Al-Amri *et al*., 2020) and northern Red Sea (e.g. Aamer *et al*., 2006; Dorgham *et al*., 2012; Devassy *et al*., 2017). The low phytoplankton biomass (chlorophyll *a*) and abundance during the present study were reported previously in the region (e.g. Khomayis, 2002; Al-Harbi and Khomayis, 2005; Touliabah *et al*., 2010; Peña-García *et al*., 2014) as well as in other coastal areas of the Red Sea (Shaikh *et al*., 1986; Qurban *et al*., 2014, 2017; Kürten *et al*., 2015; Devassy *et al*., 2017; Kheireddine *et al*., 2017). However, the phytoplankton increase during May in the sampled station, was also reported in the coastal waters of the central Red sea (Al-Aidaroos *et al*., 2019; Al-Amri *et al*., 2020; El-Sherbiny *et al*., 2021) as well as from the northern Red Sea (Devassy *et al*., 2017). The present study revealed that the diatoms were the dominant phytoplankton, followed by the dinoflagellates. These findings agree with those observed earlier in different parts of the Red Sea (Touliabah *et al*., 2010; Al-Amri *et al*., 2020; El-Sherbiny *et al*., 2021; Kürten *et al*., 2015; Devassy *et al*., 2017). The dominance of dinoflagellates during the post summer, was reported also by Touliabah *et al*. (2010) and Al-Amri *et al*. (2020). During the present study, the main cyanophyte *Trichodesmium* spp. had its peak in summer. This is a very common phenomenon in the Red Sea (Post *et al*., 2002; Kürten *et al*., 2015; Devassy *et al*., 2017; Al-Amri *et al*., 2020; El-Sherbiny *et al*., 2021). Thus, it can be supposed that temperature has a significant role in the distribution of both dinoflagellates and cyanophytes.

Despite the wide monthly and diel variations of zooplankton count, it sustained an average (5820 individuals m^{-3}) that is higher than those found in other parts of the Red Sea (Table 1). Differences in collection methods (mesh size of the plankton nets used in the collection, type of collection as well as sampling regime) can be a possible reason for these variations. On the other hand, the abundance peak of zooplankton in our study observed in December was in accordance with the peaks which were recorded in the Gulf of Aqaba and the northern Red Sea by Farstey *et al*. (2002), El-Sherbiny *et al*. (2007), Dorgham *et al*. (2012) and El-Sherbiny *et al*. (2022). On the other hand, this peak of abundance was partially agreed with the study of Abdel-Rahman (1997) and Aamer *et al*. (2006).

It appeared that the dominance of copepods in the study area is common in tropical marine ecosystems (Champalbert *et al*., 2005; Fernández de Puelles *et al*., 2019; Lukman *et al*., 2020; Wimalasiri *et al*., 2021), but with different contribution in the Red Sea regions (Table 2).

There are a few studies on the temporal variation of zooplankton in the Red Sea (Echelman and Fishelson, 1990; El-Sherbiny *et al*., 2006, 2020; Cornils *et al*., 2005, 2007) almost in the Aqaba region. The majority of the available studies focused on the variation of zooplankton groups on a latitudinal gradient (Schneider *et al*., 1987; Schnack-Schiel *et al*., 2006; Kürten *et al*., 2015, 2016; Al-Aidaroos *et al*., 2017; Karati *et al*., 2019, 2022). The present study may be the first concerning the temporal and diel variations of the surface zooplankton in a central Red Sea region. The high zooplankton abundance during autumn and winter in the study area indicates its preferring to the relatively low temperature. Similar observations were reported in the Red Sea by El-Sherbiny and Al-Aidaroos (2021). On a diel basis, the low zooplankton abundance in the early morning and noontime as compared to the evening and midnight is a good indication of their escaping the high UV radiation. The clear sky on the Red Sea allows the penetration of UV radiation much deeper during the day time (Overmans and Agustí, 2020), that causes the deep migration of sensitive organisms to avoid the surface waters during the day (Haney, 1988; Al-Aidaroos *et al*., 2014, 2015; Mantha *et al*., 2016). Due to the oligotrophic characteristics of the Red Sea, the zooplankton here faces a severe challenge to find surplus food availability (Sommer, 2000), which together with the adverse temperature and solar conditions could be the reasons behind their lower abundance during the daytime. The experimental works of El-Sherbiny and Al-Aidaroos (2021) further substantiates the above statement. Moreover, the downward DVM could explain the low zooplankton count at noontime, as they avoid predators and other environmental obstacles (Lampert, 1989; Hays, 2003).

