Vertical distribution of zooplankton in the epipelagic zone off Sharm El-Sheikh, Red Sea, Egypt

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Abstract

The purpose of the present study was to track the seasonal vertical distribution of zooplankton abundance in the epipelagic zone off Sharm El-Sheikh, Red Sea.

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Zooplankton samples were collected seasonally within the depth ranges of 0–25, 25–50, 50–75, 75–100 m at a single station off Sharm El-Sheikh City. The present study is an attempt to expand knowledge about the structure as well as the vertical distribution of the epipelagic zooplankton community in the Gulf of Aqaba in general and in its southern part in particular. The results indicate the occurrence of 52 copepod species and several species of other planktonic groups in the study area; the zooplankton standing crop fluctuated between 1124 and 4952 organisms m^{-3}. Copepods appeared to be the predominant component, forming an average of 86.5% of the total zooplankton count, and with other groups demonstrated a markedly different seasonal vertical distribution. Twelve bathypelagic copepod species were reported during the present study, and five species were new to the area, having migrated northwards from the main basin of the Red Sea.

1. Introduction

The Gulf of Aqaba is a moderately oligotrophic basin (Reiss & Hottinger 1984) and is characterized by a clear seasonal variation in both hydrographical and biological features (Wolf-Vecht et al. 1992, Manasrah et al. 2006). Being an important link in many marine food chains, zooplankton is affected directly by the surrounding environmental conditions, and its dynamics is controlled mainly by the seasonal changes of these conditions.

The vertical distribution of zooplankton in the epipelagic zone indicated a more even zooplankton distribution in well-mixed than in stratified columns (Buckley & Lough 1987, Checkley et al. 1992, Incze et al. 1996). In the northern Gulf of Aqaba, seasonal stratification is usually reported in the water column during the warm months (May to September), while deep vertical mixing occurred during the winter (Reiss & Hottinger 1984, Wolf-Vecht et al. 1992). Such seasonality led to an analogous seasonality in the structure of the zooplankton communities (Böttger-Schnack et al. 2001).

Plankton research in the Gulf of Aqaba was concentrated for a long time in the northern part. Several studies dealt with the distribution and abundance of particular zooplankton groups, such as foraminiferans (Almogi-Labin 1984), appendicularians (Fenaux 1979) and tunicates (Godeaux 1978), or of zooplankton near coral reefs (Vaissiere & Seguin 1984, El-Serehy & Abdel-Rahman 2004, Yahel et al. 2005). Copepods were the main subject of numerous studies in the northern part of the Gulf of Aqaba (Prado-Por 1990, Böttger-Schnack et al. 2001, 2008, Schnack-Schiel et al. 2008). There are also reports on the surface zooplankton from the northern Gulf (e.g. Echelman & Fishelson 1990, Aoki et al. 1990, Al-Najjar et al. 2002, Al-Najjar 2004) and from the whole of the Gulf (Khalil & Abdel-Rahman 1997), in addition to that in the water column at different depths (e.g. Kimor & Golandsky 1977, Al-Najjar & Rasheed 2005, Cornils et al. 2005, 2007, Al-Najjar & El-Sherbiny 2008). The zooplankton of the southern part of the Gulf of Aqaba has attracted but little attention, although a few studies were done in the Sharm El-Sheikh coastal area, particularly in the mangal ecosystem (Hanafy et al. 1998), in Sharm El-Maiya Bay (Aamer et al. 2007) and in the epipelagic zone (El-Sherbiny et al. 2007). These studies were concerned with the species composition and abundance of zooplankton relative to the environmental conditions in the areas studied.

The present study aimed to track the seasonal variations in the vertical distribution of the zooplankton community in the upper 100 m of the epipelagic zone off Sharm El-Sheikh. The importance of the present study is based on the fact that over 70% of the zooplankton > 100 μm inhabits the upper 100 m during the stratification of the Gulf of Aqaba (Farstey et al. 2002).

