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Monthly Variations in Abundance and Species Composition of the Epipelagic Zooplankton off Sharm El-Sheikh, Northern Red Sea

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Abstract: Seasonal changes in zooplankton abundance and species composition were investigated at one station off Sharm El-Sheikh, northern Red Sea, during May 2005 to May 2006. A total of 99 taxa and species were identified. Three main peaks of zooplankton abundance were observed in summer (July-August), in autumn (November) and in late spring (May). However, the different species within the zooplankton community displayed an obvious succession throughout the year. Copepods overwhelmingly dominated both in terms of abundance (mean: 84.7%) and diversity (68 genus and species). Most of the recorded copepod species have world-wide tropical and subtropical distribution. Other abundant groups were mollusc larvae (6.8%) and larvaceans (2.4%) which were particularly numerous during summer period. Adult copepods constituted only 22.3% of total copepods, with *Clausocalanus* sp., *Oithona plumifera*, *O. nana*, *Oncaea scottodicarloi*, *O. mediterranea* and *Paracalanus* sp. *Ctenocalanus vanus*, *Calocalanus styliremis*, *Microsetella rosa*, *Corycaeus* sp. and *C. gibbulus* being the most abundant species. Seasonal variations showed that *Oithona nana*, *Corycaeus* sp. and *C. gibbulus* and cladocerans (*Evadne tergestina*) dominated the summer communities, whereas in winter calanoid copepods *Clausocalanus* sp. were predominated. While in autumn *Oithona plumifera*, *Microsetella rosae*, *Oncaea scottodicarloi*, *O. mediterranea* were flourished.

Key words: Annual cycle, zooplankton, copepods, environmental variables, Red Sea

INTRODUCTION

Seasonal zooplankton dynamics and the driving mechanisms of their variability is a central issue of oceanographic research (GLOBEC Science Plan, 1977). Changes in species composition related to long-term trends in the ocean are a strategy used to monitor the influence of global changes on marine communities. The understanding of target species representing the evolution of ecosystem is of paramount importance. In polar and temperate waters this task is relatively simple due to the predominance of well-studied species. In warm, oligotrophic waters especially in the Red Sea the information about monthly variability of zooplankton species is sparse or lacking (Halim, 1969; Fernández de Puelles *et al*., 2003; Cornils *et al*., 2005). In spite of the importance of zooplankton in many marine food chains, relatively few systematic annual studies have been carried out in the Egyptian Red Sea coasts. In contrast to the northern part of Gulf of Aqaba, where most of studies have been conducted but focused only on isolated groups, for example planktonic tunicates and chaetognaths (Furnestin, 1958; Godeaux, 1960, 1978) appendicularians (Fenaux, 1960), microplankton (Kimor and Golandsky, 1977) and copepods (Almeida Prad-Por, 1983, 1985, 1990). Only a few multitaxonomic zooplankton studies have been conducted including, those of Schmidt (1973), Veissière and Seguin (1982 and 1984) and Echelman and Fishelson (1990). Recently, the southern part of Gulf of Aqaba

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including the area surrounding Sham El-Sheikh has subjected to more attention from the Egyptian scientists (Abdel-Rahman, 1997; El-Sherbiny, 1997; Khalil and Abdel-Rahman, 1997; Hanafy *et al*., 1998; Aamer *et al*., 2006). In view of the man-made changes including the rabid urbanization in the heavily touristic coastal areas, it is urgently need to know the function of pelagic ecosystem before its disturbance by man. For these purposes, in the present study, abundance, vertical distribution and species diversity of the epizooplankton organisms were examined for 13 months in offshore water in Sham El-Sheikh area, northern Red Sea.

MATERIALS AND METHODS

Vertical zooplankton samples were collected monthly from May 2005 to May 2006 at one fixed station 2 km offshore in front of Sharm El-Sheikh (27°45′58′′N and 34°19′11′′E, Fig. 1). The samples were collected with standard plankton net with a mouth area of 0.1256 m^2 and a mesh size of 100 micron. A weighted net was towed vertically from 100 m to surface. The hauling speed of the net was about 1.0 m sec^{-1}. The depth of the net was determined by the length of the towing wire. As the wire angle was less than 10, the actual depth limits of the vertical samples varied less than ±3 m from the present values. No clogging of the net was observed, assuming a filtration efficiency of 100%. Prior to each haul, water samples were taken at discrete depths (0, 25, 50, 75 and 100 m) with 1.5 L Nansen-bottle for temperature, nutrients and chlorophyll *a* analysis. Immediately after collection, the plankton samples were fixed in 4% buffered formaldehyde-seawater solution. In the laboratory, the collected samples were left for few days for settling and surplus water of each sample was siphoned