During this study, we particularly focused on the temporal/diel variability of the calanoid copepod *Centropages* spp. which are clearly the first of its kind information from the region. As dominant calanoid copepod, the *Centropages* spp. showed the lowest abundance during summer as compared to the other months of the year, when it recorded its high count at the evening and midnight. This contradicts with previous observations which recorded high counts of the *Centropages* spp. during summer (Lindley and Reid, 2002; Lindley and Daykin, 2005; Durbin and Kane, 2007; Mazzocchi *et al*., 2007; Kürten *et al*., 2015). The diel variability of *Centropages* spp. was simply a reflection of the total zooplankton with peak abundance towards the evening and midnight collections of the present study. Even though, it is a common phenomenon in tropical copepods (Amarasinghe *et al*., 1997; Milione and Zeng, 2008; Doan *et al*., 2019). The *Centropages* spp. are among the zooplankters that perform DVM as reported by Wu *et al*. (2013) and may be as a response to the abiotic (temperature), biotic (availability of phytoplankton) changes in the water column (Beaugrand *et al*., 2007). In our study, cladocerans were represented by the subtropical species *Penilia avirostris* that attained its high count in May-June, particularly in evening (6pm). This species is common in coastal waters (Tang *et al*., 1995) and was collected from surface water during the night (Wong *et al*., 2008). Chaetognaths in our area showed three peaks of abundance in spring, summer and autumn. In the northern Gulf of Aqaba, Cornils *et al*. (2005) reported two peaks in autumn and spring, while El-Sherbiny *et al*. (2020) observed two peaks in spring and late summer. That group too exhibited a clear diel and temporal variability with particular affinity towards low temperature and low/absent solar radiation in the Red Sea (Al-Aidaroos *et al*., 2017; and Karati *et al*., 2019, 2022).

The meroplanktonic larvae are known to be high in tropical waters (Levinton, 1982). The presence of a large number of crab larvae during the study period is mainly due to the proximity of the sampling location to the coast. The Red Sea is known for lots of adapted crab species and they spawn extensively and feed normally during the nighttime (Mastaller, 1987). Although the larvae of molluscs and decapods were the major meroplankton component in our study area they displayed less contribution to the total zooplankton than that recoded by Al-Aidaroos *et al*. (2016) and El-Sherbiny *et al*. (2019, 2020) and comparable with other studies records (Cornils *et al*., 2007; El-Sherbiny *et al*., 2007; Dorgham *et al*., 2012).

Table 1. Range and average zooplankton abundance (individuals m^{-3}) recorded in some previous studies in the Red Sea.

Area	Date/ mesh size used	Range (Average)	Reference
Off Sharm El-Sheikh area	2005–2006/100 µm	1510-2712 (2172)	El-Sherbiny *et al*. (2007)
Sharm El-Mayia Bay	2000–2001/100 µm	1326-9825 (2639)	Aamer *et al*. (2006)
Off Sharm El-Sheikh area	1995–1996/100 µm	1124-4952 (2443)	Dorgham *et al*. (2012)
Egyptian side of Gulf Aqaba	1994-1995/55 µm	1906-4138 (2576)	Khalil and Abd El-Rahman (1997)
Northern Gulf of Aqaba	2002-2003/200 µm	943-3065 (-)	Cornils *et al*. (2007)
Northern Gulf of Aqaba	1986-1989/500µm	33-317 (-)	Echelman and Fishelson (1990)
Coastal lagoons around Jeddah	1990-1991/150µm	340-4955 (2605)	Al-Aidaroos and Ghazali (1998)
Saudi waters of the Red Sea	Mar-Apr 2011/150µm	1058-25787 (5230)	Al-Aidaroos *et al*. (2016)
Saudi waters of the Red Sea	Sep 2012/150µm	787-50642 (14358)	Kürten *et al*. (2015)
Along Saudi coast of Gulf of Aqaba	August 2016/180µm	230-894 (491)	El-Sherbiny *et al*. (2019)
Central Red Sea	Jan-Dec 201٨/150µm	334-35787 (5820)	Present study

Table 2. Contributions of different zooplankton groups in comparison to some other studies in the Red Sea.