2. Material and methods

The present study was conducted seasonally from March 1995 to March 1996 at one offshore station with a depth of 300 m, about 2 km from the shore of Sharm El-Sheikh City (Figure 1). The seasonal sampling

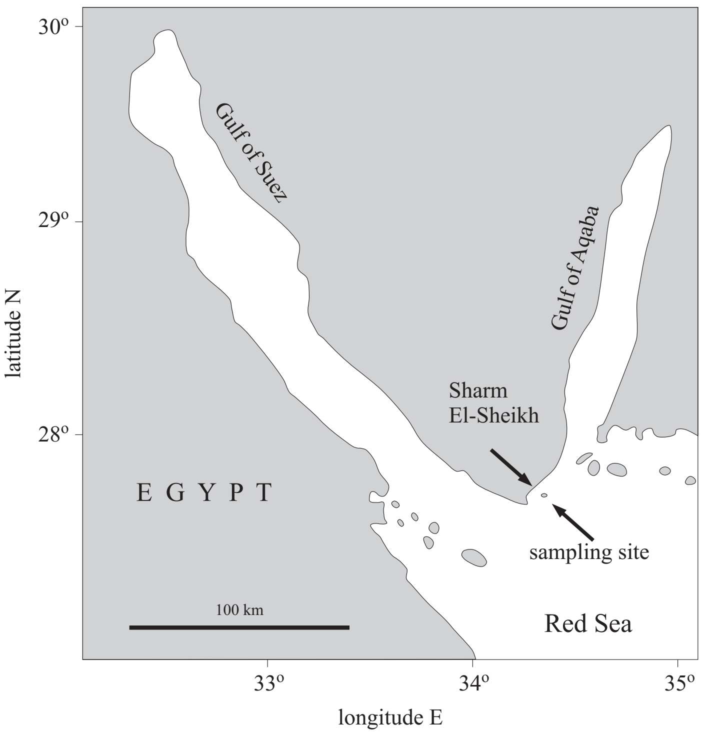

Figure 1. The Sharm El-Sheikh area and sampling site

Table 1. The times and dates of zooplankton tows off Sharm El-Sheikh

Season	Time	Day	Month	Year
spring	16:00	15	April	1995
summer	17:00	22	July	1995
autumn	16:00	18	October	1995
winter	15:00	28	January	1996

was done in spring (April), summer (July), autumn (October) and winter (January) (Table 1). Water samples were collected at 0, 25, 50, 75 and 100 m depths for the determination of water temperature, dissolved oxygen and chlorophyll *a* using a 5 l water sampler. Water temperature was measured with an ordinary mercury thermometer graduated to 0.1°C attached to the water sampler (Nansen bottle). To prevent any change in the temperature recorded at the requisite depth the water sampler was withdrawn quickly. Dissolved oxygen was determined according to Winkler's method (APHA 1985). For measuring chlorophyll *a* 2 l of seawater from each depth were passed through 35 mm diameter Sartorius membrane filters (pore size 0.45 μm). The filters were dissolved in 90% acetone and kept in a refrigerator at 4°C in complete darkness for 24 hours, after which the chlorophyll concentration was determined using a Milton Roy 601 spectrophotometer according to Parsons et al. (1984). For zooplankton analysis net hauls were carried out in the epipelagic zone (0–100 m) in the depth ranges of 0–25, 25–50, 50–75 and 75–100 m using an Apstein closing net with a 17 cm mouth diameter and 100 μm mesh size. Vertical hauls were made 2–3 hours before sunset by towing the net at a speed of 0.5–1 m s^{-1} from a motorized winch fixed on board a small motor boat. A digital flowmeter was attached to the mouth of the net to measure the volume of filtered water. After each haul the net was rinsed thoroughly by dipping in seawater, and the rinsings were added to the sample to prevent the loss of any organisms on the net material. The flowmeter was calibrated before each sampling by towing it without the net for a known distance: the number of propeller revolutions was equal to the measured distance. The samples were preserved in 4% neutralized formalin, left to settle for a few days and then concentrated to a volume of 200 ml. Each sample, in a Petri dish, was examined under a stereomicroscope, and large organisms such as fish larvae, medusae and jelly fish were removed and counted separately. The zooplankton abundance was estimated numerically by counting three aliquots of 5 ml from each concentrated sample in a Bogorov counting tray under a Hydro-Bios inverted microscope. The average of the counted aliquots was calculated and used to estimate the zooplankton abundance. Copepods and other zooplankton components were identified following Giesbrecht (1892), Williamson (1967), Heron & Bradford-Grieve (1995) and Conway et al. (2003). The three counts of total zooplankton at different depths and all seasons were treated statistically to determine the standard error and standard deviation of these counts.

