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FULL LENGTH ARTICLE

Diversity of Copepoda in a Stressed Eutrophic Bay (El-Mex Bay), Alexandria, Egypt

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Poecilostomatoida;
Copepod larvae and copepodite stages

Abstract Seasonal abundance, biomass, and taxonomic composition of copepods in El-Mex Bay (Southeastern Mediterranean region) were studied from autumn 2011 to 2012. Most species within the copepod communities displayed a clear pattern of succession throughout the investigation period. Generally copepods were the predominant group. They contributed numerically 57% of the total zooplankton counts with an average of 5083 organisms/m^3 and a total number of 203,333 individuals. The bay harbored 50 species belonging to 28 genera within 19 families and 4 orders under one class. Calanoids were represented by 24 species which formed 31.6% of total copepods predominantly *Acartia clausi*, *Calocalanus pavo*, *Clausocalanus furcatus*, *Eucalanus crassus*, *Nannocalanus minor*, *Paracalanus parvus*, *Eucalanus subcrassus*, and *Temora longicornis*. Cyclopoids comprised 13 species of which *Acanthocyclops americanus*, *Halicyclops magniceps*, *Oithona attenuata*, and *Oithona nana* were the most abundant adult copepods. Eleven Harpacticoid species were also recorded with *Euterpina acutifrons*, *Microsetella norvegica*, *Onychocamptus mohammed* being the most prevalent. It was found however, that two Poecilostomatoida species were rarely encountered in the plankton *Oncaea minuta* and *Corycaeus typicus*. Copepod larvae and copepodite stages formed the main bulk of copepod Fauna as noticed in the El-Mex Bay during the investigation period. Their percentage was 36.7% of the total count and their total numbers were 74,629 individuals with an average of 1866 organisms/m^3. The persistent relationships between total copepod counts, copepod orders, and physico-chemical variables suggested that physical factors operate on the copepod communities, either directly to limit maximum distribution along the bay, or indirectly on abundance.
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Introduction

Coastal marine areas are considered ecologically, as well as economically important and socially interesting (Calbet et al., 2001). These areas are extremely variable systems, due

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to changes in the circulation patterns of water and land fluctuations (e.g. rivers, sewage flow) which induce great temporal variability on a scale which ranges from a minimum of hours to the maximum of seasons (Walsh, 1988). Dynamics of the populations may be the result of this variability, as in planktonic forms, in particular, which thrive in coastal systems, and can hide the underlying patterns of seasonality abundance and biomass of organisms (Calbet et al., 2001).

El-Mex Bay is considered as one of the most important coastal regions in the Mediterranean Sea. It has been continuously subjected to several severe pollution problems (Dorgham, 2011 and Hendy, 2013). In spite of reducing of the industrial loads by several biological treatments and minimizing wastes from 1984 to 1995, the domestic wastes have doubled as a result of population increase in areas around the bay. That is why the load of the total discharge released into the bay had not significantly changed during this period.

Copepoda production in any natural water body is considered an equivalent to secondary producers as most of them, particularly the direct food of their larval and copepodite stages are phytoplanktons. They usually numerically and diversely outnumber other planktonic groups. Copepods, in turn contribute considerably to the food chain of many carnivores. Some fish are also largely dependent on the abundance of copepods particularly calanoids (Cushing, 1953; Cushing and Burd, 1957; Wimpenny, 1966; El-Rashidi, 1987).

Metazooplankton copepods are considered the most numerous group among the various animal species; therefore, information about their biology and physiology is key to understanding the different metazooplankton functions in the marine ecosystems (Ikeda et al., 2001).

Several studies on zooplankton abundance, composition and seasonal variations have been carried out in the coastal water of Alexandria by El-Maghraby and Halim (1965), Dowidar and El-Maghraby (1970a,b), Aboul Ezz (1975), El-Zawawy (1980), Dowidar et al.(1983), Khalil et al. (1983), Aboul Ezz et al. (1990), Aboul Ezz and Zaghloul (1990), and Abdel Aziz (1997).

The near shore waters west of Alexandria have attracted the attention of some investigators such as Hussein (1997), who studied the zooplankton standing crop and community structure in relation to the impact of waste discharge in the El-Mex Bay. Another investigator is Abdel Aziz (2000) who studied zooplankton community at the El-Dekhelah Harbor. She also studied the impact of the circulation of water and the discharge of wastes on the dynamics of zooplankton in the Alexandria Western Harbor in 2002. In 2005 she studied the short term variations in the zooplankton community in the El-Noubaria Canal (Abdel Aziz, 2005).

The characteristics of water, in relation to the populations of phytoplankton and zooplankton of El-Mex Bay and El-Umum Drain were previously studied (Soliman and Gharib, 1998; Gharib, 1998; El-Sherif, 2006; Hussein and Gharib, 2012). The results showed that, continuous discharges polluted the bay water, caused massive development of algal blooms, and gradually deteriorated the water quality, Zakaria et al. (2007) had also illustrated the effect of salinity changes and their influence on zooplankton abundance and their community structure in El-Mex Bay waters.

The distribution of copepods in the El-Mex Bay was first estimated by Dorgham (1987). Later on (Hussein, 1997) found that the zooplankton assemblages were mainly dominated by crustacean copepods. The copepods constituted 45.8% of the total zooplankton. Zakaria et al. (2007) found that in the water type ‘‘M’’ (mixed water, salinity ranged between 10‰ and 30‰) copepods constituted about 13.45% of the total zooplankton counts.

El-Mex Bay area was and still is being subjected to continuous major and drastic changes as a result of human activities. These changes are consequences of growing heavy industries (chloro-alkali plant, petrochemicals, pulp, metal plating, industrial dyes, and textiles) and of uncontrolled disposal of resulting wastes, they are also due to the huge amounts of untreated industrial wastes (Hendy, 2013) dumped in the coastal waters of the El Mex Bay. All that of course affects the ecological and biological conditions prevailing in the bay and can cause the flourishment or absence of some organisms, including zooplankters. Unfortunately, no detailed studies for the impact of environmental conditions on the distribution of zooplankton communities especially copepods along El-Mex Bay have been performed so far. Therefore, the present study is meant to deal with the distribution and relationship of copepod communities to the environmental variables in the El-Mex Bay as an important contribution to the bay biota database which is necessary in planning for optimum exploitation and sustainable development of the bay and its water resources.

Materials and methods

Study area description

El-Mex Bay is located west of the Alexandria City; it borders an industrial zone, and is one of the most densely populated cities with 6 million people (Fig. 1). The bay extends for about 7 km between longitude 29°45′ and 29°54′ E and latitude 31°07′ and 31°15′ N, from the Agami headland (west) to the Western Harbor (east). The bay occupies an area of 19.4 km^2 with a mean depth of 10 m, and water volume of 190.3×10^6 m^3. As a consequence of growing heavy industries (chloro-alkali, cement, chemicals, textile, tanneries, industrial dyes, ink, petroleum refining, meat processing, fish production, and iron or steel industries) and the uncontrolled disposal of resulting wastes, the coastal water of the El-Mex Bay receives huge amounts of untreated industrial wastes that contain heavy metals like Fe, Mn, Cu, Zn, Cd, Pb and Ni. These wastes are dumped directly into the southern part of the bay via pipelines. In addition to all that, El-Dekhelah Harbor has been recently constructed at the western side of the El-Mex Bay (Halim et al., 1995).

The bay receives about 2.547×109 $m^3\,y^{-1}$ of agricultural wastes mixed with water effluents (surplus water) from a neighboring sewage-polluted lake (Lake Mariut) with a rate of 262.8×10^6 $m^3\,y^{-1}$ via El-Umum Drain (Halim et al., 1995). The bay also receives 13×10^6 $m^3\,y^{-1}$ of industrial discharge, as well as water from the Western Harbor amounting to 1.13×10^6 $m^3\,y^{-1}$. The residence time of the El-Mex Bay water was found to be around 28 days (Halim et al., 1995). Accordingly, this bay is considered as an estuarine zone of the huge agricultural El-Umum Drain.

The seasonal variations in the current patterns in the El-Mex Bay depend mainly on the wind regime prevailing at the time. There were pronounced differences in both direction

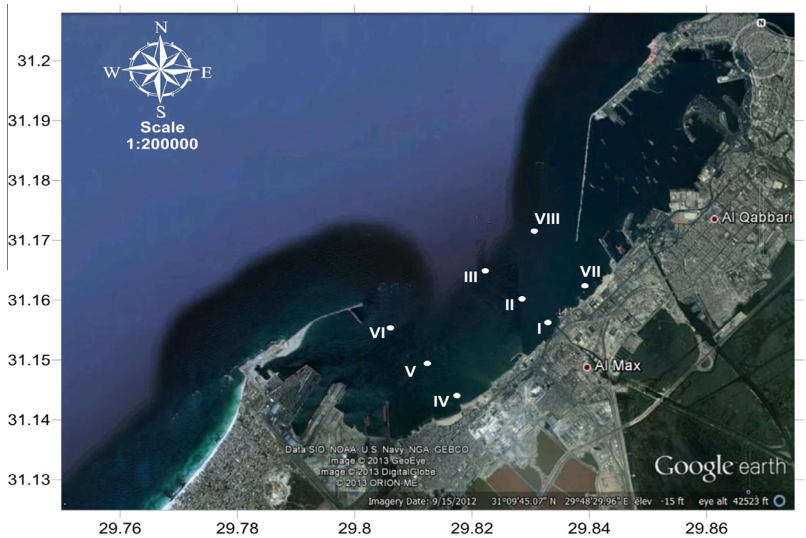

Figure 1 Map showing the locations of the studied stations at El-Mex Bay (Google earth).

and intensity of surface current in the El-Mex Bay, particularly between inshore water in front of the outfalls and offshore water. Near the industrial and agricultural outfalls, the transport of surface water is to the north, indicating a relatively strong offshore component, which may be mainly attributed to the effect of the westward outflows. The most important feature is the existence of an anticline eddy almost entirely covering the El-Mex Bay. As a consequence, the contaminated water that is discharged from both agricultural and industrial outfalls is trapped in the surface current system, and transported westward to the Agami headland (Halim et al., 1995).