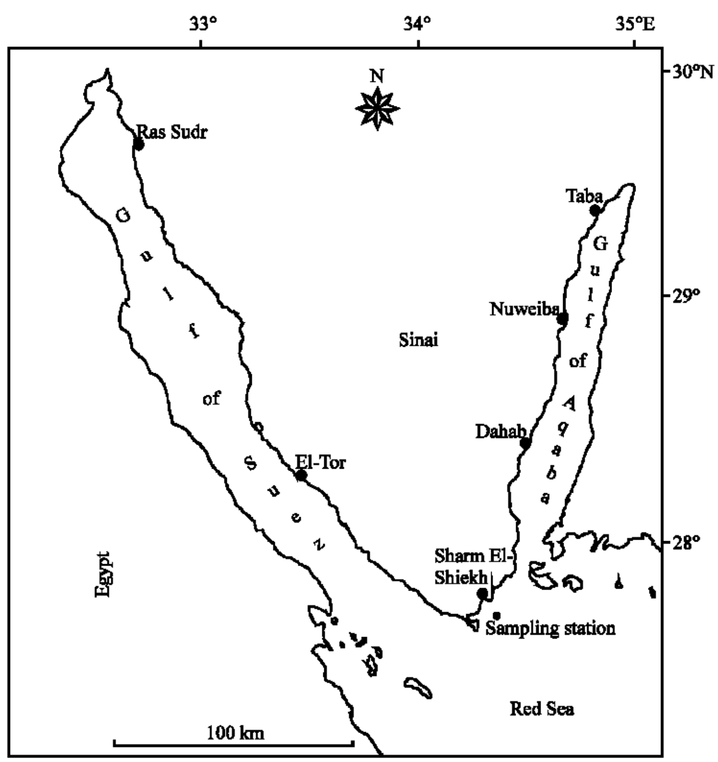

Fig. 1: Location of the sampling station off Sharm El-Sheikh, northern Red Sea

off according to the density of zooplankton organisms. Three aliquots of samples were taken by Stempel pipette and counted in Bogrove tray under Hydro-Bios inverted microscope. The standing crop of zooplankton expressed as individuals m^{-3} was calculated based on the average count and the volume of water filtered.

In order to characterize the most important groups, statistical analyses were undertaken using Spearman Correlation analysis for the principal factors, groups and species. Species richness was expressed by considering the number of species (D), diversity homogeneity were determined using Shannon Wiener diversity index (H′) and the evenness index (J′) according to Pielou (1966).

RESULTS

Hydrography and Phytoplankton Biomass

The seasonal variation of surface temperature (Fig. 2) showed a 7.7°C differences between February (22.8°C) and August (30.5°C). At 100 m depth, temperature only varied 2.5°C between April and November (22.1 and 24.7°C, respectively). Seasonal thermocline was recorded between 50 and 75 m depth during summer months. However, vertical mixing was detected during November-May period.

Very low nutrient concentrations (nitrate, nitrite, phosphate and silicate) were measured throughout the annual cycle (Table 1 and Fig. 2), with highest values mainly at deeper water layers (75 and 100 m), during the autumn and spring. Higher concentrations of nitrate was recorded from late summer to December at the lower depths with maximum of 1.7 μg $atom^{-L}$ at 100 m depth in December (average 0.82 μg $atom^{-L}$). Nitrite concentrations were very low and showed one peak in November (average 0.45 μg $atom^{-L}$). Silicate showed three peaks at the 75 and 100 m layers in November (average 4.31 μg $atom^{-L}$). The maximum concentration of phosphate was detected in June, October and April (averages 0.35, 0.34 and 0.37 μg $atom^{-L}$, respectively). The mean annual concentration of chlorophyll *a* was rather low (average 0.35 mg m^{-3}), with its highest value of 2.73 mg m^{-3} appeared in September at 25 m depth. However, other minor increases were detected in June at 75 m depth, in May at 100 m and in January-February at 25-50 m layers. All of these environmental variables (range and stander deviation) are given in Table 1.