3. Results and discussion

The surface water temperature varied seasonally from a winter minimum of 22.8°C to a summer maximum of 30.5°C. The vertical thermal profile showed clear stratification in summer and slight differences during other seasons, whereas the vertical thermal difference within the epipelagic zone was small (Figure 2).

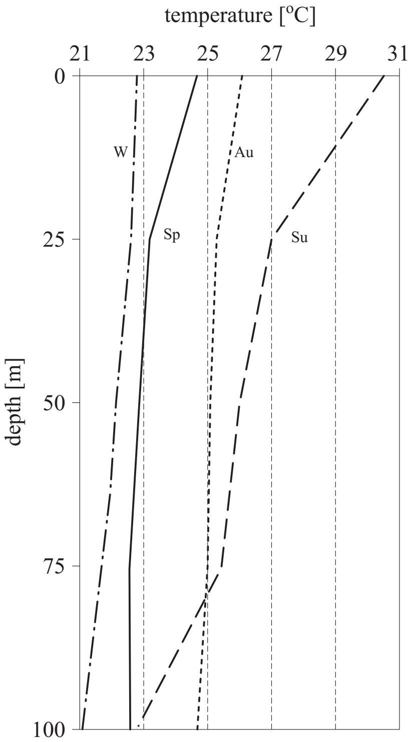

Figure 2. Vertical distribution of water temperature in the epipelagic zone off Sharm El-Sheikh in winter (W), spring (Sp), summer (Su) and autumn (Au)

Dissolved oxygen was relatively high in the surface water (6.6–7 mg l^{-1}) as well as within the epipelagic zone (5.3–7.8 mg l^{-1}), with some stratification during summer, autumn and winter, and distinct stratification in spring (Figure 3). In our study, maximum dissolved oxygen in spring coincided with the highest content of chlorophyll *a* within the depth range of 50–75 m, supporting the role of phytoplankton photosynthesis in the oxygenation of the water column.

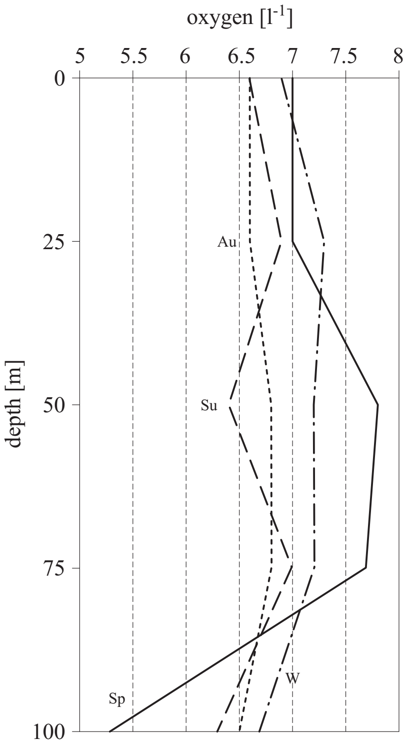

Figure 3. Vertical distribution of dissolved oxygen in the epipelagic zone off Sharm El-Sheikh in spring (Sp), summer (Su), autumn (Au) and winter (W)

The phytoplankton biomass in the epipelagic zone exhibited low as well as moderate values over the year, whereas concentrations of chl *a* fluctuated between 0.04 μg l^{-1} at 100 m in spring and 1.12 μg l^{-1} at 75 m, also in spring. The surface water was usually poor in phytoplankton, whereas the vertical profile displayed slight variations during summer, autumn and winter, and displayed a clear subsurface chlorophyll high in spring (Figure 4).