Sampling

Sampling was carried out at eight stations seasonally (Fig. 1) during the period from autumn 2011 to 2012. Three stations (I, II, and III) were chosen in front of the El-Umum Drain, while the other three stations (IV, V, and VI) were situated west of the first three stations and the final two stations (VII and VIII) were chosen east of the first three stations.

Samples were collected vertically by using a standard plankton net (55 μm mesh size), lowered near the bottom up to the water surface. The collected fauna were fixed in 5% formalin solution. Copepods were identified down to their species level by investigation each one under binocular microscope Identification of different Copepod species was carried out according to Sars (1911, 1918, 1927), Gurney (1927, 1931, 1932, 1933), Rose (1933), Trogouboff and Rose (1957), Edmondson (1959) (Wilson and Yeatman, 1959), Hardig and Smith (1960), Hutchinson (1967), WORMS's database.

Estimation of standing crop was done as follows

1. Sub samples of 1 ml were transferred to a counting chamber (Bogorov chamber) using a plunger pipette.
2. This operation was performed three times and the average of the three counts was taken.
3. Copepods were counted to species level and the standing crop was calculated and estimated as organisms per cubic meter according to the following formula (Santhanam and Srinivasan, 1994):

$$N = n(v/V) \times 1000$$

where:

N: Total number of copepods per cubic meter.
n: Average number of copepods in 1 ml of the sample.
v: Volume of copepods concentrate (ml).
V: Volume of total water filtered (L).

Along with the collection, temperature was measured, and water samples were tested for salinity, phytoplankton biomass (Chlorophyll-a), and dissolved oxygen. All that was done according to procedures described by Strickland and Parsons (1972).

All collected data in the present study were tabulated and appropriate graphs were constructed. The data were subjected to the statistical treatment to find biological indices. The correlation coefficient (r) analysis was computed using MINITAP 14 program for copepods with the ecological measured parameters and chlorophyll-a concentration at $p \leqslant 0.05$.

Results

Water characteristics of the El-Mex Bay

Physico-chemical parameter values were measured at each of the eight stations along the El-Mex Bay during the different seasons in (Fig. 2). There was a general trend of increasing temperature, salinity and chlorophyll-a during summer 2012. El-Mex Bay seemed to be impacted by various land-based sources and man-made activities. Near shore stations were influenced by the discharge from the El-Umum Drain as well as from water flowing from the Western Harbor. Low salinities (reaching 10.82‰ during winter) were observed inshore, matching the high flow period of brackish water from the Lake Mariut. Oxygen levels declined to 5.6 mg/l due to the anoxic nature of the lake water. The discharge of nutrients (nitrates and phosphates) rendered the bay an eutrophic system, with chlorophyll-*a* levels varying between 10.14 µg/l in spring 2012 and 34.38 µg/l in summer 2012.

Chlorophyll-*a* is considered as an essential component that is responsible for photosynthesis. It is the primary photosynthesis pigment in all oxygen evolving photosynthetic plants. In the present study chlorophyll-*a* concentration was used as an indicator of phytoplankton abundance and biomass in coastal and estuarine waters. In the present study the maximum chlorophyll-*a* concentrations recorded in summer 2012 was 34.38 ± 15.46 µg/l. The high concentration of Chl-a content recorded in the water coincided with low salinity and high values of nutrient salts, which reflects such eutrophication conditions caused by drainage effluents. These data agreed with those obtained by El-Sherif (2006) where Chl-a ranged from 9.4 to 21.3 µg/l.

Faunal composition

Subclass Copepoda appeared as the predominant component of zooplanktons in the El-Mex Bay. It numerically contributed 57% of the total zooplankton population in the bay with an average of 5083 organisms/m^3 and a total of 203,333 individuals. The adult copepods formed 63% of total copepod counts (128,704 individuals) with an average of 3218 organisms/m^3 while, the rest were represented by immature forms that constituted about 37% (74,629 individuals) with an average of 1866 organisms/m^3. The copepod population comprised 50 species belonging to 28 genera within 19 families and 4 orders under one class. The four orders were as follows:

The first order was Harpacticoida (Sars, 1903) represented by 8 families within 9 genera and 11 species.

The second order was Cyclopoida (Burmeister, 1835) represented by 2 families, 7 genera and 13 species.

The third order was Calanoida (Sars, 1903) represented by 8 families with 11 genera and 24 species.

The fourth order was Poecilostomatoida (Burmeister, 1835) comprising two families with 2 genera and 2 species (Plates 15–20).

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Crustacea
Class: Maxillopoda
Subclass: Copepoda
Infraclass: Neocopepoda
Superorder: Podoplea

A- Order: Harpacticoida (Sars, 1903)
Family: Miraciidae (Dana, 1846)
Subfamily: Diosaccinae (Sars, 1906)
Genus: *Schizopera* Sars G.O., 1905
Species: *clandestina* Klie, 1924
Subfamily: Miraciinae (Dana, 1846)
Genus: Macrosetella Scott A., 1909
Species: gracilis Dana, 1847*

Family: Peltidiidae (Claus, 1860)
Subfamily: Clytemnestrinae (Scott, 1909)
Genus: *Clytemnestra* Dana, 1847
Species: *rostrata* Brady, 1883*
Species: *scutellata* Dana, 1847*

Family: Euterpinidae (Brian, 1921)
Genus: *Euterpina* Norman, 1903
Species: *acutifrons* Dana, 1847*

Family: Canthocamptidae (Brady, 1880)
Subfamily: Canthocamptinae (Brady, 1880)
Genus: *Mesochra* Boeck, 1865
Species: *lilljeborgii* Boeck, 1865

Family: Metidae (Boeck, 1873)
Genus: *Metis* Philippi, 1843
Species: *jousseaumei* Richard, 1892*

Family: Ectinosomatidae (Sars G.O., 1903)
Genus: *Microsetella* Brady & Robertson D., 1873
Species: *norvegeca* Boeck, 1865*
Species: *rosea* Dana, 1847*

Family: Ameiridae (Boeck, 1865)
Genus: *Nitokra* Boeck, 1865
Species: *lacustris* Shmankevich, 1875
Accepted name: *Nitokra lacustris lacustris* Shmankevich, 1875

Family: Laophontidae (Scott T., 1904)
Genus: *Onychocamptus* Daday, 1903
Species: *mohammed* Blanchard & Richard, 1891

B- Order: Cyclopoida (Burmeister, 1835)
Family: Cyclopidae (Rafinesque, 1815)
Genus: *Acanthocyclops* Kiefer, 1927
Species: *americanus* Marsh, 1893

Genus: *Halicyclops* Norman, 1903
Species: *magniceps* Lilljeborg, 1853bbbb

Genus: *Cyclops* Müller O.F., 1785
Species: *gracilis* Lilljeborg, 1853

Accepted name: *Metacyclops gracilis* Lilljeborg, 1853
Genus: *Mesocyclops* Sars G.O., 1914
Species: *leuckarti* Claus, 1857
Accepted name: *Mesocyclops leuckarti leuckarti* Claus, 1857
Species: *vernalis* Fischer, 1853
Accepted name: Acanthocyclops vernalis vernalis Fischer, 1853
Genus: ***Diacyclops*** Kiefer, 1927
Species: ***bicuspidatus odessanus*** Shmankevich, 1875

Genus: ***Eucyclops*** Claus, 1893
Species: ***agilis*** Koch, 1838
Accepted name: *Eucyclops agilis agilis* Koch, 1838
Family: Oithonidae (Dana, 1853)
Genus: *Oithona* Baird, 1843
Species: *attenuata* Farran, 1913
nana Giesbrecht, 1893
plumifera Baird, 1843
similis Claus, 1866
simplex Farran, 1913
tenuis Rosendorn, 1917MBF
Superorder: Gymnoplea (Giesbrecht, 1882)

C- Order: Calanoida (Sars, 1903)
Family: Acartiidae (Sars G. O., 1903)
Genus: *Acartia* Dana, 1846

