Copepod dynamics in the epipelagic zone of two different regional aquatic ecological basins at the northern Red Sea, Egypt

Hamed A. El-Serehy[1,2*], Nasser S. Abdel-Rahman[3], Khaled A Al-Rasheid[1], Fahad A. Al-misned[1], Hesham M. Shafik[4,5]and Magdy M.Bahgat[5]

[1] Zoology Department, College of Science, King Saud University, Riyadh 1145 Saudi Arabia
[2] Port Said University, Faculty of Science, Marine Science Department, Port Said, Egypt
[3] National Institute of Oceanography & Fisheries, Suez, Egypt
[4] Hungarian Academy of Sciences, Limnoecology Research Group, University of Pannonia, H-8200 Veszprem, Egyetem u. 10, Hungary
[5]Department of Botany and Microbiology, Faculty of Science, Port Said University, Egypt
* Author to whom correspondence should be addressed
*helserehy@ksu.edu.sa

Abstract: This study was conducted to observe the copepod community structure in the oligotrophic habitats of the Gulf of Aqaba. The study investigates the community's temporal and spatial fluctuation and its profile of vertical distribution in sandy habitats when compared to the coral reef habitats of the gulf. Sampling was carried out through four cruises during spring (March 2008), summer (June 2008), autumn (September 2008) and winter (December 2008). Nutrient concentrations were found to be very low. The copepod community of the Gulf of Aqaba was found to be dominated by 81 species. All 81 of these species were encountered in the waters of sandy coasts (Ras Burka and Nuweiba), but, surprisingly, only 51 were found in the waters of the coral reef area (Hibika and Abu Galoum). Seasonal changes in the vertical and horizontal distribution of planktonic copepods are described for a 100 m water column in the Gulf of Aqaba, covering spring, summer, autumn and winter. Four different distribution patterns exemplified by planktonic copepods are highlighted: (1) a horizontal variance, demonstrating an inverse distribution pattern between sandy and coral reef habitats, in which the population density was greater offshore at the coral reef stations, while it was greater inshore at the sandy stations; (2) a vertical distribution pattern in which approximately 50% of the population occurred in the upper 25 m of the water column of the gulf, while less than 10% occurred between the depths of 75 and 100 m; (3) a seasonal distribution pattern in which the copepods exhibited considerable fluctuation in their occurrence and abundance, with a peak in winter (December) and minimum abundance values during summer (September); (4) a site distribution patterns with a peak in population density at the northern stations and a decline southwards. These patterns of copepod distribution in the Gulf of Aqaba suggested a strong influence from local endemic geographic and hydrographic differences, the predation impact of local inhabitants and the policy of "better dead than unfed", but no response to water nutrient levels. It is suggested that copepods in the coral reef habitats of the Gulf of Aqaba serve as a preferable food item for the higher trophic levels of the reef inhabitants.

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1. Introduction

Among various animal taxa occurring as metazooplankton in the world's oceans, copepods are the most numerous taxa (55%-95%) in most sea areas (Longhurst, 1985). Copepods play integral roles in energy flow and material cycling in the entire water column (Neunes, 1965; Mauchline, 1998). Because they constitute the main bulk of metazooplankton and are an important intermediate link in the marine food chain. Copepods are therefore of special interest when studying marine ecosystems.

Although the role of Copepoda in coral reef communities is not yet clear, their contribution to energy transfer along the food chain of the coral reef ecosystem is very important (Alldredge and King, 1977; Roman et al., 1990). In addition, Copepoda represent a significant part of the diet for various coral reef inhabitants (Robichaux et al., 1981).

The oligotrophic Gulf of Aqaba is very rich in coral reefs which are diverse ecosystems, with high productivity and an abundance of organisms in relatively nutrient poor waters (Goreau et al., 1971). In the Gulf of Aqaba, seasonal stratification is usually reported in the water column during the warm months of summer, while deep vertical mixing occurred during the cold months of winter (Reiss and Hottinger, 1984; Wolf-Vecht et al., 1992). The vertical distribution of zooplankton in the epipelagic zone indicated a more even zooplankton distribution in well-mixed than in stratified columns (Buckley and Lough, 1987; Checkley et al., 1992; Incze et al., 1996).

The distribution of Copepoda in the Gulf of Aqaba was firstly described by Schmidt (1973) who provided preliminary data on the displacement volume and numerical abundance of the total copepod assemblage in one station in the northern part of the gulf. Por (1979) reported eighteen species of Copepoda in the coasts of the Gulf of Aqaba while Kahan and Bar-El (1982) identified new species of Harpacticoida in the gulf. The first counts of calanoid Copepoda were reported by Almeida Prado-Por and Por (1981). Vaissiere and Seguin (1984) gave preliminary studies of the zooplankton groups from the coral reef and open sea areas of the Gulf of Aqaba. Almeida Prado-Por (1983, 1985 and 1990) studied the diversity, dynamics and the daily cycle of vertical distribution of the Calanoida (Copepoda) in the Gulf of Aqaba. Echelman and Fishelson (1990) also listed surface zooplankton and copepods in the northern part of the gulf. A variety of other studies have been conducted on the zooplankton of the Gulf of Aqaba, such as those of Genin *et al*. (1995), Khalil and Abdel-Rahman (1997), El-Serehy and Abdel-Rahman (1999), Al-Najjar (2000), Böttger-Schnack (2001), Sommer et al. (2002), Abdel-Rahman and El-Serehy (2004), Al-Najjar and El-Sherbiny 2008 and Dorgham et al., 2012.