Zooplankton Abundance

Total zooplankton community showed consistently high abundance during late spring and early summer attaining its highest density of 2712 individuals m^{-3} in August (Table 2). Irregular increases were also observed throughout the year especially in October and November, mainly due to the increase in copepods. On the other hand, the minimum abundance was recorded in March (1510 individuals m^{-3}). Zooplankton communities were represented mainly by holoplanktonic group copepods with an average of 1840 individuals m^{-3}, constituting 84.7% of total zooplankton. While the other groups (tunicates, chaetognaths, pteropods, mollusc veliger larvae and cladocerans) formed collectively 15.3% of total zooplankton. Copepods dominated the community all year round

Table 1: Minimum, maximum and standard deviation (±SD) of selected physico-chemical variables in offshore station in Sharm El-Sheikh area, northern Red Sea

Parameters	Minimum	Maximum	Mean	±SD
Temperature	22.06	26.36	24.14	2.03
DO	6.58	7.75	6.94	0.55
Nitrate	0.14	0.81	0.47	0.43
Nitrite	0.02	0.25	0.09	0.12
Phosphate	0.02	0.37	0.18	0.23
Silicate	0.49	4.31	1.98	1.40
Chlorophyll *a*	0.18	1.11	0.35	0.42

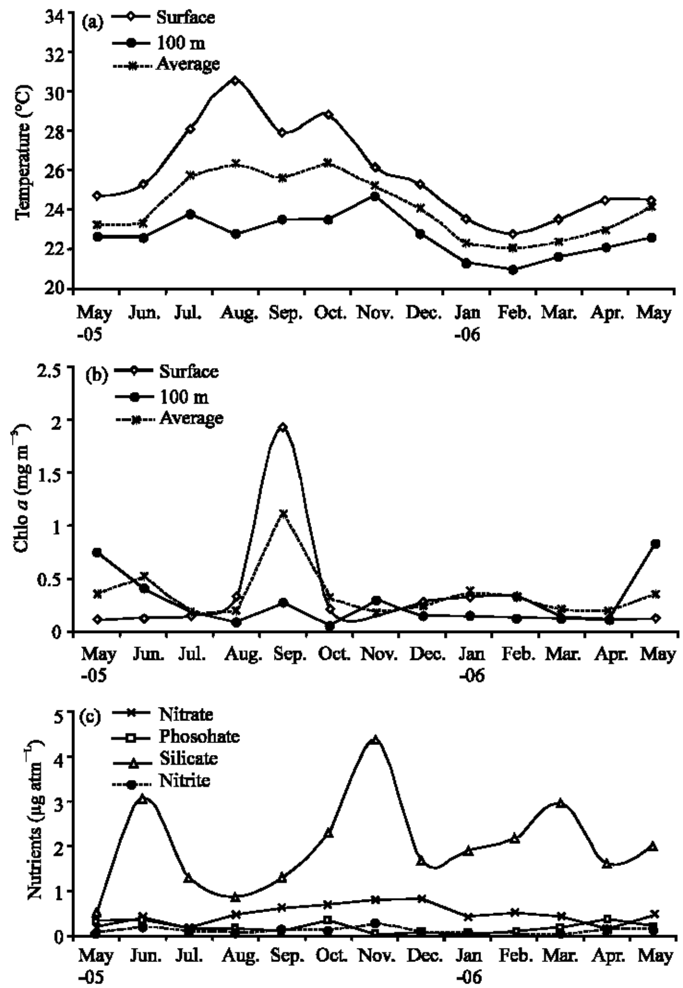

Fig. 2: The annual variation of (A) mean water column temperature (°C), (B) main nutrient salts concentration (µg atom^{-L}) and (C) chlorophyll *a* concentration (mg m^{-3}) at the surface and 100 m depth at the sampling station

Table 2: Standing stock of major metazoan groups of zooplankton (No. of individuals m^{-3}) in the upper 100 m off Sharm El-Sheikh area during the period between May 2005 and May 2006