Species: *clausi* Giesbrecht, 1889*
Accepted name: *Acartia Acartiura clause* Giesbrecht, 1889
Species: *discaudata* Giesbrecht, 1881*
Accepted name: *Acartia Acartiura discaudata* Giesbrecht, 1881
Species: *grani* Sars G.O., 1904*
Species: *latisetosa* Kritchagin, 1873*
Accepted name: *Paracartia latisetosa* Kritchagin, 1873
Species: *longiremis* Lilljeborg, 1853*
Accepted name: *Acartia Acartiura longiremis* Lilljeborg, 1853
Species: *negligens* Dana, 1849*
Accepted name: *Acartia Acartia negligens* Dana, 1849
Family: Paracalanidae (Giesbrecht, 1893)
Genus: *Acrocalanus* Giesbrecht, 1888
Species: *gibber* Giesbrecht, 1888*
Species: *gracilis* Giesbrecht, 1888*

Genus: *Calocalanus* Giesbrecht, 1888
Species: pavo Dana, 1852*

Genus: *Paracalanus* Boeck, 1865
Species: *aculeatus* Giesbrecht, 1888*
Species: *parvus* Claus, 1863*

Family: Calanidae (Dana, 1849)
Genus: Calanus Leach, 1816
Species: *finmarchicus* Gunnerus, 1770*

Genus: *Nannocalanus* Sars G.O., 1925
Species: *minor* Claus, 1863*

Family: Centropagidae (Giesbrecht, 1893)
Genus: Centropages Krøyer, 1849
Species: *orsinii* Giesbrecht, 1889*
Species: *typicus* Krøyer, 1849*

Family: Clausocalanidae (Giesbrecht, 1893)
Genus: *Clausocalanus* Giesbrecht, 1888
Species: *arcuicornis* Dana, 1849*
Species: *furcatus* Brady, 1883*
Species: *paululus* Farran, 1926*
Species: *pergens* Farran, 1926*
Species: *Clausocalanus* sp. Giesbrecht, 1888*

Family: Eucalanidae (Giesbrecht, 1893)
Genus: *Eucalanus* Dana, 1852
Species: *crassus* Giesbrecht, 1888*
Accepted name: *Subeucalanus* Geletin, 1976 *crassus* Giesbrecht, 1888
Genus: *Eucalanus* Dana, 1852
Species: *subcrassus* Giesbrecht, 1888*
Accepted name: *Subeucalanus'* Geletin, 1976 *subcrassus* Giesbrecht, 1888

Family: Pontellidae (Dana, 1853)
Genus: *Labidocera* Lubbock, 1853
Species: *pavo* Giesbrecht, 1889*

Family: Temoridae (Giesbrecht, 1893)
Genus: *Temora* Baird, 1850
Species: *longicornis* Müller O.F., 1785*

Genus: Coreciousa
Species: *typicus*

D- Order: Poecilostomatoida (Burmeister, 1835)
Family: Oncaeidae (Giesbrecht, 1893)
Genus: *Oncaea* Philippi, 1843
Species: *minuta* Giesbrecht, 1893*
Accepted name: *Triconia minuta* Giesbrecht, 1893

Family: Corycaeidae Giesbrecht, 1893
Genus: *Corycaeus* Dana, 1845
Species: *typicus* (Krøyer, 1849)
*: Marine species

Temporal variations in diversity and density

According to the study of the diversity of copepods, the data showed that marine forms were represented by 31 species with 14 fresh water species recorded, but only five brackish forms.

The density of marine species was found to be 59% of the total adult copepods (MR), 39% freshwater species (FW), and 2% brackish water species (Fig. 3a). Meanwhile, the percentage of different copepod forms including the immature, was represented as follows: the highest value was recorded for the marine forms 37% (75,137 individuals) with an average of 1878 organisms/m^3 followed by the immature forms which had a high percentage of about 36% (74,629 individuals) with an average (1866 organisms/m^3). The freshwater species were of 25% (50,461 individuals and 1294 organisms/m^3) and the remaining forms were brackish and were represented by 2% (3106 individuals and 107 organisms/m^3) Fig. 3b.

The seasonal variations of different copepod species (Fig. 4) showed that the marine species reached their maximum numbers at the beginning of the study during the first autumn (24 species). During spring and summer they reached (23 species), then they declined to 21 species in autumn 2012, and finally reached their minimum diversity during winter (18 species). On the other hand, freshwater species flourished during autumn 2011 and winter 2012 (12 species) and reached their minimum diversity during summer (8 species). Meanwhile, brackish forms showed a high diversity during autumn 2011, during winter and summer 2012 they were found to be 4 species and declined to their lowest diversity during spring (2 species).

The temporal variations of different copepod forms are displayed in Fig. 5. During winter, immature forms harbored the half percentage 50% of the total copepods (17,976 individuals) with an average of 2247 organisms/m^3 this was accompanied with a decrease in freshwater percentage to be about 6% (2184 individuals) with an average of 273 organisms/m^3. Marine species, on the other hand, had a high density of 43% (15,271 individuals) with an average of 1909 organisms/m^3, and finally brackish lined to 1% (469 individuals and average 94 organisms/m^3).

Spatial and temporal variations

The spatial and temporal variations of total copepod species (Fig. 6) showed that the highest density of individuals was

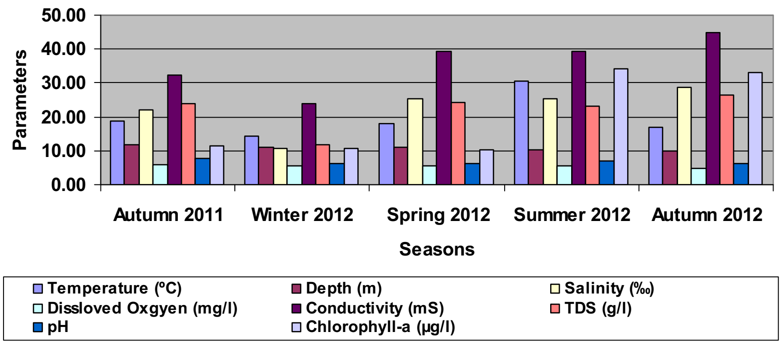

Figure 2 Water quality collected along coastal water of El-Mex Bay.

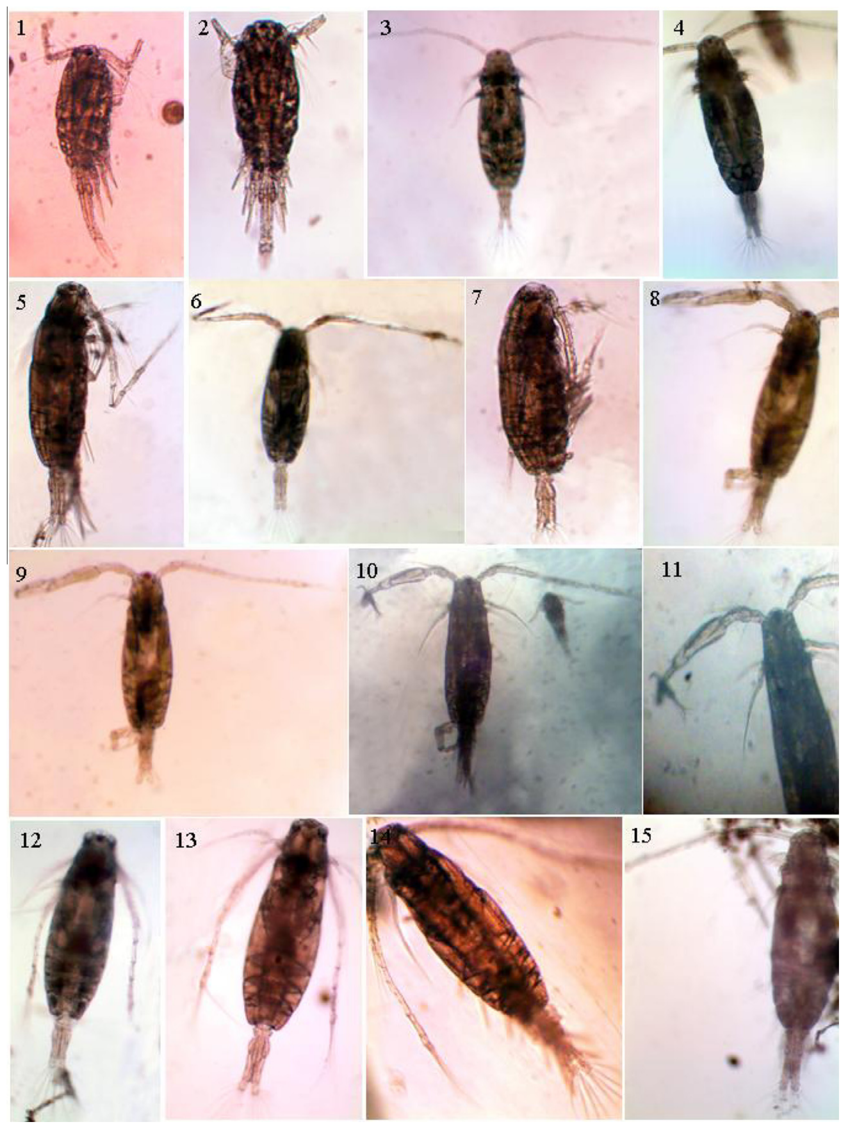

Plate 1 (1and 2) *Acanthocyclops americanus* (3 and 4) *Acartia clausi* (5–7) *Acartia discaudata* (8–11) *Acartia grani* (12 and 13) *Acartia latisetosa* and (14 and15) *Acartia negligenus*.