The present study highlights and seeks to compare the community composition, population dynamics, the vertical, horizontal and seasonal distribution patterns of planktonic copepods in the epipelagic zone of two different regional aquatic ecological basins (sandy and coral reef habitats) along the eastern side arm of the Red Sea (Gulf of Aqaba).

2. Material and Methods

a. *Area of study*

The Gulf of Aqaba, a side arm of the Red Sea that forms the eastern border to the Sinai Peninsula, shows a number of hydrographical and physical characteristics that lead to peculiarities regarding its chemical zonation and the dynamics and composition of the planktonic community. Being surrounded by desert, there is no allochthonous nutrient input, and due to the resulting low concentrations of nutrients and chlorophyll *a* and low primary productivity, it is classified as ultraoligotrophic (Reiss and Hottinger, 1984). It is a 180-km-long, deep (max. depth 1,820 m), narrow basin (2–25 km wide), with no pronounced shelf region. It is separated from the Red Sea by a shallow sill (max. depth 242 m), the Strait of Tiran. There are two major marine basins: the northern one extending south to Nuweiba with a maximum depth of 1000 m, and the southern one which extends to the straits of Tiran and sounds 1800 m. In comparison to other tropical oceans, it shows a weak vertical stratification. Cooling of the surface water and very high evaporation rates lead to a vertical mixing depth of the water column in the winter of up to 900 m (Genin et al., 1995). Due to the climatic conditions, there is a thermohaline circulation in the Gulf of Aqaba. The resulting loss of deep, nutrient-rich, and more saline water across the Strait of Tiran is compensated by the inflow of warm, nutrient-depleted surface waters from the Red Sea (Plaehn et al., 2002). The winter mixing brings up nutrients from deep waters, which accumulate in the surface layer in spring when, due to increasing water temperature, stratification sets in. This usually leads to a pronounced spring bloom.

b. *Sampling and laboratory techniques*

Four cruises were carried out in the Gulf of Aqaba during spring (March 2008), summer (June 2008), autumn (September 2008) and winter (December 2008) in order to study the distribution strategies of Copepoda in sandy and coral reef habitats. Four sites were selected (Figure 1); two of which (Ras Burka and Nuweiba) lie in sandy coastal areas, while the other two (Hipika and Abu Galoum) lie in coral reef coastal areas.

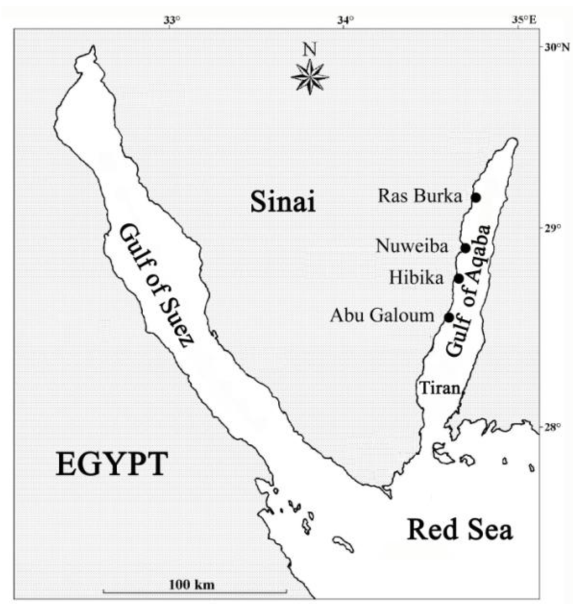

Figure 1. Map showing the four sampling sites chosen along the eastern side arm of the Red Sea (Gulf of Aqaba).

Collections were made during daytime high tide. British Admiralty tide table predictions for the Sharm El-Sheikh area were checked before each visit. A single fixed transect was laid out at each of the sandy and coral reef sites. The length of each transect was 2 km perpendicular to the seashore. A plastic line knotted at 500 m intervals was used to divide each transect into four equally spaced stations for horizontal tows. At each of these stations a 100 m measuring tape and closing standard plankton net of 90 µm-mesh size, and with a mouth opening of 0.16 m^2, were used to perform vertical tows. At each site surface zooplankton were collected from discrete distance intervals from 0~500, 500~1000, 1000~1500 and 1500~2000 m and thence subsurface zooplankton were collected from discrete depth intervals from 0~ 25, 25~50 , 50~75 and 75~100 m. A flow meter (Rigosha, Saitama, Japan) was mounted in the mouth of the net to register the volume of water passing through the net. Zooplankton samples were split on board, and 1/2 aliquots were immediately preserved with 5% borax-buffered formalin-seawater, and the other 1/2 aliquots were filtered through 25 mm diameter Whatman glass fibre filters (GF/F) and stored at -18 ^{o}C for later determination of inorganic nutrients.