The epipelagic zooplankton off Sharm El-Sheikh was composed mainly of copepods, which constituted seasonally 78.6–93.2% of the total zooplankton with a mean of 86.5%. The molluscan larvae (gastropods and bivalves) were second in order of abundance, making up 2.6–15.2% with a mean of 7.6%, followed by appendicularians (1.4–3.7%, mean: 2.4%) and chaetognaths (0.7–1.6%, mean: 1.1%). Cnidarians demonstrated a comparatively small relative abundance (0.2–1.4%) in the total zooplankton. The contributions of the main groups to the total zooplankton during the present study (Table 1) were roughly similar to those reported in another study (El-Sherbiny et al. 2007), but are more or less different from those found in the northern Gulf of Aqaba (Cornils et al. 2005).

The zooplankton density during the present study showed relatively wide seasonal variations in the water column ($\sim 1.1 \times 10^3 - \sim 5 \times 10^3$

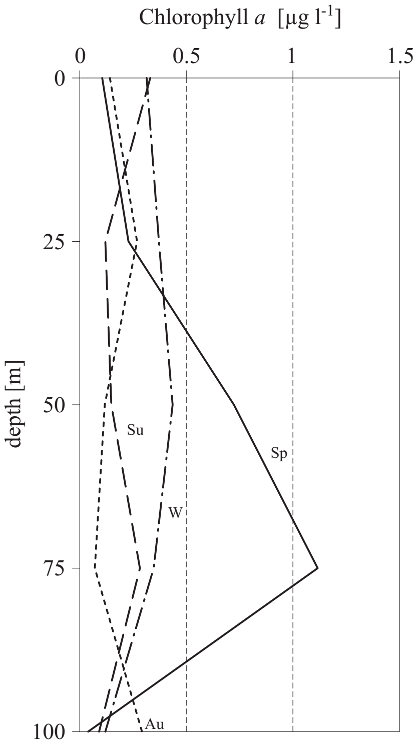

Figure 4. Vertical distribution of chlorophyll *a* in the epipelagic zone off Sharm El-Sheikh in spring (Sp), summer (Su), autumn (Au) and winter (W)

organisms m^{-3}), with a conspicuously high density (4952 and 4445 organisms m^{-3}) within the surface layer (0–25 m) in summer and the 25–50 m depth range in spring. The standard error and standard deviation of total zooplankton density are given in Table 2. The vertical profile demonstrated decreasing zooplankton density with depth during all seasons, particularly in the deep layer from 50 to 100 m (Figure 5). The relatively low zooplankton

Table 2. Contributions [%] of the major groups to the total zooplankton at different parts of the Gulf of Aqaba (present study at Sharm El-Sheikh, Cornils et al. 2007 at northern Gulf where the counts were calculated from figure, El-Sherbiny et al. 2007 at southern Gulf)

Group	Present study		Cornils et al. (2007)		El-Sherbiny et al. (2007)	
	[%]	[count m^{-3}]	[%]	[count m^{-3}]	[%]	[count m^{-3}]
Copepods	87.9	2112	78.8	~1206	84.7	1840
Molluscan larvae	6.6	186	8.0	~122	8.4	182
Appendicularians	2.2	59	2.5	~38	2.4	52
Chaetognatha	1.0	27	2.4	~37	1.2	26
Cnidaria	0.6	17	0.3	~5	0.9	19

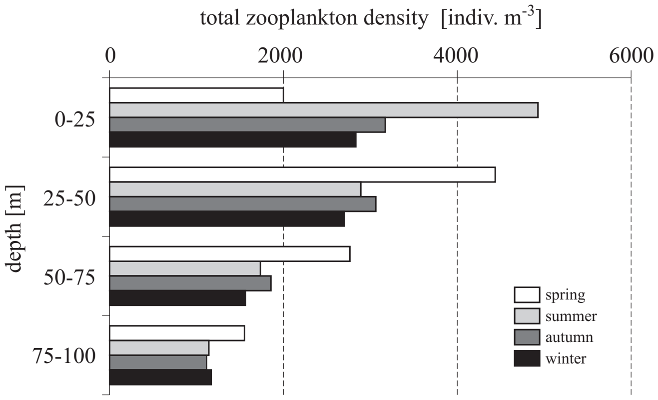

Figure 5. Zooplankton density in the epipelagic zone off Sharm El-Sheikh in spring, summer, autumn and winter