recorded at station IV (7109 organisms/m^3 and total of 35,547 individuals) with total number of 28 species. This information was recorded from the previously mentioned station and took the whole period of the study; it also included the immature forms. On the other hand, the lowest density was attained at station II (16,896 individuals and average of 3379 organisms/m^3) with 29 species. The highest number of species was recorded at stations I and III (35 species) with total number of individuals

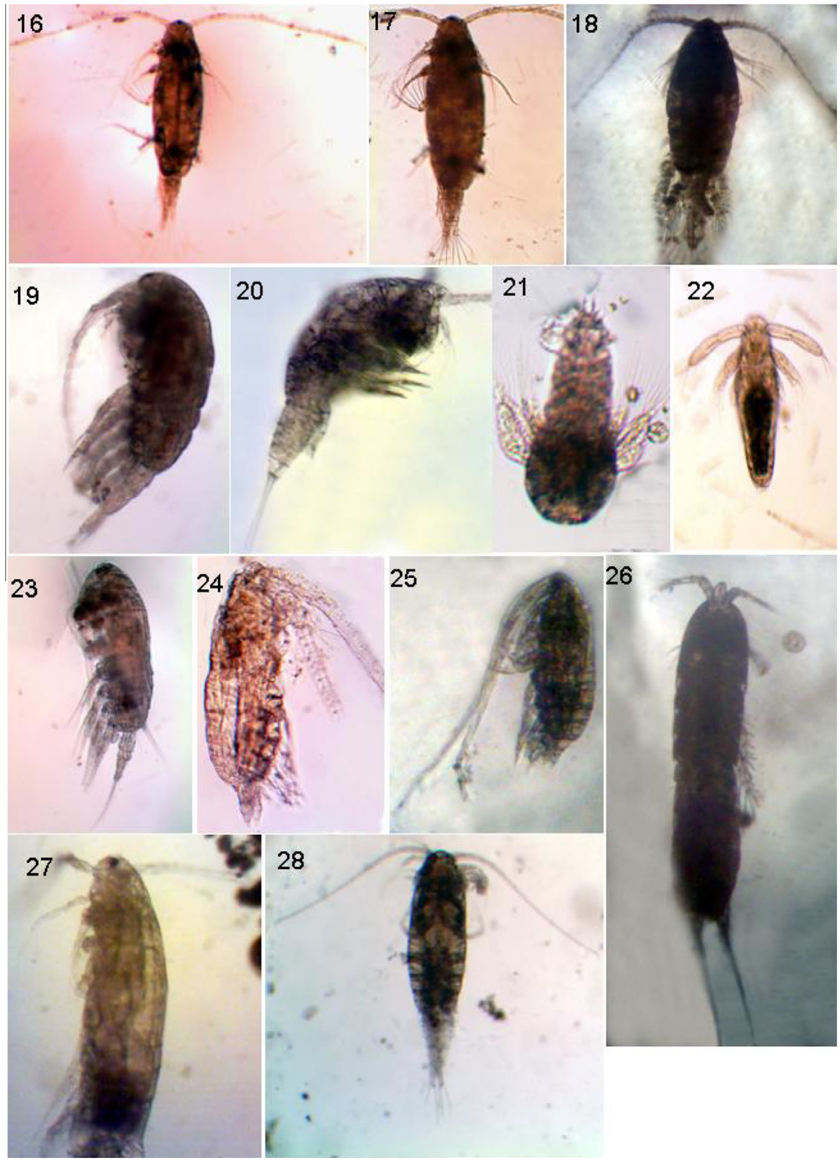

Plate 2 (16 and 17) *Acartia longiramus* (18 and 19) *Temora longicornis* (20) *Metis jousseaumei* (21) Copepodite stage and (22) Nauplius larva of Copepoda *(*23) *Calanus finmarchicus* (24and 25) *Calocalanus pavo* (26) *Schizopera clandestina* (27) *Centropagus typicus* and (28) *Centropagus orsinii.*

23,089 and 4618 organisms/m^3 for station I and total of 21,655 individuals and 4331 organisms/m^3 for station III.

During autumn of 2012, the number of individuals reached its maximum values of 99,878 individuals and 12,485 organisms/m^3 with 31 species. It was then followed by the density of 35,900 individuals and 4487 organisms/m^3 (32 species) in the winter of 2012. While, during autumn 2011 the maximum diversity of species was recorded to be 40 species with 27,718 individuals and 3465 organisms/m^3. Summer of 2012 on the other hand, showed minimum number of species which was 30 (Fig. 6).

Dynamics of copepod orders

The adult copepods were represented in this study by; Calanoida which was the prevailing order as they formed 31.5% of total copepods with total numbers of 64,070 individuals and an average of 1602 organisms/m^3. The second dominant order was Cyclopoida which was represented by 21.6% and the total of 43,833 individuals with an average of 1096 organisms/m^3. Harpacticoida was represented by only 10% with a total individual number of 20,397 and an average of 510 organisms/m^3. Poecilostomatoida appeared too rare, they formed only 0.2% with a total number of 404 individuals and an average of 67 organisms/m^3. On the other hand, Copepod larvae and copepodite stages formed the main bulk of the copepod Fauna in the El-Mex Bay during the investigation period, they showed a percentage of 36.7% and their total numbers were 74,629 individuals and average of 1866 organisms/m^3 (Fig. 7).

Temporal variations of different adult copepod orders and immature forms at the El-Mex Bay during the different seasons are shown in Figs. 8 and 9. Autumn 2011 and summer 2012 seasons were the most suitable ones for Cyclopoida to flourish. Cyclopoida recorded 37% of the total copepods

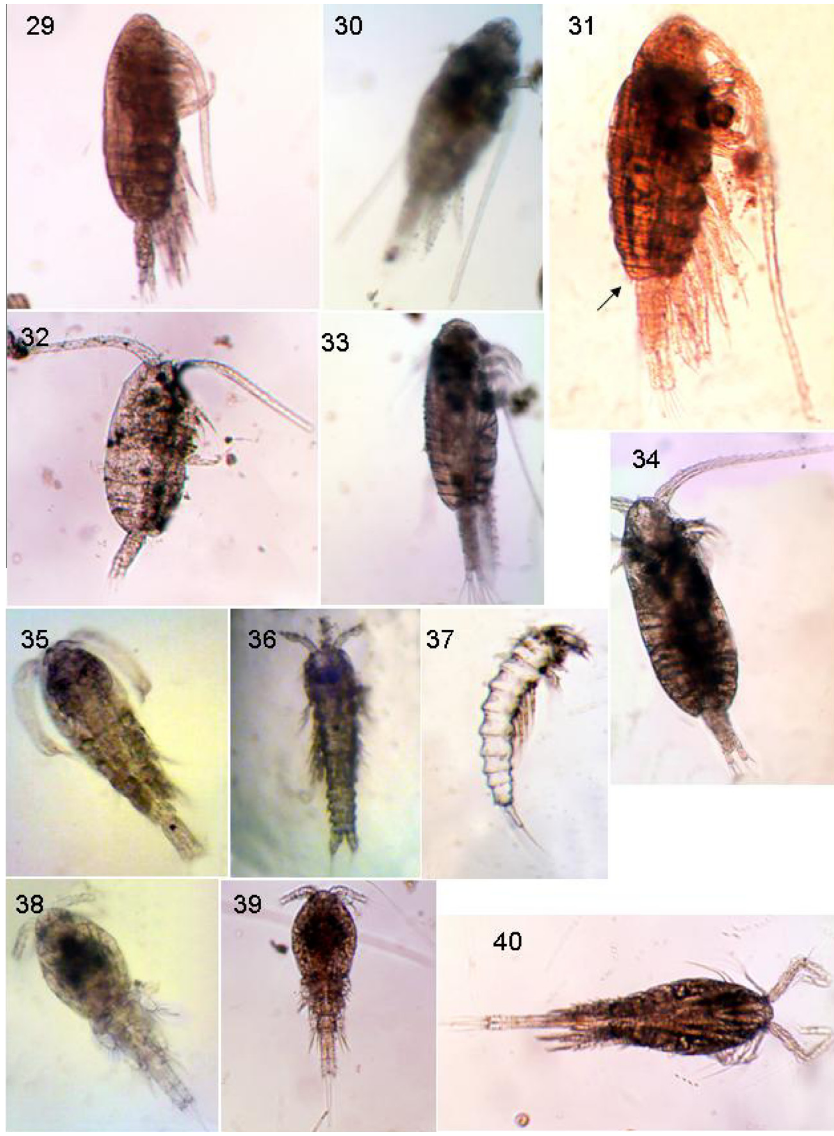

Plate 3 (29) *Clausocalanus furcatus* (30) *Clausocalanus arcuicornis* (31) *Centropagus abdominalis* and (32) *Clausocalanus paululus* and (33 and 34) *Clausocalanus pergens* (35) *mesocyclops leuckarti* (36 and 37) *Onychocamptus mohammed* (38 and 39) *Cyclops* sp. and (40) *Diacyclops bicuspidatus odessanus*.