For chlorophyll *a* concentrations, 2 l of water samples were filtered onto GF/F filters, wrapped in small Petri dishes and aluminium foil, frozen (-18 ^{o}C), and measured flurometrically. Water temperature and salinity were determined using a CTD system (Seabird SBE-9, Washington, USA).

At the land-based laboratory, copepods in the zooplankton samples were identified and counted under a dissecting microscope. The accurate identification of copepods was done by dissecting each copepod, using fine needles on a glass slide in a 1:1:2 mixture of glycerine, alcohol, and water. Many publications and taxonomic references were used for identification, such as Giesbrecht (1892), Trégouboff and Rose (1957), Newell (1963), Gonzalez and Bowman (1965), Williamson (1967), Bradford-Grieve (1994), Bradford-Grieve and Jillett (1980), Bradford-Grieve et al. (1983), Heron and Bradford-Grieve (1995) and Boltovskoy (1999).

c. *Data analysis*

The statistical test, analysis of variance, one factor ANOVA (Underwood, 1981) was followed. The least significant difference test (Steel and Torrie, 1986) was applied to test whether the density of the different microplankton groups varied significantly between sites and seasons.

3. Results

a. *Physical properties, nutrients and chlorophyll a*

The physical parameters of the four different locations in the Gulf of Aqaba were listed in Table (1). Water temperature was between 23 and 25.3 ^{o}C, and salinity was between 40.1 and 40.6 psu. Nutrient concentrations (Table 1) were extremely low and did not differ greatly between sites. Only nitrate showed some distinct spatial variation, with the values measured at the sandy stations exceeding those of the other (coral reef stations) by three – to four folds. Though generally low, the initial concentrations of total chlorophyll *a* showed pronounced temporal and spatial variation (Table 1). The highest concentration was measured at Ras Burka and with values of 0.25 µg l^{-1}, while the lowest values of 0.14 µg l^{-1} were recorded at Abu Galoum.

b. *Species composition*

A total of 81 species of Copepoda were recorded during the present investigation, belonging to 39 genera, 42 families and 4 orders. Namely: Calanoida, Poecilostomatoida, Cyclopoida, and Harpacticoida. All 76 of these copepod species were recorded in the water of the sandy stations of Ras Burka and Nuweiba, but only 51 species were recorded in the coral reef stations of Hibika and Abu Galoum. Thus, whilst no copepod species that was present in the coral reef stations was absent from the sandy stations, a total of 30 copepod species that were present in the sandy stations were absent from the water of coral reef stations (13 Calanoida, 10 Poecilostomatoida, 4 Cyclopoida and 3 Harpacticoida). These 30 species are: *Acartia centrura*, *Acrocalanus gibber*, *A. longicornis*, *Paracalanus aculeatus*, *Calanopia minor*, *Calocalanus pavoninus*, *C. styliremis*, *Centropages furcatus*, *Clausocalanus arcuicornis*, *Phaenna spinifera*, *Temora stylifera*, *Temoropia mayumbaensis; Undinula vulgaris; Lubbockia squillimana*, *Oncaea dentipes*, *O. media*, *Sapphirina opalina*, *Corycaeus clause*, *C. erythraeus*, *C. ovalis*, *C. speciosus*, *C. subulatus*, *Farranula gibbula; Oithona similes*; *Copilia* sp*; Corycaeus* sp.*; Oncaea* sp. *Clytemnestra scutellata*, *Macrosetella gracilis* and *Microsetella norvegica*.

c. *Site and seasonal dynamics*

The magnitude of the standing crop of copepods attained its highest density at Ras Burka, which sustained an average annual number of 3186 ind. m^{-3}**.** This site is characterized by higher chlorophyll *a* values and relatively nutrient-rich water with high concentrations of phosphate and nitrate (Table 1). On the other hand, a marked decline in the copepod densities from northern sites towards southern ones was noticed. The average annual number of individuals at Nuwebia decreased to 3076 ind. m^{-3}, then to 1459 ind. m^{-3} at Hibika and to 963 ind. m^{-3} at Abu Galoum, respectively. It is clear that there is a highly significant difference in copepod density between the four sites ($p < 0.05$). Seasonally, the Copepoda exhibited considerable fluctuations in their occurrence and abundance (Figure 2), with a peak in winter (December), and minimum abundance values during summer (June).

d. *Horizontal and vertical distribution*

A further finding was that the population density of planktonic Copepoda was greater offshore at the coral reef stations of Hibika (1940 ind. / m^3 versus 341 ind. / m^3 inshore) and Abu Galoum (890 ind. / m^3 versus 251 ind. / m^3 inshore), while it was greater inshore at the sandy sites of Ras Burka (6970 ind. / m^3 inshore while 1316 ind. / m^3 offshore) and Nuweiba (7460 ind. / m^3 and 1120 ind. / m^3 offshore). In addition, approximately 50% of the planktonic copepod population occurred in the upper 25 m of the water column of the gulf, while less than 10% occurred between 75 and 100 m in the gulf water. The variation in population density was, on both the above measures, more marked at the sandy sites than at the coral reef sites.