Taxa	May 2005	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. 2006	Feb.	Mar.	Apr.	May	Mean	(%)
Coelenterata	19	11	22	27	43	22	8	4	7	16	12	30	18	19	0.9
Mollusca	150	85	442	408	189	136	60	272	186	127	49	85	134	182	8.4
Polychaeta	18	12	54	17	27	16	12	10	11	10	7	12	14	17	0.8
Cladocera	0	3	130	2	10	10	0	2	0	0	0	1	11	13	0.6
Ostracoda	5	6	8	6	16	8	10	11	8	8	14	6	10	9	0.4
Copepoda	2371	1762	1849	2134	1632	2060	2253	1426	1499	1800	1376	1917	2107	1840	84.7
Chaetognatha	43	19	26	29	55	18	17	6	26	21	21	29	10	26	1.2
Larvacae	54	37	118	71	6	34	32	54	58	77	22	59	74	52	2.4
Thaliacae	2	2	3	3	5	29	17	5	11	8	3	5	5	8	0.4
Miscellaneous	5	2	6	14	11	9	4	4	6	9	5	4	4	7	0.3
Holoplankton	2515	1842	2161	2290	1775	2190	2337	1509	1611	1931	1465	2077	2261	1975	91.0
Meroplankton	152	96	496	422	220	151	76	284	200	144	45	70	125	196	9.0
Total zooplankton	2667	1938	2657	2712	1995	2341	2413	1793	1811	2075	1510	2147	2386	2172	100

and determined the general pattern of zooplankton annual distribution. The seasonal cycle of copepods showed four peaks of abundance (Table 2), one during late spring, one in early summer, one in autumn (coinciding that of total zooplankton) and one in late winter. While minimum abundance was observed in March 2006. Copepod larval stages (nauplii and copepodites) play an important role in the copepods abundance and always cause the copepod peaks especially copepodite stages. Nauplii formed 15.1% of the total zooplankton with its highest density of 600 individuals m^{-3} in May 2005 (forming 25.3% of the total copepods). While, copepodites contributed collectively about 59.9% of total copepods (average 1102 individuals m^{-3}). Their maximum abundance was recorded during October forming 73.8% of total copepods. While their lower densities were detected in March (Table 2).

Zooplankton Species Composition

A total of 99 taxa and species of zooplankton organisms were recorded during the present study off Sharm El-Sheikh, northern Red Sea. Off them, 69 genus and species belonging to copepods (48 species of calanoids, 14 species of pocilostomatoids and 4 species of harpacticoids) were identified. Most of the recorded species has world-wide tropical and subtropical distribution. The adult copepods constituted only 22.3% of the total copepods and showed their maximum abundances in August, November and February, while minimum was observed during December. *Clausocalanus*, *Oithona*, *Oncaea* and *Paracalanus* were the most abundant genera. The most dominant species were the small calanoid herbivores species namely; *Clausocalanus* sp., *Paracalanus* sp., *Ctenocalanus vanus* and *Calocalanus styliremis*. While *Oithona plumifera*, *O. nana*, *Oncaea scottodicarloi*, *O. mediterranea*, *Corycaeus* sp. and *C. gibbulus*, were the most predominated pocilostomatoids. These species together with two harpacticoid *Macrosetella atlantica* and *M. rosae* were the 12 most abundant copepods (forming 76.5% of total adults) and can be considered key species of the copepod assemblages at the studied area.

During autumn, copepod such as *Oithona plumifera*, *Oncaea scottodicarloi* and *O. mediterranea* predominated the zooplankton community, although some other copepods as *Microsetella rosae* and *Paracalanus* sp. were also high abundant. During late winter the small calanoid *Clausocalanus* sp. exhibited their seasonal peaks beside *Oncaea scottodicarloi*. In spring *Oithona plumifera*, *Ctenocalanus vanus* and *Oncaea mediterranea* were the predominant, while in summer, the small calanoid copepod *Paracalanus* sp. was the most dominated (Fig. 3).

The second most abundant group was meroplankton (contributed 9% of total zooplankton) following by larvaceans (2.4%). Meroplanktonic groups dominated by mollusc larvae which played a significant role in the numerical density of total zooplankton (8%) and meroplankton (89%). They attained their highest numbers in July and August. Gastropod larvae dominated total mollusc and meroplankton group (forming 76 and 70%, respectively) showing its maximum in July. While bivalve veligers were significantly less numerous reaching their maximum numbers in August-September. Polychaete, cirripede, decapod and echinoderm larvae were rarely encountered and dominated in summer period, while medusae dominated in February.