(10,293 individuals and 1287 organisms/m^3) and 31% (5636 individuals and 704 organisms/m^3) respectively. Cyclopoida dropped down to record the lowest percentage in winter which became 6% (1987 individuals and 248 organisms/m^3), then increased gradually in the following spring to record 12% (2555 individuals and 319 organisms/m^3) before flourishing in the summer.

Calanoida increased and reached its maximum percentages during two seasons; winter and spring (40% and 36%) with a total number of 14,374 individuals (1797 organisms/m^3) and 7799 individuals (975 organisms/m^3) respectively. Their abundance declined during autumn 2011 (23% with 6389 individuals and 799 organisms/m^3). On the contrary, the copepodite stages and nauplii larvae constituted the main bulk of total Copepoda where their maximum percentage occurred during winter (50% with 17,976 individuals and 2247 organisms/m^3) while, during autumn 2012 they were (32% with 31,952 individuals and 3994 organisms/m^3).

Order Poecilostomatoida was rarely encountered in the El-Mex Bay through the study period, it ranged between maximum counts of 194 organisms/m^3 during autumn, 2012 to a minimum of 36 organisms/m^3 during spring.

The spatial distribution of immature forms showed their maximum persistence at all the stations in the El-Mex Bay with a maximum appearance at station VII (49% of the total copepods in this station) with total number 15,230 individuals 3046 organisms/m^3, the minimum number however, was of 5463 individuals and 1093 organisms/m^3 at station V. According to densities of different orders in different stations, the first important order was Calanoida which recorded an average number of 1602 organisms/m^3 in the studied area. They reached their maximum value at station IV (12,505 individual's 2501 organisms/m^3) and declined at stations VII (5679 individuals 1136 organisms/m^3). Cyclopoida recorded an average number of 1096 organisms/m^3 in the bay, the maximum count of Cyclopoida was observed at station IV where it was 7780

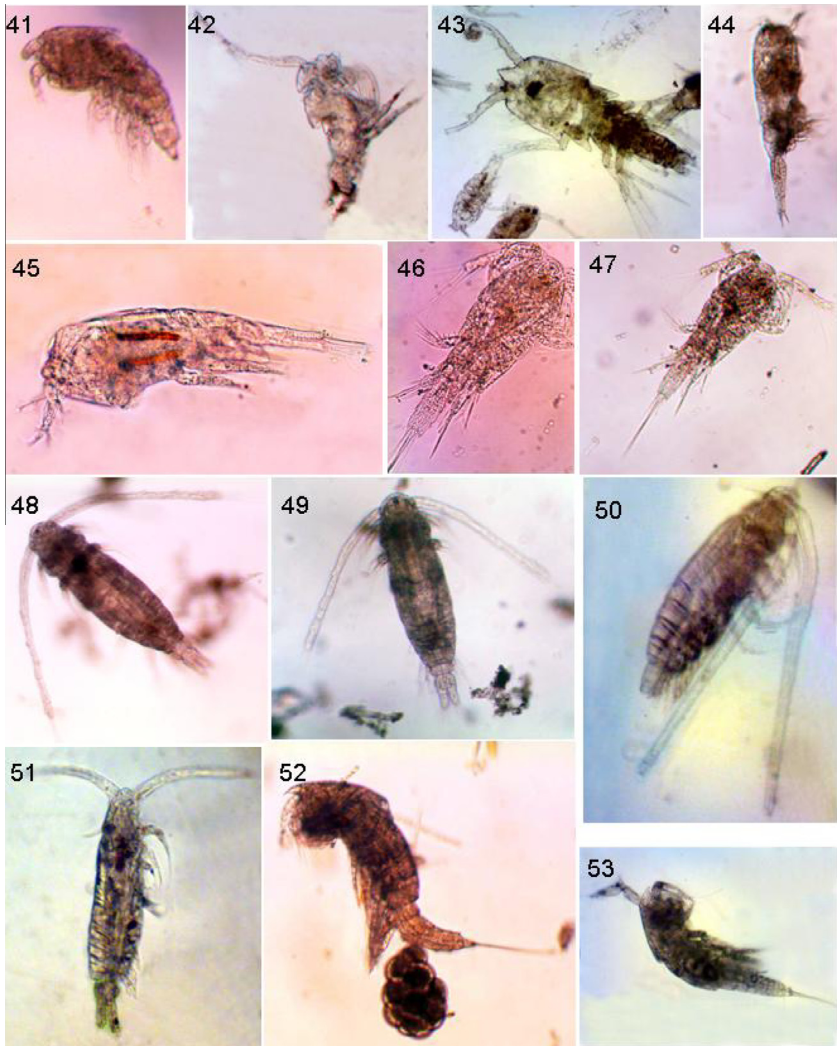

Plate 4 (41) *Clytemnestra rostrata* (42 and 43) *Clytemnestra scutellata* (44 and 45) *Coreciousa typicus* (46 and 47) *Cyclops vernalis* (48 and 49) *Eucalanus subcrassus* (50 and 51) *Eucalanus crassus* and (52 and 53) *Euterpina acutifrons*.

individuals and 1556 organisms/m^3, while the minimum count was 2682 individuals (536 organisms/m^3) at station II. Station IV contained the maximum number of Harpacticoida being 3358 individuals (672 organisms/m^3), while station V showed the minimum number of 1266 individuals and 253 organisms/m^3. On the other hand, Poecilostomatoida appeared to be rare in the studied stations of the El-Mex Bay. They were recorded at stations I, VII and VIII, while they were recorded with an average of 102 organisms/m^3 in station V and with a minimum of 36 organisms/m^3 at station III (Fig. 10).

Results of occurrence and distribution of copepod species are displayed in Fig. 11. The frequency occurrence of the copepod species varied from season to season during the entire study period where the higher percentage of occurrence value was recorded (100% of all study period) for 17 forms namely, *Acanthocyclops americanus*, *Halicyclops magniceps*, *Oithona attenuata*, *Oithona nana*, *Acartia clausi*, *Calocalanus pavo*, *Clausocalanus furcatus*, *Eucalanus crassus*, *Nannocalanus minor*, *Paracalanus parvus*, *Eucalanus subcrassus*, *Temora longicornis*, *Euterpina acutifrons*, *Microsetella norvegica*, *Onychocamptus mohammed*, Copepodite stage, and Nauplius larvae of Copepoda. In contrast, 7 species were restricted to only one station and represented the lower frequency of occurrence percentage; they were *Acartia grani*, *Clausocalanus arcuicornis*, *Clausocalanus paululus*, *Labidocera pavo*, *Clytemnestra scutellata*, *Metis jousseaumei*, and *Microsetella rosea*.

Ten species were presented during four seasons of the study period, they were; *Diacyclops bicuspidatus odessanus*, *Oithona plumifera*, *O. similis*, *Acrocalanus gibber*, *A. gracilis*, *Calanus finmarchicus*, *Centropagus orsinii*, *C. typicus*, *Clytemnestra rostrata*, and *Mesochra lilljeborgii*. The remaining species were divided into 7 species and had a frequency occurrence of 60% during the study period, and 11 species with frequencies occurred during two seasons as shown in Fig. 11.

The spatial distribution of species presented in Fig. 12 shows those 17 specimens were recorded from all the stations (frequency of occurrence 100% of the study area). The species were, *A. americanus*, *A. clausi*, *C. pavo*, *C. furcatus, C. rostrata*, *D. bicuspidatus odessanus*, *E. crassus, Euterpina acutifrons*, *H. magniceps*, *N. minor*, *Oithona attenuate*, *O. nana*, *O. simillis*, *P. parvus*, *Subeucalanus crassus,* Copepodite stage and nauplius larvae of Copepoda. In contrast, 4 species restricted only to one station were, *A. grani*, *C. paululus*, *C. scutellata*, and *M. jousseaumei*. On the other hand, 8 species recorded