Table 1. Physical properties, nutrient concentrations and Chlorophyll *a* values at the four stations along the Gulf of Aqaba during the present study.

	Sites							
	Ras Burka		Nuweiba		Hebika		Abu Galoum	
Parameter	Inshore	Offshore	Inshore	Offshore	Inshore	Offshore	Inshore	Offshore
Water Temperature (°C)	24.1 ± 2.2	23.7 ± 3.1	23.8 ± 1.5	23.6 ± 2.4	23.5 ± 2.4	23.2 ± 1.8	23.6 ± 3.3	23.1 ± 2.8
Salinity (psu)	40.6 ± 3.7	40.3 ± 3.2	40.2 ± 3.1	40.2 ± 3.3	40.2 ± 4	40.3 ± 3.5	40.3 ± 3.5	40.4 ± 3.3
NO_3 (μmol l^{-1})	1.04 ± 0.09	1.01 ± 0.07	1.01 ± 0.04	1.0 ± 0.07	0.30 ± 0.03	0.35 ± 0.04	0.23 ± 0.10	0.24 ± 0.04
NH_4 (μmol l^{-1})	0.83 ± 0.09	0.71 ± 0.06	0.89 ± 0.18	0.77 ± 0.08	0.53 ± 0.04	0.64 ± 0.09	0.44 ± 0.10	0.52 ± 0.08
Si (μmol l-1)	1.13 ± 0.04	1.08 ± 0.03	1.17 ± 0.02	1.11 ± 0.03	1.08 ± 0.03	1.10 ± 0.04	1.06 ± 0.02	1.09 ± 0.02
P (μmol l^{-1})	0.12 ± 0.01	0.11 ± 0.01	0.12 ± 0.05	0.11 ± 0.01	0.09 ± 0.01	0.11 ± 0.02	0.08 ± 0.01	0.09 ± 0.01
Chlorophyll *a* (μg l^{-1})	0.21 ± 0.01	0.15 ± 0.01	0.22 ± 0.02	0.19 ± 0.01	0.15 ± 0.01	0.21 ± 0.02	0.13 ± 0.01	0.19 ± 0.02
	Sites							
	Ras Burka		Nuweiba		Hebika		Abu Galoum	
Parameter	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
Water Temperature (°C)	25.3 ± 2.4	24.2 ± 3.1	24.6 ± 2.9	23.0 ± 1.6	25.5 ± 1.8	23.9 ± 2.6	25.4 ± 1.5	24.4 ± 2.4
Salinity (psu)	40.3 ± 3.1	40.2 ± 3.1	40.3± 3.5	40.1 ± 3.5	40.3 ± 3.0	40.2 ± 3.2	40.2 ± 3.1	40.2 ± 3.1
NO3 (μmol l^{-1})	1.04 ± 0.06	1.00 ± 0.08	1.0 ± 0.05	0.90 ± 0.03	0.37 ± 0.03	0.31 ± 0.04	0.40 ± 0.04	0.37 ± 0.09
NH_4 (μmol l^{-1})	0.86 ± 0.10	0.72 ± 0.18	0.83 ± 0.04	0.78 ± 0.04	0.61 ± 0.09	0.57 ± 0.06	0.55 ± 0.06	0.52 ± 0.11
Si (μmol l^{-1})	1.11 ± 0.3	1.0 ± 0.02	1.13 ± 0.04	1.1 ± 0.04	1.07 ±0.02	1.02 ±0.03	1.09 ± 0.03	1.04 ± 0.02
P (μmol l^{-1})	0.14 ± 0.00	0.12 ± 0.01	0.12 ± 0.05	0.12 ± 0.01	0.11 ± 0.01	0.09 ± 0.01	0.09 ± 0.01	0.06 ± 0.01
Chlorophyll *a* (μg l^{-1})	0.25 ± 0.02	0.15 ± 0.02	0.20 ± 0.01	0.17 ± 0.01	0.21 ± 0.01	0.15 ± 0.02	0.19 ± 0.00	0.14 ± 0.01

4. Discussions

In the Gulf of Aqaba, Copepoda is the dominant zooplankton group, comprising nearly 70 % of the total number of metazooplankton in the Gulf of Aqaba (Schmidt, 1973; Echelman and Fishelson, 1990; Khalil and Abdel-Rahman, 1997; El-Serehy and Abdel-Rahman, 1999 and Al-Najjar, 2000).

A particularly significant and surprising finding from this study is that the overall abundance and diversity of planktonic copepods was greater in the sandy areas than in the coral reef areas. Since coral reef habitats are usually associated with greater species abundance and diversity this finding was opposite to what would normally be expected, even though the mean abundance of planktonic copepods in the coral reef areas of the Gulf of Aqaba is comparable with estimates from other coral reef sites such as the Great Barrier Reef (Alldredge and King, 1977; Roman et al., 1990) and the Marshall Islands (Gerber and Marshall, 1982), but of lower magnitude than in the Caribbean coral reef sites (Glynn, 1973).