Larvaceans was represented by *Oikopleura* sp. and *Fertillaria* sp. *Oikoplura* sp. population fluctuated widely throughout the sampling period from relatively low densities in May and March to a peak abundance in July (forming 4.3% of the total zooplankton). Their numbers remained relatively high through August indicating that *Oikoplura*, like other major zooplankters, were most abundant during summer. A few individuals of *Fertillaria* were also taken during July, August, March and April.

Cladocerans was represented only by *Evadne tergestina* and sampled mostly during the warm period from June to October with one main high peak in July constituting 4.9% of the total zooplankton count. Chaetognatha was sampled throughout the year and represented only by *Sagitta* sp. (constituting 1.2% of the total zooplankton). Their highest abundance appeared in September (2.8% of the total zooplankton).

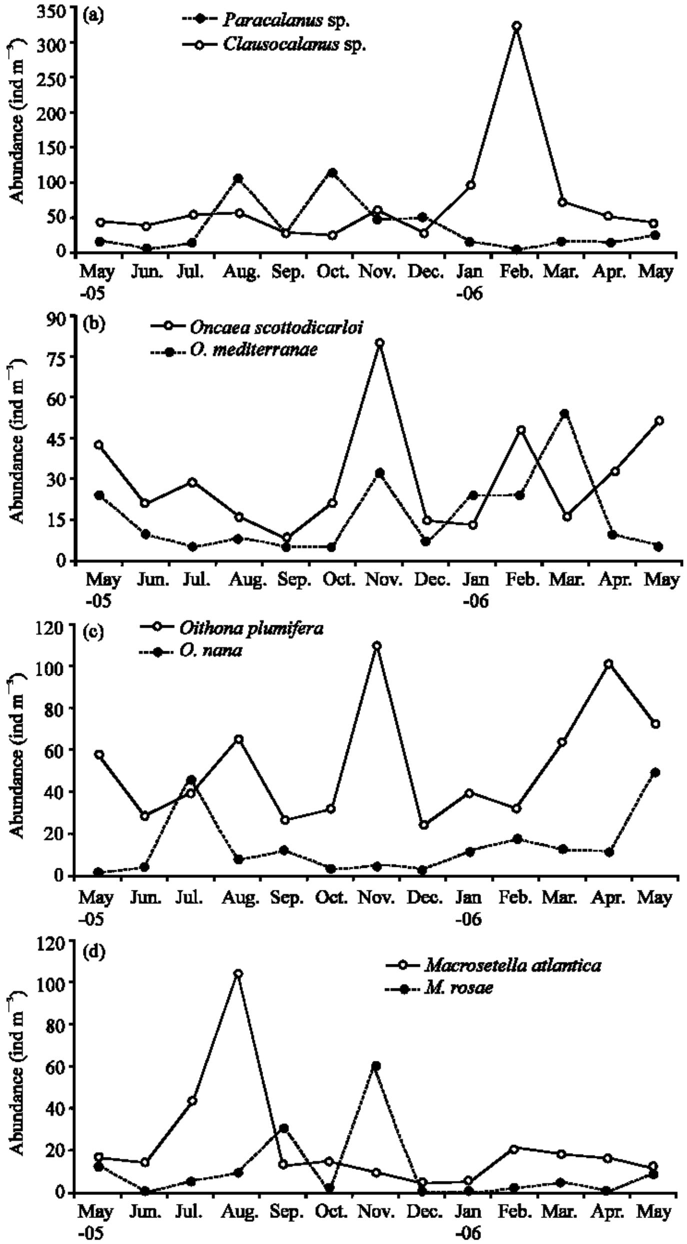

Fig. 3: Seasonal Variation in the abundance of the main copepod species (individuals m^{-3}) at the sampling station

Pteropods represented by four species (*Cresies acicula*, *C. virgula*, *Euclio* sp. and *Diacria* sp.). *Cresies acicula* was the most abundant one and attained its maximum in April and May 2006, respectively. Apart from this peak, the count was markedly low all the year round. The other species namely; *Cresies virgula*, *Euclio* sp. and *Diacria* sp. were recorded sporadically with very few numbers. Siphonophores formed 0.5% of total zooplankton with highest densities in September