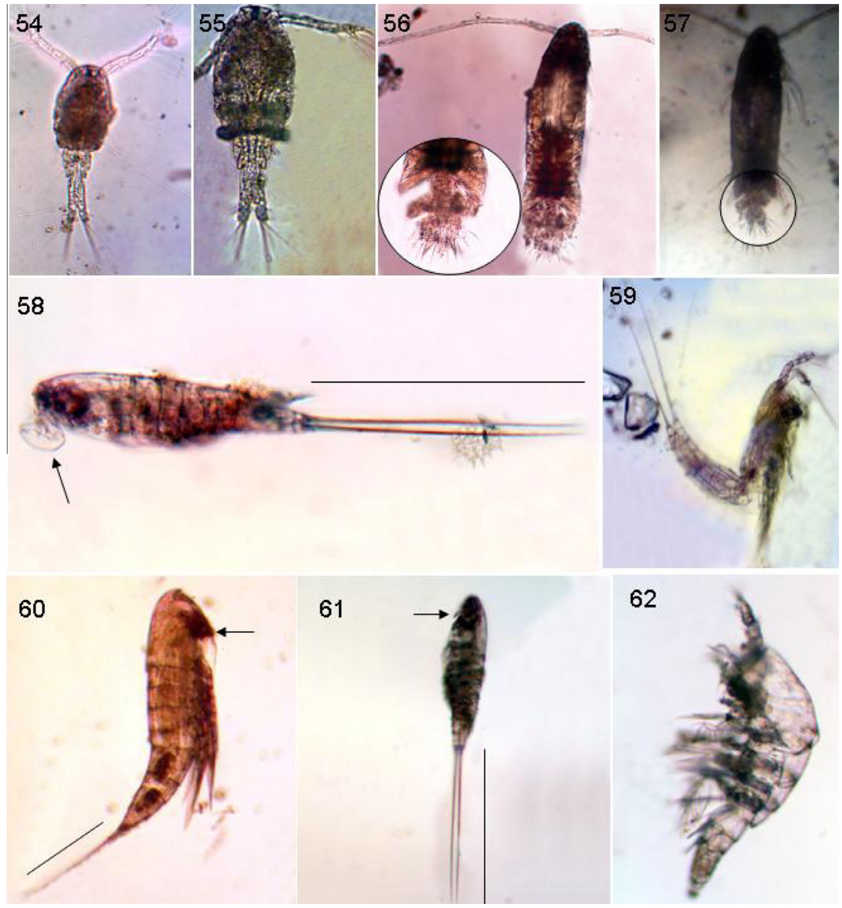

Plate 5 (54 and 55) *halycyclops magnisips* (56 and 57) *Labidocera pavo* (58) *Macrosetella gracilis* (59 and 60) *Microsetella norvegica* (61) *Microsetella rosea* and (62) *Mesochra lilljeborgii*.

at two stations were, *Acartia longiramus*, *Clausocalanus* sp., *Macrostella gracilis*, *M. rosea*, *Nitocera lacustris*, *Oithona simplex*, *O. tenuis*, and *Paracalanus aculeatus* with an occurrence value of 25% of the study area.

Concerning the frequency of occurrence, its percentage was 37.5% of the bay where nine species, *Shizopera clandestina*, *C. typicus*, *C. arcuicornis*, *Cyclops gracilis*, *C. vernalis*, *Eucyclops agilis*, *L. pavo*, *M. lillijeborgii*, and *Oncaea minuta* were recorded at three stations. Three species namely; *Acartia discaudata*, *C. typicus*, and *O. plumifera* were recorded at four stations and had an occurrence percentage of 50%.

A. negligenus, *A. gibber*, *C. orsinii*, and *Clausocalanus pergens* occurred at five stations while, only two species occurred at the sixth station to represent occurrence percentage of 75% of the bay *Mesocyclops leuckarti* and *T. longicornis*. On the other hand, 5 species were recorded at 7 stations; they were *Acartia latistosae*, *A. gracilis*, *C. finmarchicus*, *M. norvegica*, and *O. mohammed* with an occurrence percentage of 87.5%.

Data analysis

Correlation matrix

Processing the resulted data by using MINITAP release 14 program to find the correlation between the total copepods, different Copepod orders and the environmental parameters resulted as the following:

At $P \leqslant 0.05$ total copepod counts were negatively correlated with depth during autumn 2011, spring and autumn 2012 and r values were 0.878, 0.763 and 0.692 respectively. While during summer they negatively correlated with the total dissolved salts with r = 0.709. On the other hand, total copepod counts were positively correlated with water temperature at a value of 0.862 during autumn 2012 (Table 1).

A significant positive correlation between Cyclopoida and total copepod occured during autumn 2011, summer and autumn 2012 (r = 0.70, 0.83, and 0.91 respectively) but with a negative correlation in pH and conductivity (r = −0.69 and −0.70 respectively) during winter, it also showed a strong positive correlation with NO_2 (μM) (r = 0.74) during the same season. On the other hand, Cyclopoida were positively correlated with temperature at value r = 0.68 during spring and autumn 2012. A negative correlation between Cyclopoida and NO_2 (μM) occured during autumn 2012 with value r = −0.75.

The order Harpacticoida was negatively correlated with salinity during autumn 2011 (r = −0.72) and also with depth during spring (r = −0.79), but positively with total copepods (r = 0.70). During summer season a positive correlation between the same order and total copepod counts occured as well (r = 0.78). During autumn 2012, a negative correlation

Plate 6 (63) *Clausocalanus* sp. (64) *Nitocera lacustris* (65–69) *Oithona nana*, and (70 and 71) *Oithona plumifera*.

was constructed between Harpacticoida and Total dissolved solids TDS ($r = -0.73$) and with conductivity ($r = -0.72$).

Calanoida had a positive correlation with total copepods as larvae and copepodite stages ($r = 0.94$ and 0.76 respectively) during winter. During spring, it was correlated with total copepods and Harpacticoida ($r = 0.87$ and 0.82). There is a negative correlation between Calanoida and both TDS and chlorophyll-*a* during summer ($r = -0.67$ and -0.75) and a positive correlation with total copepod counts ($r = 0.68$). It was negatively correlated with NO_2 (μM) during autumn 2012 ($r = -0.85$).

Larvae and copepodite stages were positively correlated with total copepod counts during autumn 2011, winter, spring, summer, and autumn 2012 ($r = 0.87$, 0.92, 0.89, 0.68, and 0.76 respectively). A negative correlation was seen between immature forms and depth during autumn 2011, spring and autumn 2012 ($r = -.82$, -0.69, and -0.72). During spring, they negatively correlated with chlorophyll-*a* ($r = -0.91$). Larvae and copepodite also, correlated negatively with total dissolved solids TDS during summer ($r = -0.69$). A positive correlation was seen between immature stages and temperature and pH ($r = 0.80$ and 0.69) during autumn 2012.

The results of cluster analysis using MINITAB Release 14 computer programs based on seasons and station data including the physico-chemical parameters and copepod composition are illustrated in the following dendrograms.

Generally, similarity between the different studied seasons was relatively too high. The results showed that there were two main clusters between different seasons with 96.32% similarity between them; the first cluster separates the winter season. The second cluster divided into two sub-clusters with similarity of 98.35% between them. The first sub-cluster included autumn 2011 and summer which recorded the highest similarity of 99.85% between them, while the second sub-cluster linked spring and autumn 2012 with 99.05% similarity (Fig. 13).

The analysis of similarity between the studied stations indicated in the dendogram Fig. 14 showed that, locations were divided into two major clusters with 86.69% similarity between them. The first cluster was divided into two sub-clusters with a similarity of 96.73%, the first sub-cluster included stations I and II with maximum similarity of 99.47% between them, while the second sub-cluster separated station VII only.

The second cluster was divided into two sub-clusters with a similarity of 95.16%, one of them separated station V from the remaining four stations. The second sub-cluster included stations III, IV, VI and VIII with a similarity of 98.35% between them. The similarity between IV and VIII was the second

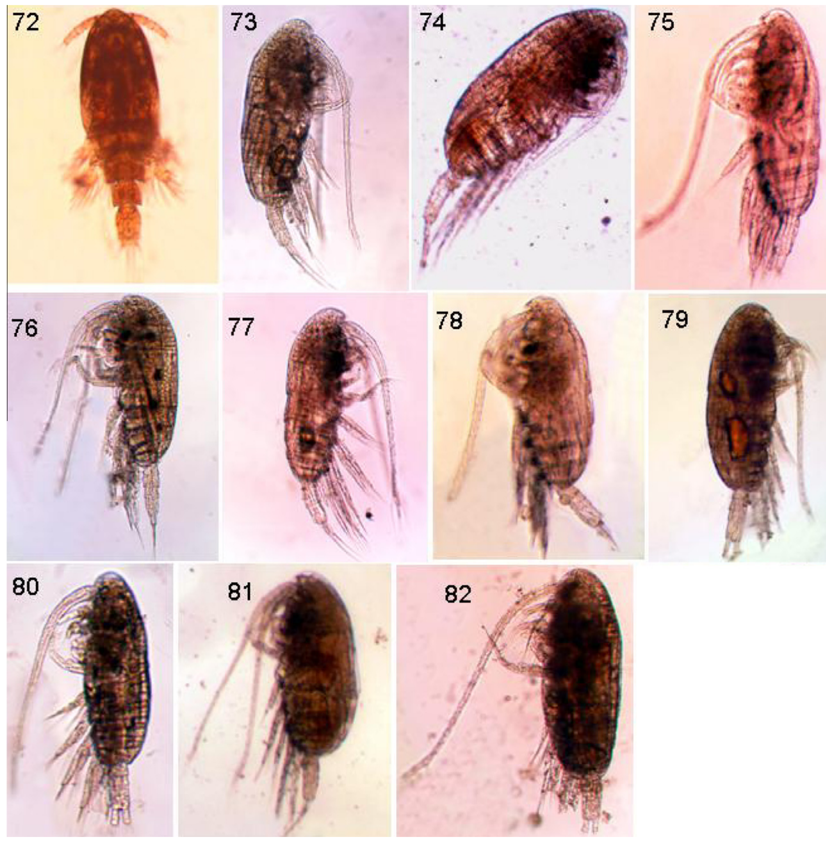

Plate 7 (72) *Oncaea minuta* (73) *Paraclanus parvus* (74) *Clausocalanus arcuicornis* (75–77) *Nanocalanus minor* (78) *Acrocalanus gracilis* (79 and 80) *Clausocalanus furcatus* (81) *Acrocalanus gibber* and (82) *Paracalanus aculeatus*.