One explanation for this fluctuation in copepod abundance is that it is principally geographic in origin. The sandy sites of Ras Burka and Nuweiba are, broadly, further north than the coral reef sites. According to the hypothesis suggested by Mergner and Schuhmacher (1974) and Hulings (1979), the surface water flows southward on both sides of the gulf, while the deeper water flows northward along the east coast and southward along the western bank. With the prevailing north wind, this circulation induces an upwelling in the northern part of the gulf. Kimor and Golandsky (1977) have shown that the particular hydrographic conditions prevailing in this environment affect the distribution of micro-plankton and this might explain the higher population density of planktonic copepods at the northern stations of Ras Burka and Nuweiba compared with the southern ones.

The sandy site at Ras Burka, however, is not significantly further north than the coral reef site at Hibika but there is a significant variation in the abundance and diversity of planktonic copepods between these sites that is difficult to attribute purely to geographic and hydrographic differences. Whilst the distribution pattern of planktonic copepods is likely to be affected by a range of different factors, it is suggested that the increased presence of predators is likely to be the most significant of these (Barnes and Hughes, 1999). Observation of the feeding habits of different coral reef fish, and examination of their gut contents, clearly indicates extensive feeding on endemic reef copepod species (Williams et al., 1988). Moreover, predation on copepod species by reef inhabitants, as well as by zooplanktivores in waters flowing over coral reefs, is intense (Glynn, 1973; Hamner et al., 1988). This increased level of predation may explain the decrease in copepod species composition in the waters of the coral reef stations of Hibika and Abu Galoum compared to those of the sandy stations of Ras Burka and Nuweiba that was observed during the present study (from 81 to 51 species).

The data presented in this study suggests that, in the Gulf of Aqaba, among Calanoida, thirteen species should be considered the most preferable food items for coral reef zooplanktivores (*Acartia centrura*, *Acrocalanus gibber*, *A. longicornis*, *Paracalanus aculeatus*, *Calanopia minor*, *Calocalanus pavoninus*, *C. styliremis*, *Centropages furcatus*, *Clausocalanus arcuicornis*, *Phaenna spinifera*, *Temora stylifera*, *Temoropia mayumbaensis* and *Undinula vulgaris*). Similarly, among Poecilostomatoida, ten species should be considered the most preferable food items (*Lubbockia squillimana*, *Oncaea dentipes*, *O. media*, *Sapphirina opalina*, *Corycaeus clause*, *C. erythraeus*, *C. ovalis*, *C. speciosus*, *C. subulatus*, *Farranula gibbula* and *Oithona similes*). Three species of Harpacticoida (*Clytemnestra scutellata*, *Macrosetella gracilis* and *Microsetella norvegica*) and four of Cyclopoida (*Oithona similes*, *Copilia* sp; *Corycaeus* sp.; *Oncaea* sp.) should also be considered preferable food for coral reef zooplanktivores.

In addition to the difference in levels of species diversity between the two types of site in this study, the data of the present study shows that an inverse relationship was observed between the horizontal distributions of planktonic copepods in coral reef as compared to sandy areas, i.e. there was higher copepod density inshore in sandy areas and offshore in coral reef areas. This inverse relationship is here attributed to the existence of nutrient and detritus substances which encourage the flourishing of phytoplankton as food materials for planktonic copepods. In the sandy areas the existence of nutrient and detritus substances declines as one moves further offshore, whilst in the coral reef areas, the presence of the offshore reefs results in an increase in nutrient as one moves offshore (Table 1).

The horizontal distribution pattern is supplemented by a parallel vertical distribution pattern in which, across all four sites, but especially at Ras Burka and Nuweiba, the density of copepods