density in the study area may be attributed to the low phytoplankton biomass (chl $a = 0.04$–1.12 μg l^{-1}), which seems to be a common occurrence in the Gulf of Aqaba (Khalil & Abdel-Rahman 1997, Cornils et al. 2005, 2007, El-Sherbiny et al. 2007). The zooplankton peaks of our study in spring and summer support those found in summer (Farstey et al. 2002) and in spring (Al-Najjar 2000) in the northern Gulf, but surface zooplankton peaked in winter (Echelman & Fishelson 1990, Khalil & Abdel-Rahman 1997).

Although the abundance of the zooplankton groups illustrated more or less similar distributional patterns along the water column over the year, small differences were observed for some groups. During spring, all groups sustained the highest density in the subsurface layer (25–50 m), while in summer and autumn their highest density were reported within the surface layer (0–25 m), except the autumn copepods, which were present at a higher density in the 25–50 m depth range.

The contribution of taxa other than copepods to the total zooplankton abundance at Sharm El-Sheikh was considerable. Appendicularians were the second most abundant holoplankton group after copepods, amounting to 3–160 organisms m^{-3}, with the highest density in summer and winter. These densities are quite close to those at the northern Gulf of Aqaba (Cornils et al. 2005, 2007), but lower than in the northern Red Sea (Böttger-Schnack 1995, Cornils et al. 2007). Comparatively high densities (108–160 organisms m^{-3}) of appendicularians were found during the present study in all seasons, either within the surface (0–25 m) or in the subsurface layer (25–50 m) (Figure 6). In the northern Gulf of Aqaba, two appendicularian peaks were observed in June and August (Fenaux 1979, Cornils et al. 2007), and densities

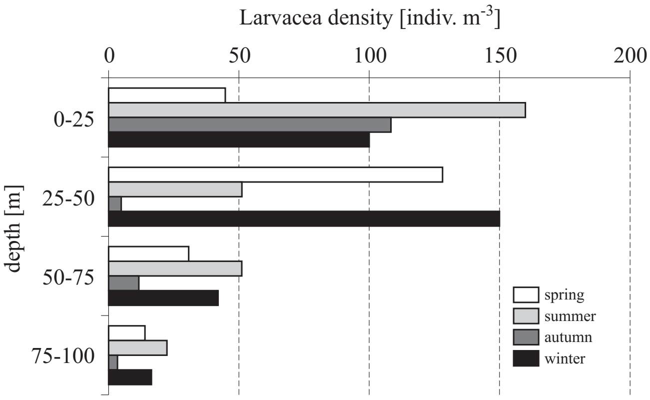

Figure 6. Density of appendicularians in the epipelagic zone off Sharm El-Sheikh in spring, summer, autumn and winter

were usually high during stratified conditions, particularly in summer and autumn (Cornils et al. 2007).

Chaetognaths ranked third in abundance among holoplankton groups during the present study, with *Sagitta* spp., being predominant at densities between 6 and 99 organisms m^{-3}. Roughly similar densities were found in the same area (El-Sherbiny et al. 2007) and in the northern Gulf of Aqaba (Cornils et al. 2005, 2007), but higher ones were also reported in the northern Gulf (Kimor & Golandsky 1977). In our study, chaetognaths were more abundant in the surface layer during summer, autumn and winter, whereas in spring they attained their highest density within the subsurface layer (25–50 m) (Figure 7).