Table 3: Species diversity indices of total zooplankton off Sharm El-Sheikh area during the period between May 2005 and May 2006

Month	No. of species	Richness	Shannon index	Evenness
May 2005	58	7.25	1.88	0.46
June	47	6.05	1.69	0.44
July	58	7.22	2.21	0.54
August	52	6.41	2.28	0.58
September	54	6.89	2.17	0.54
October	64	8.08	1.78	0.43
November	54	6.78	2.11	0.53
December	51	6.60	1.86	0.47
January 2006	51	6.66	1.98	0.50
February	65	8.37	2.31	0.55
March	53	7.16	2.24	0.56
April	51	6.52	2.03	0.52
May	57	7.21	2.11	0.71

forming about 1.6% of the total zooplankton. Adult polychaetes rarely sampled in the study area and represented by *Tomopetris* and *Vanadis* sp. Sapls and doliolids contributed a small part of the plankton (0.4% of the total counts). *Doliulm denticulatum* attained its peak in October. *Thalia democratica* was the only representative of order Salpia. It was recorded only during October and December.

Statistical Analysis

A significant Spearman correlation was obtained between temperature and total zooplankton ($r = 0.559$; $p<0.05$) as well as with dominant copepod genera, *Paracalanus* and *Corycaeus* ($r = 0.74$; $p<0.01$ and $r = 0.66$; $p<0.05$, respectively). No correlations were found between chlorophyll *a* concentration and abundance of various zooplankton taxa, suggesting complex trophic interactions. Zooplankton community is characterized by high species diversity (99 genera and species). The diversity indices of total zooplankton and copepods showed its highest number of species (65 and 47 species, respectively) in February, while their minimum values were observed during June (Table 3). Richness and Shannon Weiner index showed its highest values in February (8.37 and 2.31, respectively) and lowest in June. On the other hand, the maximum value of Evenness occurred in May (0.71) and minimum in October (Table 3).

DISCUSSION

The present study provides basic information on the vertical zooplankton abundance and composition in the epipelagic layer (0-100 m) off Sharm El-Sheikh area. Zooplankton fluctuate seasonally showed three peaks of abundance. These peaks were not markedly differ from other samples collected from the Red Sea proper (Delalo, 1966; Ponomarova, 1968; Weikert, 1980; Beckman, 1984), from northern Red Sea (Abdel-Rahman, 1997; El-Sherbiny, 1997; Khalil and Abdel-Rahman, 1997; Aamer *et al*., 2006) and from Gulf of Aqaba (Almeida Prado-Por, 1983; Echelman and Fishelson, 1990). These small differences may be related to sampling methods and/or mesh size of the used net. The outnumbering of copepod stages (nauplii and copepodites) than adults may be related to the mesh size used (100 μm) and/or belonging of these larvae to several species that have different breeding season under favorable condition (multivolatine species). Raymont (1983) stated that the occurrence of early stages of copepods almost throughout the year in the warm seas.

According to seasonal distribution, the highest zooplankton abundance in late winter-early spring could be associated with convective mixing which considered the most important source of nutrient transport in the euphotic zone (Morcos, 1970; Klinker *et al*., 1978; Levanon-Spanier *et al*., 1979; Cornils *et al*., 2005). The maximum density in zooplankton in summer during the strongly stratified period when the autotrophic food was limited, suggesting the main species could maintain their biomass by selecting food other than phytoplankton.