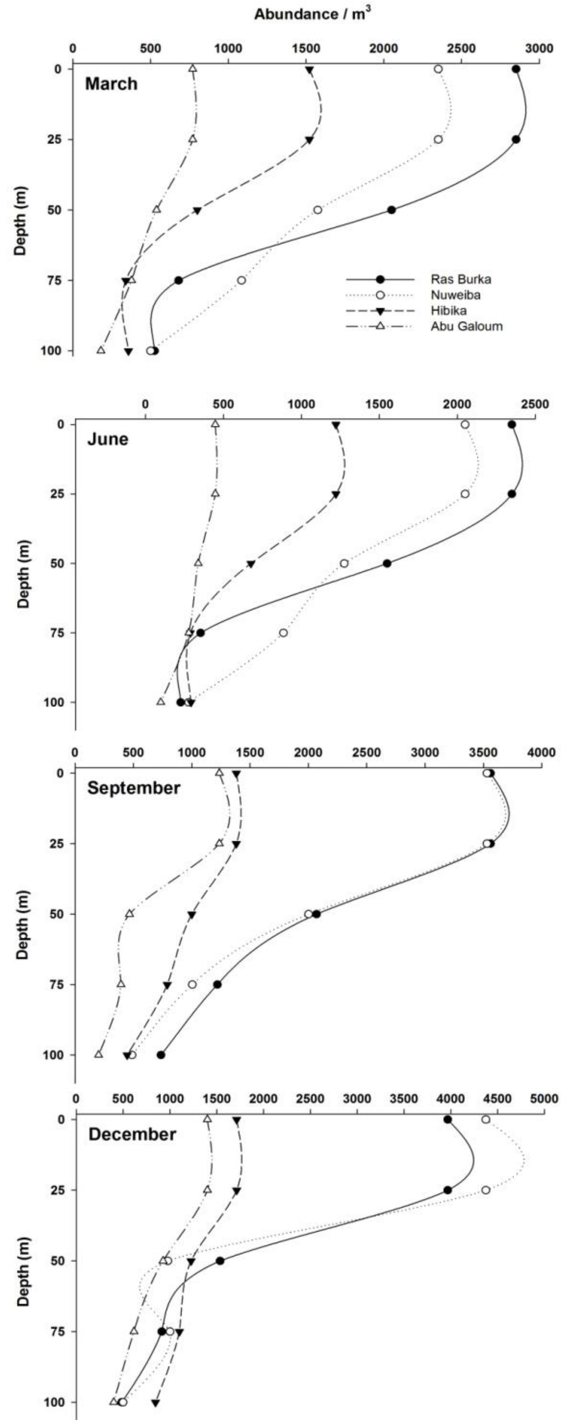

Figure 2. Denisty of planktonic copepods in the epipelagic zone of the coral reefs (Hibika and Abu Galoum) and sandy shores (Ras Burka and Nuweiba) of the Gulf of Aqaba in Spring (March), summer (June), autumn (September) and Winter (December).

was greater at shallower depths. As with the horizontal distribution pattern, this vertical distribution is likely to be principally a reflection of greater availability of food close to the surface. When food availability is very low, even in circumstances where they might face greater threat of predation, animals tend to employ the policy of "better dead than unfed" and thus remain in surface waters at least until they have consumed sufficient food. Even though migration towards the surface might pose a greater risk of predation for copepods, experimental evidence and field observations have shown that these risks are mitigated to some degree by the opportunity for visual predator avoidance (Pearre, 2003). The higher light levels closer to the surface (both through sunlight and moonlight) have been to provide an additional visual cue for such avoidance behaviour (Ringelberg, 1995). Experimental and field data has also shown that other environmental parameters, such as temperature, levels of dissolved oxygen and salinity can influence the profile of vertical distribution (Ringelberg, 1995).

The data in Figure (2) shows a seasonal variation in the population structure of planktonic copepods in the Gulf of Aqaba. Bechmann (1984) attributed the winter peak of zooplankton in the Indian Ocean and the Persian Gulf, which pours into the Red Sea through Bab El Mandab during winter, to the water exchange pattern prevailing toward the Red Sea. As summer approaches, the plankton density in the Red Sea decreases as the surface habitat becomes more hostile due to increasing temperature, and the recruitment from the Arabian Gulf diminishes with the decreasing rate of water exchange. This hypothesis can also explain the winter peak of planktonic copepods in the Gulf of Aqaba during the present study.

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Corresponding Author:
Prof. Hamed A. El-Serehy
Department of Zoology College of Science, King Saud University Riyadh 1145, Saudi Arabia
E-mail: helserehy@ksu.edu.sa

References

1. Abdel-Rahman NS, El-Serehy HA. The planktonic Copepoda of the Red Sea: A review 1-Calanoida. Proc 3rd Int. Conf. Biol. Sci. Tanta Univ., 2004; 3 (1): 328-350.
2. Al- Najjar TH. The seasonal dynamics and grazing control of phyto- and mesozooplankton in the northern Gulf of Aqaba. Ph.D. Thesis Bremen University, 2000.
3. Al- Najjar TH, El-Sherbiny MM. Spatial and seasonal variations in biomass and size structure of zooplankton in coastal waters of the Gulf of Aqaba. Jordan Journal of Biological Sciences, 2008, 1 (2): 55-59.
4. Alldredge A, King JM. Distribution, abundance and substrate preference of demersal reef zooplankton at Lizard Island Lagoon, Great Barrier Reef. Mar. Biol., 1977, 41: 317-333.
5. Almeida Prado-Por MS. The diversity and dynamics of Calanoida (Copepoda) in northern Gulf of Eilat (Aqaba), Red Sea. Oceanol. Acta., 1983, 6(2): 139-145.
6. Almeida Prado-Por MS. Distribution of the calanoid Copepoda along the Gulf of Eilat (Aqaba), Red Sea. Rapp. Comm. Int. Mer. Medit., 1985, 29 (9): 249-252.
7. Almeida Prado-Por MS. A diel cycle of vertical distribution of the Calanoida (Crustacea: Copepoda) in the Northern Gulf of Aqaba. Bull. Nat. Inst. Oceanogr., Monaco, 1990, 7: 109-116.
8. Almeida Prado-Por MS, Por, FD. First data on the Calanoida (Copepoda) of the Northern Gulf of Elat (Red Sea). Rapp. Comm. Int. Mer. Medit., 1981, 27(7): 173-174.
9. Bechmann W. Mesozooplankton distribution on transect from the Gulf of Aden to the central Red Sea during the winter monsoon. Oceanol. Acta, 1984, 7: 87-102.
10. Boltovskoy D. South Atlantic Zooplankton. Backhuys Publishers, Leiden, 1999, pp 1-1706.
11. Böttger-Schnack R. Taxonomy of Oncaeidae (Copepoda, Poecilostomatoida) from the Red Sea. II. Seven species of Oncaea s. Str. Bull. Br. Mus. Nat. His. (Zool.), 2001, 67: 25-84.
12. Bradford-Grieve JM. Systematic of ecology of New Zealand Central East Coast sampled at Kaikoura. Memoirs. N. Z. Oceanographic Institute, 1972, 54: 1-82.
13. Bradford-Grieve JM. The marine fauna of New Zealand: Pelagic calanoid Copepoda: Megacalanidae, Calanidae, Paracalanidae, Mecyno-ceridae, Eucalanidae, Spinocalanidae, Clausocalanidae. Wellington NIWA, 1994, 102. 23 (9): 1029-1035.
14. Bradford-Grieve JM, Haakonsen L, Jillett JB. The marine fauna of New Zealand: Pelagic calanoid copepods: families Euchaetidae, Phaenidae, Scolecithricidae, Diaixidae, and Tharybidae. Memoirs. N. Z. Oceanographic Institute, 1983, 90: 1-150.