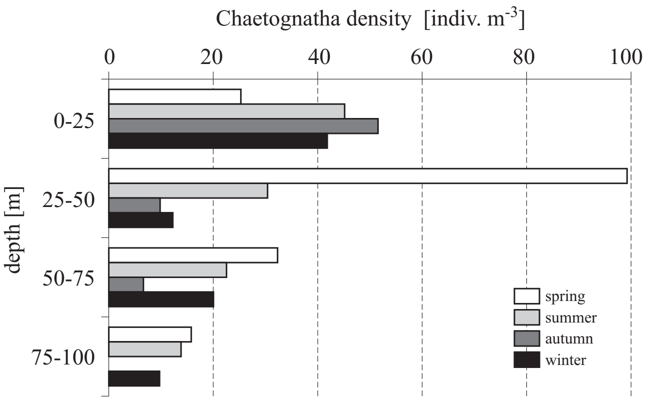

Figure 7. Density of Chaetognatha in the epipelagic zone off Sharm El-Sheikh in spring, summer, autumn and winter

Cnidarians played only a small role (0.2–1.4% of the total zooplankton), with a mean of 0.7% and a total density of 2–70 organisms m^{-3}. Siphonophores were present at a relatively high density (61 organisms m^{-3}) within the surface layer in summer, while other cnidarian medusae had low densities over the year, with a winter maximum (19 organisms m^{-3}) in the surface layer (Figure 8). This corroborates the limited role of cnidarians in different parts of the Gulf of Aqaba (Khalil & Abdel-Rahman 1997, Cornils et al. 2005, 2007, El-Sherbiny et al. 2007).

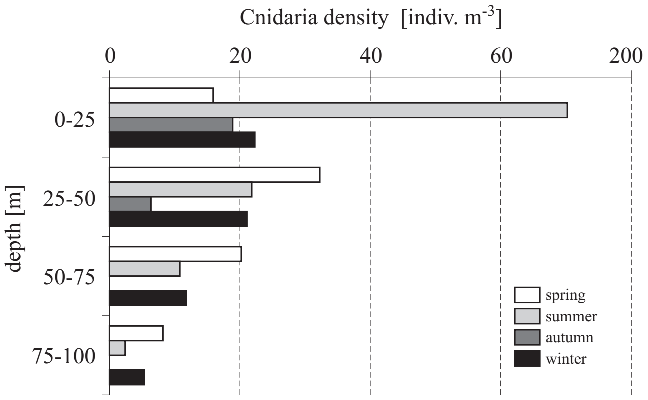

Figure 8. Density of cnidarians in the epipelagic zone off Sharm El-Sheikh in spring, summer, autumn and winter

Meroplanktonic larvae made up 7.9% of the total zooplankton in the present study and were absolutely dominated by molluscan larvae. There was a greater proportion of gastropod veligers (5.3%) than bivalves (2%), while the proportion of polychaetes was very small (0.6%). These proportions were comparatively lower than those reported throughout the Gulf of Aqaba (Khalil & Abdel-Rahman 1997, Cornils et al. 2005, 2007, El-Sherbiny et al. 2007).

Copepods were the most diversified group, represented by 52 species of calanoids (33 species), cyclopoids (14 species) and harpacticoids (5 species), with the lowest species richness (31 species) in summer and the highest (40 species) in winter. A markedly higher number of calanoids (48 species) was found in the vicinity of Sharm El-Sheikh (El-Sherbiny et al. 2007).

The copepod density varied seasonally between 1011 organisms m^{-3} within the depth range of 75–100 m in summer and 3872 organisms m^{-3} within the 25–50 m depth range in spring. In the water column the highest densities in the 50–75 m and 75–100 m depth ranges were also reported in

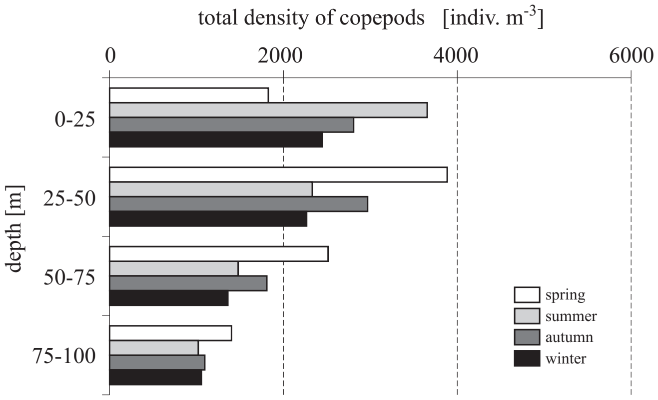

Figure 9. Total density of copepods in the epipelagic zone off Sharm El-Sheikh in spring, summer, autumn and winter

spring, whereas in the upper layer (0–25 m) densities were the highest in summer (Figure 9).