In the present study, the most widely distributed zooplankton species were the most abundant ones, such as *Clausocalanus* sp., *Oithona plumifera*, *Oikopleura* sp., *Paracalanus* sp., *Oncaea scottodicarloi*, *Microsetella atlantica*, *Corycaeus* sp., *Oncaea mediterranea*, *Corycaeus gibbulus*, *Ctenocalanus vanus* and *Oithona nana Calocalanus styliremis* and *Evadne tergestina*. These species were more or less similar to those recorded in other northern Red Sea waters (Abdel-Rahman, 1997; El-Sherbiny, 1997; Khalil and Abdel-Rahman, 1997; Cornils *et al*., 2005; Aamer *et al*., 2006). The predominance of the above cited copepod genera is interesting because the same ones are found in the more oligotrophic waters in subtropical water of the Atlantic Ocean (Fernández de Puelles and Braun, 1996; Hernandez-Leon, 1998). There is some evidence that the seasonal changes in the occurrence and abundance of most adult copepods are related to the amount and quality of food. The maximum abundance of the bigger species of small filterators, *Clausocalanus* sp. that recorded in February coincides with the diatom peak in the area of study (Kimor and Golandsky, 1977). This finding is in agreement with Almeida Prado-Por (1983) in Gulf of Aqaba and Abdel-Rahman (1997) and El-Sherbiny (1997) in the northern Red Sea. These species have world-wide distribution in warm water and were found in high abundance in tropical and subtropical Atlantic and adjacent areas (Sander and Moor, 1978; Kouwenberg, 1994). Also winter peak is similar to that found in such oligotrophic water in the Mediterranean Sea (Calbet *et al*., 2001 in Bay of Blanes, NW Mediterranean). While the high abundance of *Paracalanus* sp. during the warm period (August and September) which seem to be the breeding season may be explained by its characteristics as euryhaline and eurythermal cosmopolitan genus (Sewell, 1948). The maximum abundance of *Ctenocalanus vanus* appeared in spring in addition to small increase in September. This species seems to be common during late winter and remain under the thermocline in summer and this agrees with Kouwenberg (1994) in northwestern Mediterranean. Poecilostomatoid copepods play an important role in the copepod composition comprising 41% of the adult copepods. This agree with Böttger (1987) in central Red Sea, who found that the genus *Oncaea* hold a key position in the community structure of Red Sea plankton. *Oncaea scottodicarloi* and *O. mediterranea* were dominated and showed their maximum densities during autumn (November) and late winter-early spring (February-March). This may be indicating the presence of this genus in lower epipelagic zone in summer. This agrees with Böttger-Schnack *et al*. (1989); Böttger-Schnack (1990a and b) and El-Sherbiny (1997) results in the Red Sea and Malt *et al*. (1989) in the Lebanon waters. The predominance of *Oithona plumifera* than *O. nana* may be due to its oceanic distribution (Nishida, 1985).

The seasonal distribution and abundance of other groups (chaetognaths and tunicates) were insignificantly differing from recorded at other Red Sea waters (Echelman and Fishelson, 1990; El-Sherbiny, 1997; Aamer *et al*., 2006) and other similar oligotrophic environments (Greenwood, 1980). *Evadne tergestina*, the only reported cladocerans, is a thermophilic species showing its maximum densities mainly during warm period. This agrees with Komarovsky (1956) in Gulf of Aqaba.

The high contribution of meroplanktonic groups (9%) reflects the role of benthic fauna of the coastal area. The seasonal abundance indicates that summer and winter is the suitable seasons for the reproduction of most benthic organisms (August for bivalve and July-August and December-January for gastropods). This partially agrees with El-Sherbiny (1997) who found that the maximum peaks of meroplankton appeared in June and November. El-Rashedi (1992) found that the settlement seasons for most gastropod species in Sharm El-Sheikh area were spring and autumn.

The majority of recorded copepod species are epipelagic, few are mesopelagic or bathypelagic form including; *Calanus tenuicornis*, *C. robustior*, *Eucalanus attenuatus*, *Rhincalanus nasutus*, *Pseudocalanus elongatus*, *Euchaeta concinna*, *Phaenna spinifera*, *Pleuromamma abdominalis*, *P. xiphias*, *Lucicutia flavicornis*, *Haloptilus longicornis*, *Scolecithrix auropecten*, *S. chelips*, *S. ctenopus*, *Mecynocera clausi* and *Lubbockia squillimana*.

The highest species diversity of total zooplankton was recorded during October and February, while, the minimum diversity was observed in late spring and summer. This is comparable with Halim (1969) and El-Sherbiny (1997) who mentioned that the population reaches its maximum diversity in winter and the lowest in May-June. At least three processes can be responsible for the periodical winter increase in the number of species; upward vertical migration, availability of food and/or the influx throughout the strait of Bab-el-Mandab. Also, Weikert (1980) showed that most of copepod species migrate seasonally to cool water layer, avoiding rising surface temperature during summer. Many authors stated that winter is the most productive season (e.g., Levanon-Spanier *et al*., 1979; Kimor and Golandsky, 1977). The seasonal difference in the number of species is mainly correlated to the current system in the Red Sea (Beckmann, 1984; Weikert, 1987).

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