15. Bradford-Grieve JM, Jillett JB. The marine fauna of New Zealand: Pelagic calanoid copepods: family Aetideidae. Memoirs. N.Z. Oceanographic Institute, 1980, 86: 1-102.
16. Buckley LJ, Lough RG. Recent growth, biochemical composition, andprey field of larval haddock (Melanogrammus aeglefinus) and Atlantic cod (Gadus morhua) on Georges Bank, Canad. J. Fish. Aquat. Sci., 1987, 44 (1), 14–25, http://dx.doi.org/10.1139/f87-003.
17. Checkley DMJr, Dagg MJ, Uye S. Feeding, excretion and egg production by individuals and populations of the marine planktonic copepods *Acartia* spp. and *Centropages furcatus.* J. Plankton Res., 1992, 14 (1):71–96, http://dx.doi.org/10.1093/plankt/14.1.71.
18. Claessens M, Wickham SA, Post AF, Reuter M. Ciliate community in the oligotrophic Gulf of Aqaba, Red Sea. Aquat Microbial Ecol., 2008, 53: 181-190.
19. Claessens M, Wickham SA, Post AF, Reuter M. A paradox of the ciliates? High ciliate diversity in a resource-poor environment. Mar. Biol., 2010, 157: 483-494.
20. Dorgham MM, Elsherbiny MM, Hanafy MH. Vertical distribution of zooplankton in the epipelagic zone off Sharm El-Sheikh, Red Sea, Egypt. Oceanologia, 2012, 54 (3): 473-489.
21. Echelman T, Fishelson L. Surface zooplankton dynamics and community structure in the Gulf of Aqaba, Red Sea. Mar. Biol., 1990, 107: 179-190.
22. El-Serehy HA, Abd El-Rahman NS. Zooplankton ecosystem at the Egyptian natural Protectorates of the Gulf of Aqaba, Red Sea. J. Egypt. Ger. Soc. Zool., 1999, (30): 67-81.
23. Genin A, Lazar B, Brenner S. Vertical mixing and coral death in the Red Sea following the eruption of Mount Pinatubo. Nature, 1995, 112: 507-510.
24. Gerber RP, Marshall N. Characterization of the suspended particulate organic matter and feeding by the lagoon zooplankton at Enewetok Atoll. Bull Mar. Sci., 1982, 32: 290-300.
25. Giesbrecht W. Systematik und Faunistik de pelagischen Copepoden des Golfes von Neapel. Fauna Floara Golf. Neapel, 1892, 9: 831 pp.
26. Glynn PW. Ecology of a Caribbean Reef. The Porites Reef-Flat Biotope: Part II. Plankton Community with Evidence for Depletion. Mar. Biol., 1973, 22: 1-21.
27. Godeaux J. The Gulf of Aqaba, a zone of great biological interest. UNESCO. Tech Papers Mar Sci., 1986, 49, 104-106.
28. Gonzalez JG, Bowman TE. Planktonic Copepods from Bahia fosforescent, Puerto Rico and adjacent waters. Proc. U S. Nat.Mus. Smith. Inst. Washington, D. C., 1965, 117 (3531).
29. Goreau T, Goreau NI, Younge CM. Reef Corals: Autotrophs or heterotrophs?. Biol. Bull., 1971, 14*1*: 247-260.
30. Hamner WM, Jones MS, Carleton JH, Hauri IR, Williams DM. Zooplankton , plankitovorous fish, and water currents on a windward reef face: Great Barrier Reef, Australia, Bull Mar Sci., 1988, 42: 459-479.
31. Heron GA, Bradford-Grieve JM. The marine fauna of New Zealand: Pelagic Copepoda: Poecilostomatoida: Oncaeaidae. Memoirs. N. Z. Oceanographic Institute, 1995, 104: 1-57.
32. Hulings NC. Currents in the Jordan Gulf of Aqaba. Dirasat (nat. Science; Univ. Jorden), 1979, 6, 21-33.
33. Incze LS, Aas, P, Ainare T. Distributions of copepod nauplii and turbulence on the southern flank of Georges Bank: implications for feeding by larval cod (*Gadus morhua*), Deep-Sea Res. Pt. II, 1996, 43 (7–8), 1855–1874, http://dx.doi.org/10.1016/S0967-0645 (96) 00055-0.
34. Johannes RE. Ecology of organic aggregates in the vicinity of a coral reef. Limnol. Oceanogr, 1967, 12, 189-195.
35. Kahan D, Bar-El T. *Schizopera elatensis* n. sp. (Copepoda, Harpacticoida) from Elat, Israel. *Crustaceana*, 1982, 42(3): 308-314.
36. Khalil MT, Abdel-Rahman NS. Abundance and diversity of surface zooplankton in the Gulf of Aqaba, Red Sea, Egypt. J. Plankton Res. 1997, 19:927-936.
37. Kimor B. Microplankton of the Red Sea, the Gulf of Suez and the Levantine Basin of the Mediterranean. Bull Institut Océanogr Monaco, 1990, 7**,** 29-38.
38. Kimor B, Golandsy B. The microplankton of the Gulf of Eilat: aspects of seasonal and bathymetric distribution. Mar. Biol., 1977, 42: 55-76.
39. Longhurst, A.R. The structure and evolution of plankton communities. Prog. Oceanogr., 1985, 15:1-35.
40. Mauchline J. Advances in Marine Biology. Vol. 33, the biology of calanoid copepods. San Diego Academic Press, 1998.
41. Mergner H, Schuhmacher H. Morphologie. Okologie und Zonierung in Korallenriffen bei Aqaba (Golf von Aqaba, Rotes Meer). Helgolander wiss. Meeresunters, 1974, 26: 238-258.
42. Neunes HW. A simple key for common pelagic Mediterranean copepods. A tool for the identification of species in production and