The proportions of copepods in the upper 100 m at Sharm El–Sheikh (78–93% of total zooplankton) were mainly due to the predominance of copepodites (55.4%) and nauplii (20.2% of total copepods). In contrast nauplii substantially outnumbered copepodites in other parts of the Red Sea (Abdel-Rahman 1993) and the Gulf Region (Michel et al. 1986, Dorgham & Hussein 1997). The adult forms constituted 24.4% of the total copepods, with approximately similar proportions of calanoids and cyclopoids (44.9 and 42.2% respectively) and a much smaller one of harpacticoids (12.9%).

Calanoids were present in the highest abundance in winter, cyclopoids in autumn and harpacticoids in summer (Figure 10a–c). Calanoids and harpacticoids displayed a similar vertical distribution in the epipelagic zone, having the highest density both at 25–50 m depth during winter and spring and in the surface layer (0–25 m) during summer and autumn. The abundance of cyclopoids peaked at 25–50 m depth in spring and in the surface layer during other seasons. Several species exhibited relatively high percentages in the total density of adult copepods (Table 3), either through their occasional appearance in high densities, or because they occurred all the year round. Among these species, *Calocalanus pavo*, *Lucicutia flavicornis*, *Corycaeus* sp., *Oithona plumifera*, *Oithona nana*, *Oncaea mediterranea*, *Oncaea scottodicarloi*, *Nannocalanus minor*, *Calocalanus styliremis*, *Clausocalanus furcatus*, *Lubbockia squillimana*, *Microsetella atlantica* and *Microsetella rosea* were persistently recorded in the water column with variable seasonal densities.

It is worth mentioning that some of the copepods in the present study are bathypelagic, usually being found below 200 m depth (Weikert 1982, 1987),