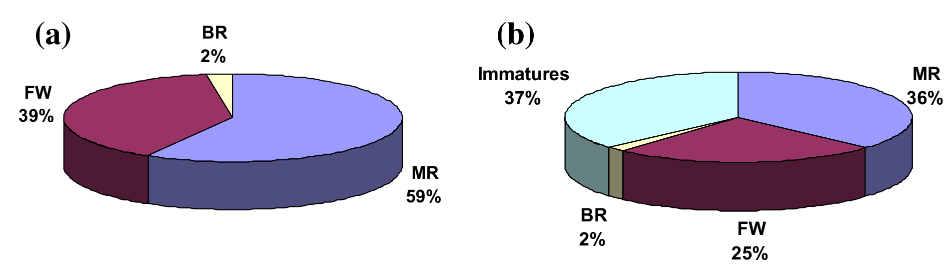

Figure 3 The overall density (a) percentage of the adult copepods and (b) Percentage of the different copepod communities. Freshwater (FW), marine species (MR), brackish (BR) and immature forms.

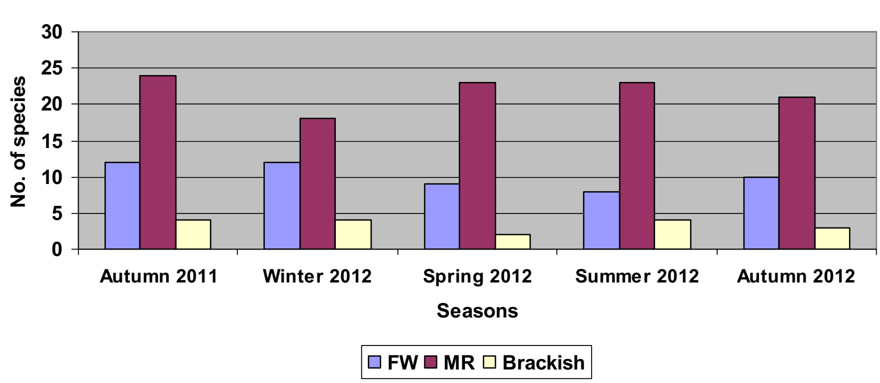

Figure 4 Seasonal variations in number of copepod forms during the study period in El-Mex Bay.

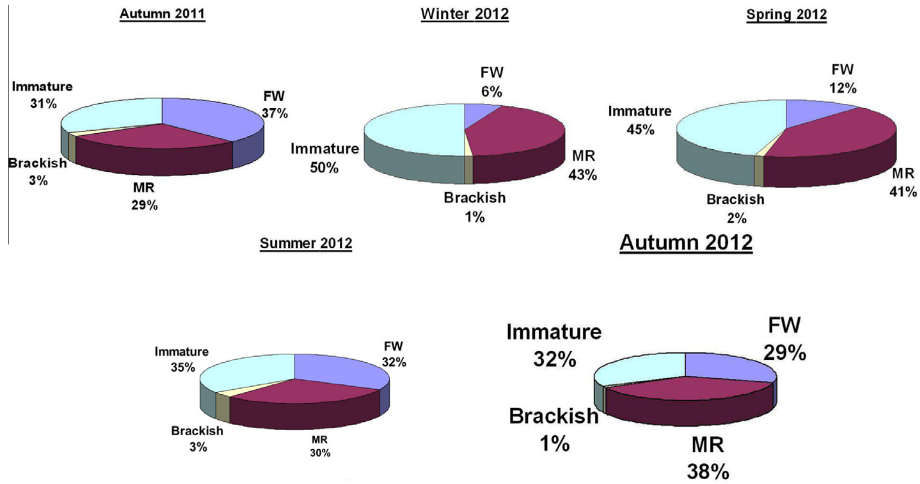

Figure 5 The percentages of copepod forms to the total during the study period.

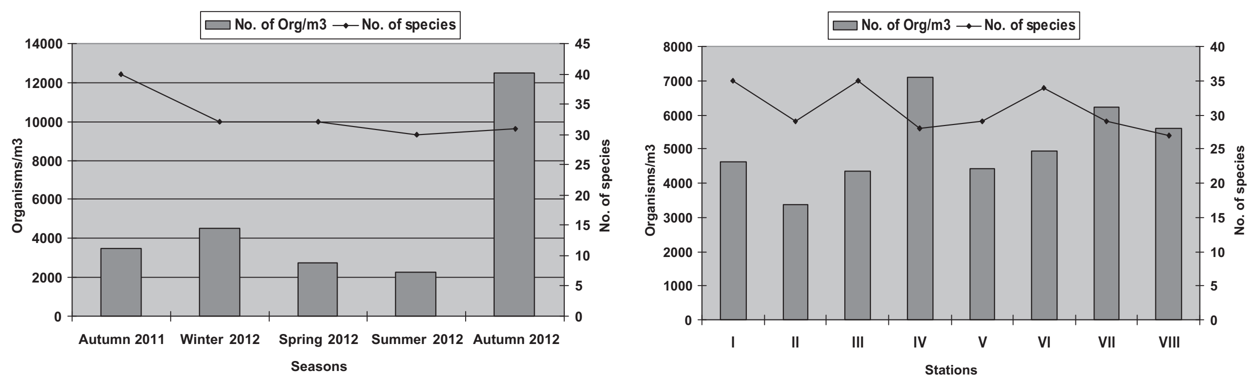

Figure 6 The spatial and temporal variations of copepods communities during the investigation period.

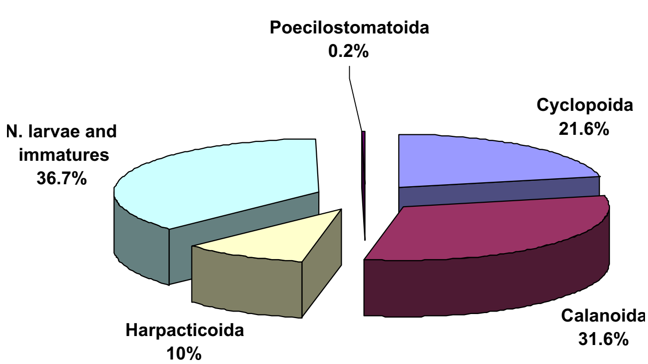

Figure 7 Faunal composition of adult copepod and immature forms in El-Mex Bay during the investigation period.

highest similarity being 99.32% followed by a similarity between stations III and VI which was 98.95%.

Discussion

The present results agree with the observations of (Blanco et al., 1990) who recorded copepods as being the most abundant taxa in polluted waters.

Among the most tackled subjects in this area is the water quality and its relation to the changes in the animal's community composition. Several authors have noted that it is difficult to designate a single abiotic factor as being a limiting one which controls the biological processes that are taking place in the bay water (Kaartvedt and Svendsen, 1995; Buyukates and Roelke, 2005; Abo-Taleb, 2010). However, they all concluded that such processes are mainly controlled by a combination of factors acting at different rates throughout successive months of the year.

It is apparent from the present data that water temperature did not deviate from the normal seasonal fluctuations on the southeastern coast of the Mediterranean Sea (15–30 °C) (Boyd, 1979). This study showed that pH values were always on the slight alkaline side and lower than that of the open sea. The decrease in the pH value coincided with the drop in oxygen content due to the effect of accumulating organic pollutants as well as the discharge of brackish water. El-Mex Bay demonstrated a wide range of variations in its salinity on the spatial scale relative to the dispersal pattern of the discharged waste waters. The salinity of the near-shore waters sustained usually low values, increasing seaward to exceed 26.1‰ in the open part of the sea that reflects the effect of land drainage.

The water column of the El-Mex Bay suffers from pronounced turbidity, particularly in front of the land runoff,

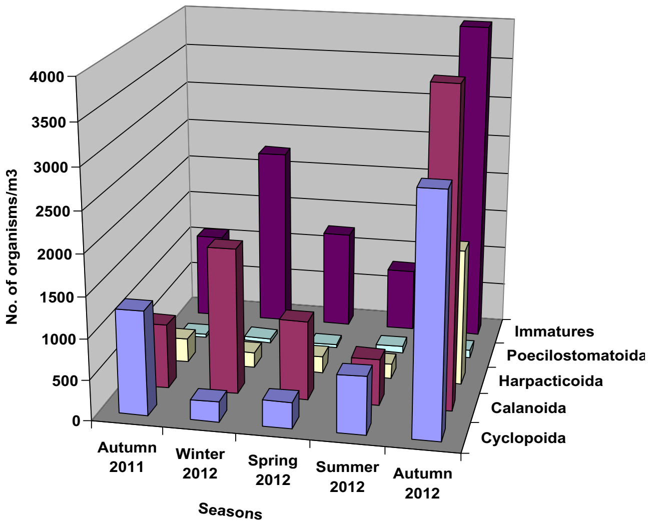

Figure 8 Seasonal changes in total species counts (organisms/m^3) of different copepod orders and immature forms in the El-Mex Bay during the investigation period.

where the Secchi disc readings were mostly < 1 m. Such turbidity is attributed to the strong mixing caused by discharged wastes, heavy traffic of fishing boats, and high count of plankton organisms. However, the open area of the bay shows comparatively high transparency (up to 5 m). These observations agreed with Mahmoud et al. (2009), Dorgham (2011) and Hendy (2013).