radioaccumulation studies. Pubbl. Staz. Zool. Napoli, 1965, 34: 462 - 475.
43. Newell GE. Marine plankton, a practical guide. Hutchinson Educational Ltd., London 5th Edition, 1963, 221pp.
44. Pearre S. Eat and run?. The hunger/satiation hypothesis in vertical migration: history, evidence and consequences. Biol. Rev., 2003, 78, 1-79.
45. Plaehn O, Baschek B, Badewien TH, Walter M, Rhein M. Importance of the Gulf of Aqaba for the formation of bottom water in the Red Sea. J Geophys Res, 2002, 107: 1-17.
46. Por FD. The Copepoda of Di Zahav pool (Gulf of Elat, Red Sea). Crustaceana, 1979, 37 (1): 13-30.
47. Reiss Z, Hottinger L. The Gulf of Aqaba: ecological micropaleontology. Springer, Berlin, Heidelberg New Yourk 354 pp, 1984.
48. Ringelberg J. Changes in light intensity and diel vertical migration: a comparison of marine and freshwater environments. J. Mar. Biol. Assoc. UK, 1995, 75: 15-25.
49. Robichaux DM Cohen AC, Reaka MJ, Allen D. Experiments with zooplankton on coral reef. Mar. Ecol., 1981, 2: 77-94.
50. Roman MR, Furnas MJ, Mullin MM. Zooplankton abundance and grazing at Davies Reef, Great Barrier Reef, Australia. Mar. Biol., 1990, 105: 75-82.
51. Schmidt HE. Vertical distribution and diurnal migration of some zooplankton in the Bay of Eilat (Red Sea). Helgoländer wiss. Meeresunters, 1973, 24: 333-340.
52. Sommer U, Berninger UG, Bottger-Schnack R, Cornils A, Hagen W, Hansen T, Al-Najjar TH, Post AF, Schnack-Schiel SB, Stibor H, Stubing D, Wickham S. Grazing during early spring in the Gulf of Aqaba and the northern Red Sea. Mar. Ecol. Prog. Ser., 2002, 239: 251-261.
53. Steel RGD, Torrie JH. Priciples and procedures of statistics. A biometric approach, 2nd ed. McGraw Hill, Inc.
54. Trégouboff G, Rose M. Manuel de planctonlogie Méditerranéenne. Centre national de la recherché scientifique, Paris, 1957, Tome 1: 1-587; Tome 2:pl. 1-207.
55. Underwood AJ. Techniques of analysis of variance in Experimental Biology and Ecology. Oceanography and Marine Biology Annual Review, 1981, 19: 513-605.
56. Vaissiere R, Seguin G. Initial observations of the zooplankton micro distribution on the fringing reef at Aqaba (Jordan). Mar. Biol., 1984, 83: 1-11.
57. Williams DMcB, Dixon P, English S. Cross-shelf distribution of copepods and fish larvae across the central Great Barrier Reef. Mar Biol., 1988, 99: 577-589.
58. Williamson DI. On a collection of planktonic Decapoda and Stomatopoda (Crustacea) from the Mediterranean coast of Israel. Bull. Sea Fish Res. Sta. Haifa., 1967, 45: 32-46.
59. Wolf-Vecht A, Paldor N, Brenner S. Hydrographic indications of advection/convection effects in the Gulf of Eilat, Deep-Sea Res. Pt. A, 1992, 39 (7–8): 1393–1401, http://dx.doi.org/10.1016/0198-0149 (92) 90075-5.

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