Area	Collection	Main zooplankton groups					Reference
		Cn	**ML**	**Co**	**Ch**	**Tu**	
Egyptian side of Gulf Aqaba	(Surface)	<1	-	75.5	<1	1.7	Khalil and Abdel-Rahman (1997)
Northern Gulf of Aqaba	(0-100m)	0.3	8	78.8	2.4	2.5	Cornils *et al.* (2007)
Off Sharm El-Sheikh area	(0-100m)	0.9	8.4	84.7	1.2	2.4	El-Sherbiny *et al*. (2007)
Off Sharm El-Sheikh area	(0-100)	0.6	6.6	87.9	1	2.2	Dorgham *et al.* (2012)
Saudi waters of the Red Sea	(Surface)	0.9	11.6	69.7	4.5	4	Al-Aidaroos *et al.* (2016)
Hurghada coastal waters	Surface	2	12	53	10	0.6	Abu El-Regal *et al.* (2018)
Along Saudi coast of Gulf of Aqaba	(0-200m)	0.7	16.1	58.8	9.1	8	El-Sherbiny *et al*. (2019)
Coastal waters of Sharm El-Sheikh area	Surface	0.7	18.1	68.2	0.6	3.1	El-Sherbiny *et al*. (2020)
Central Red Sea	Surface	1.2	7.3	79.5	1.7	1.5	Present study

Cn: Cnidarians, ML: Mollusc larvae, Co: Copepods, Ch, Chaetognaths and Tu: Tunicates

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الاختلافات الزمنية واليومية في وفرة العوالق الحيوانية في وسط البحر الأحمر مع التركيز على جنس *السنتروباجس* من مجدافيات الأرجل

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المستخلص. تمت دراسة الاختلافات الزمنية واليومية لوفرة العوالق الحيوانية في منطقة أمام مدخل شرم أبحر وسط البحر الأحمر. أوضحت النتائج ارتفاع درجة الحرارة والملوحة والمعروفة للبحر الأحمر. كما أوضحت البيانات ضعف مستوي المغذيات غير العضوية والعوالق النباتية والكتلة الحيوية (الكلوروفيل أ) مؤكدة على أن منطقة الدراسة تعتبر فقيرة التغذية. كان متوسط كثافة العوالق النباتية قليلًا نسبياً (٢٤٨.٨٠± ٣٠٦.٩٦ X ١٠$^{-٣}$ خلية في المتر المكعب) مع وجود بعض الزيادات العرضية في قيمتها في شهر مايو (١٠٨٢.٣٤ X ١٠$^{-٣}$ خلية في المتر المكعب)، حيث ظهرت أعلى كثافة نتيجة لزيادة أحد أنواع الدياتومات. وسيطرت الدياتومات على مجموعة العوالق النباتية مكونة نسبة ٧٠.٦٪ من العدد الكلي، بينما سادت مجموعة ثناية الأسواط في فصل الصيف. أظهرت العوالق الحيوانية اختلافا كبيراً في كثافتها العددية خلال فترة الدراسة (١٥٢٣ و٢٣١٧١ فرد لكل متر مكعب)، وكثافتها اليومية (٢٦٩٤ و٦٨٥١ فرداً لكل متر مكعب). وبشكل موسمي كانت الوفرة العددية للعوالق الحيوانية عالية في الفترة الأكثر برودة. كما أوضح التباين اليومي وجود أعلى كثافة للعوالق الحيوانية في فترة المساء ومنتصف الليل. وكانت مجموعة مجدافيات الأرجل هي المجموعة السائدة من العوالق الحيوانية، حيث شكلت ٧٩.٥٪ من النسبة الكلية للعوالق، تلاها مجموعة متفرعة القرون والديدان السهمية والزنبقيات ويرقات السلطعون (٤.٨ و١.٧ و١.٥ و٢.٨٪ على الترتيب). وكما هو الحال في العدد الكلي للعوالق الحيوانية، فقد أوضحت النتائج سلوك المجموعات الراسية لنفس النمط في التغيرات اليومية والموسمية تقريباً. أما جنس *السنتروباجس* من مجموعة مجدافيات الأرجل فقد أظهر زيادة في الكثافة في كل من الربيع والخريف، والتي تميل الي درجة الحرارة المعتدلة. بينما ظهرت كثافات مرتفعة نسبياً في المساء ومنتصف الليل. كما يتضح من هذه الدراسة، إن توزيع العوالق الحيوانية في وسط البحر الأحمر يعتمد بشكل رئيسي على التأثير التراكمي لكل من الحرارة والإشعاع الشمسي، في حين أن بعض أنواع *السنتروباجس* لديهم ميل لدرجة الحرارة المعتدلة، مما يدل على سلوكها الأصلي.

الكلمات المفتاحية: العوالق الحيوانية، الاختلافات الشهرية، الاختلافات اليومية، الوفرة العددية، البحر الأحمر.