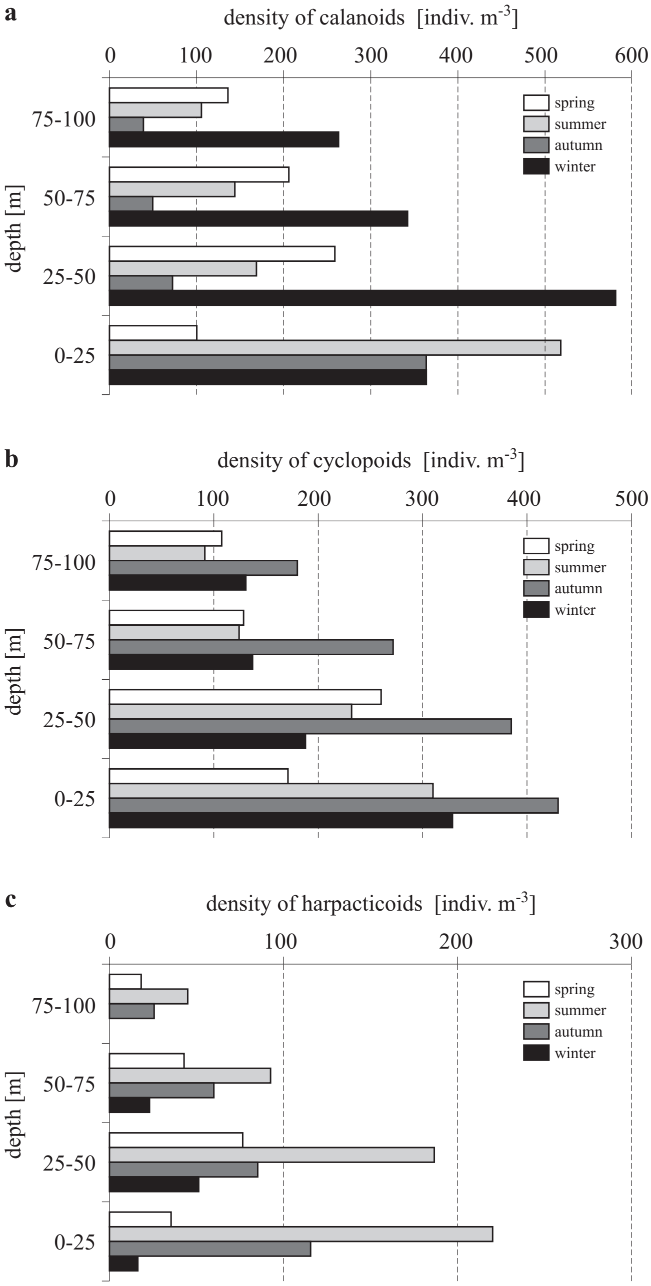

Figure 10. The densities of adult copepods: calanoids (a), cyclopoids (b) and harpacticoids (c) in the epipelagic zone in spring, summer, autumn and winter

Table 3. Contribution [%] of the dominant species to total adult copepods

Species	[%]	Species	[%]
Cyclopoids		*Calocalanus pavo*	3.8
Oithona plumifera	10.5	*Clausocalanus arcuicornis*	3.6
Oncaea scottodicarloi	8.6	*Acrocalanus gibber*	3.3
Corycaeus sp.	4.7	*Nannocalanus minor*	2.7
Oncaea mediterranea	3.7	*Lucicutia flavicornis*	2.3
Farranula gibbulus	3.8	*Ctenocalanus venus*	2.2
Oithona nana	2.7	*Calocalanus styliremis*	1.9
Calanoids		**Harpacticoids**	
Paracalanus sp.	6	*Microsetella atlantica*	7.3
Clausocalanusfurcatus	5.4	*Microsetella rosea*	4.1

but off Sharm El-Sheikh in low densities (Table 4). Furthermore, *Acartia danae*, *Scolecitrichopsis ctenopus*, *Oncaea minuta*, *Sapphirina intestinalis* and *Clytemnestra scutellata* are new records for the northern Red Sea, indicating their northward migration, as they had previously been confined to the main basin of the Red Sea.

Table 4. Bathypelagic copepod species and their seasonal maximum count (organisms m^{-3}); Sp = spring, Su = summer, Au = autumn, W = winter

Species	Sp	Su	Au	W
Mesocalanus tenuicornis	0	6	0	38
Phaenna spinifera	0	0	2	0
Eucalanus attenuatus	0	0	19	19
Rhincalanus nasutus	2	0	0	48
Euchaeta concinna	6	0	0	13
Archescolecithrix auropecten	6	0	0	16
Haloptilus longicornis	0	6	6	22
Macadrewella chelips	0	0	32	6
Lucicutia flavicornis	11	32	13	48
Scolecitrichopsis ctenopus	3	13	10	16
Mecynocera clause	6	0	32	5
Lubbockia squillimana	10	13	13	3

Environmental conditions, particularly temperature and food availability, have a crucial effect on zooplankton abundance (Webber & Roff 1995, Christou 1998). In the Gulf of Aqaba temperature plays a role in the prevailing seasonality (Reiss & Hottinger 1984), resulting in a homogeneous distribution throughout the deep vertical mixed layer in late winter, when the plankton community shows no differences within the mixed layer

(Cornils et al. 2005). In other seasons the majority of the zooplankton is concentrated within the upper 100 m (Cornils et al. 2005). Temperature is an important factor controlling the abundance of zooplankton (Goldman & Heron 1983), increasing the growth and feeding rates of zooplankton species within the range of their thermal tolerance (Omori & Ikeda 1984). Different zooplankters of the same group showed different reactions to temperature variations (Mathew 1977), but the fluctuation in the abundance of planktonic forms may be related not only to water temperature but also to its indirect influences on their food items (Arnemo 1965).

4. Conclusions

The present study has shown that the zooplankton in the epipelagic zone off Sharm El-Sheikh experienced distinct vertical variations in species composition and abundance in different seasons. Copepods were the overwhelmingly predominant component (86.5%), while other holoplanktonic groups like appendicularians, chaetognaths and cnidarians together contributed a comparatively small relative abundance (4.2%) in addition to a moderate percentage of meroplankton (8.2%). Several bathypelagic copepods were observed, and also few species that had newly migrated to the area from the central Red Sea.

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