Large amount of nutrients reached the bay water through the wastewater discharges from the El-Umum Drain and El-Nubareia canal, since the maximum values were recorded in the bay water that was located at the front of the land run-off. In contrast, the relatively low concentrations during the period 2003–2005 represented the amount of nutrients in water areas especially those that are far from the entrance of the

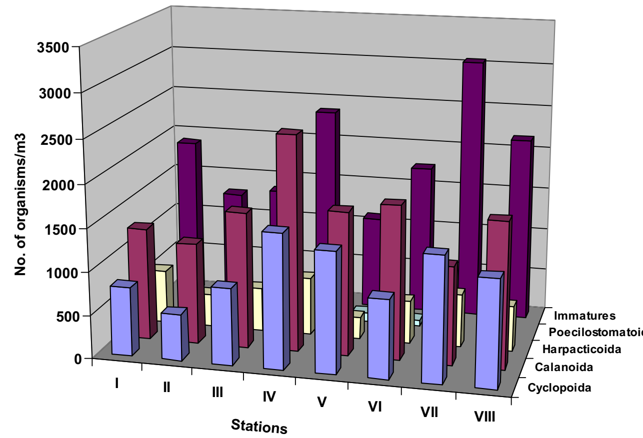

Figure 10 Spatial changes in total individual counts (organisms/m^3) of different copepod orders in El-Mex Bay at different stations.

El-Umum Drain. It is clear that the El-Mex Bay is characterized by a great load of organic matter on the long-term scale. The phytoplankton demonstrated pronouncedly intensive growth in the El-Mex Bay, maximizing the level of eutrophication conditions, since the inter-annual records over the past three decades indicate pronouncedly high chlorophyll-a concentration in the bay as found by Dorgham (2011). Due to that, no changes occurred in the controlling of waste discharges in the bay, a permanent eutrophication condition has been recorded in the bay till the present study.

Chlorophyll-*a* is considered an essential component that is responsible for photosynthesis. It is the primary photosynthesis pigment in all oxygen evolving photosynthetic plants. In the present study chlorophyll-*a* concentration was an indicator of phytoplankton abundance and biomass in coastal waters. In the present study the maximum chlorophyll-*a* concentrations were recorded at station (I) 52.65 μg/l. The high concentration

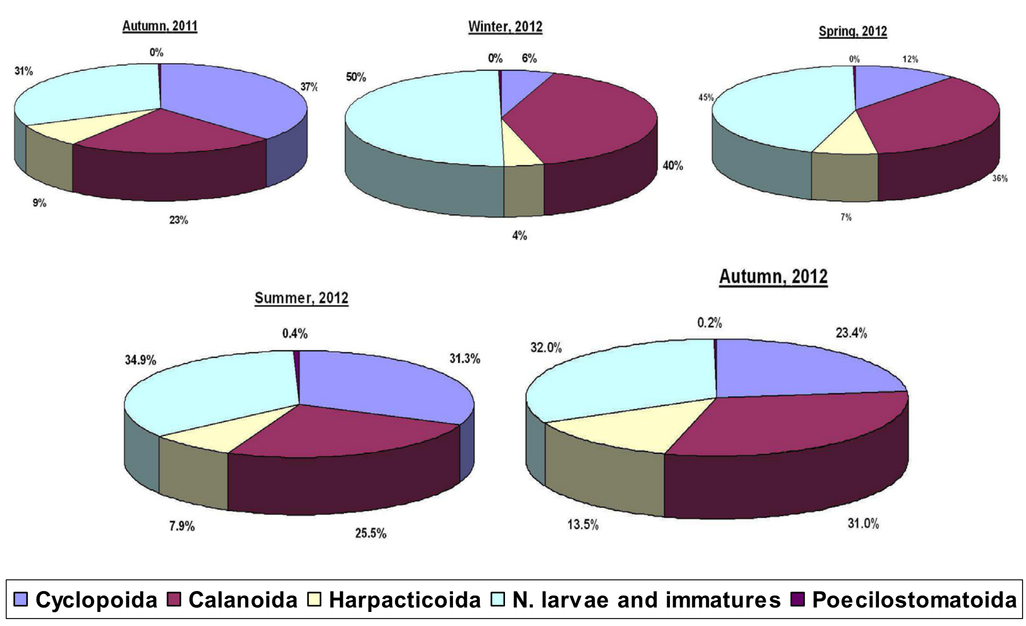

Figure 9 Seasonal changes in percentages of different copepod orders, and immature forms in the El-Mex Bay.

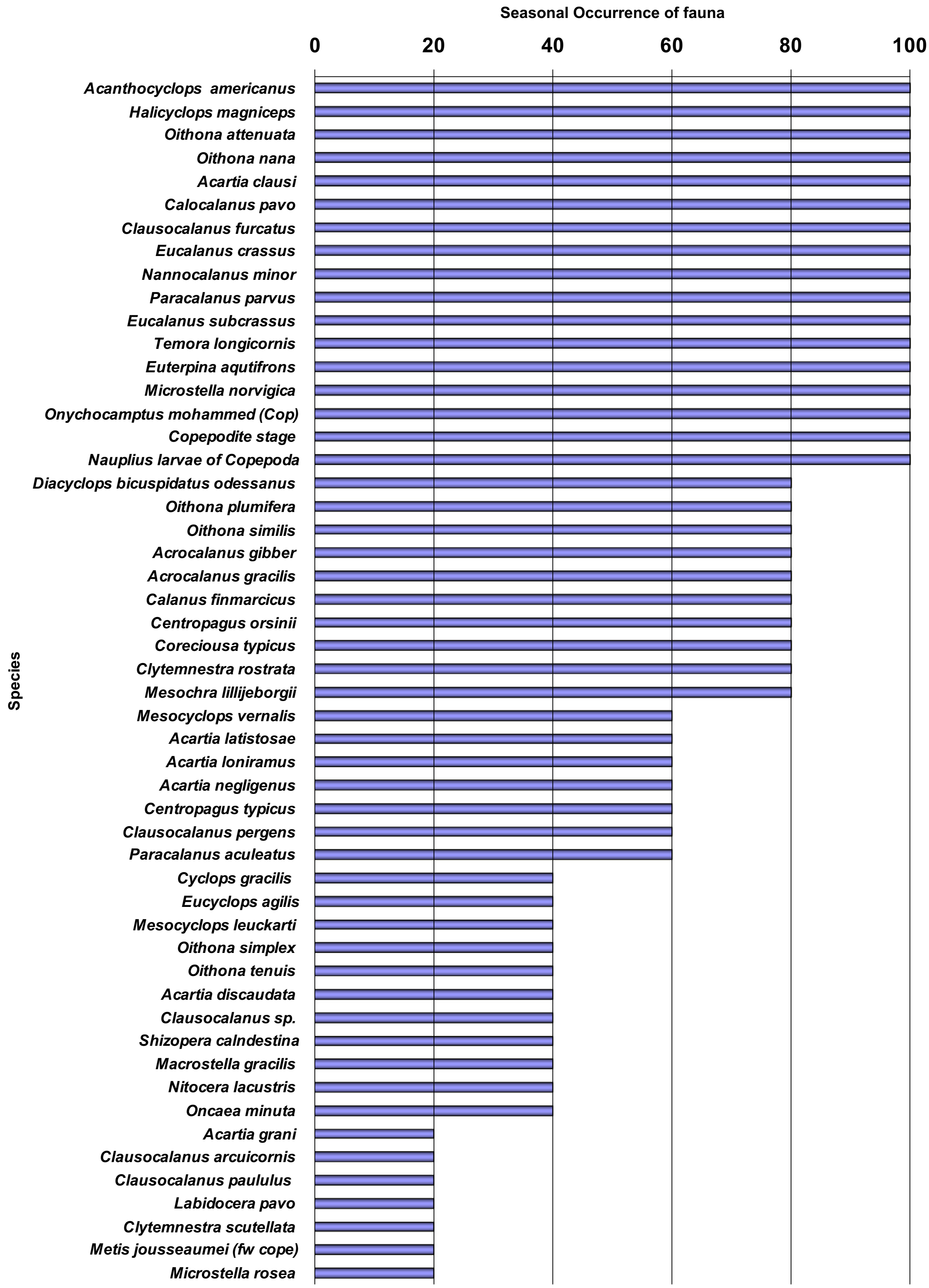

Figure 11 Histogram showing the frequency of occurrence of Copepoda during different seasons.

of Chl-a content recorded in water coincides with low salinity, high temperature and high values of nutrient salts. That reflects the eutrophication condition that is caused by drainage of effluents. These data agreed with those obtained by El-Sherif (2006) and Hendy (2013) where Chl-a ranged from 9.4 to 21.3 µg/l. Gharib (1998) observed that the phytoplankton abundance and the number of species increased consistently toward the outer region of the El-Mex Bay, where the salinity was high.

All copepod organisms observed in El-Mex waters were eurythermic and euryhaline forms living under a range of

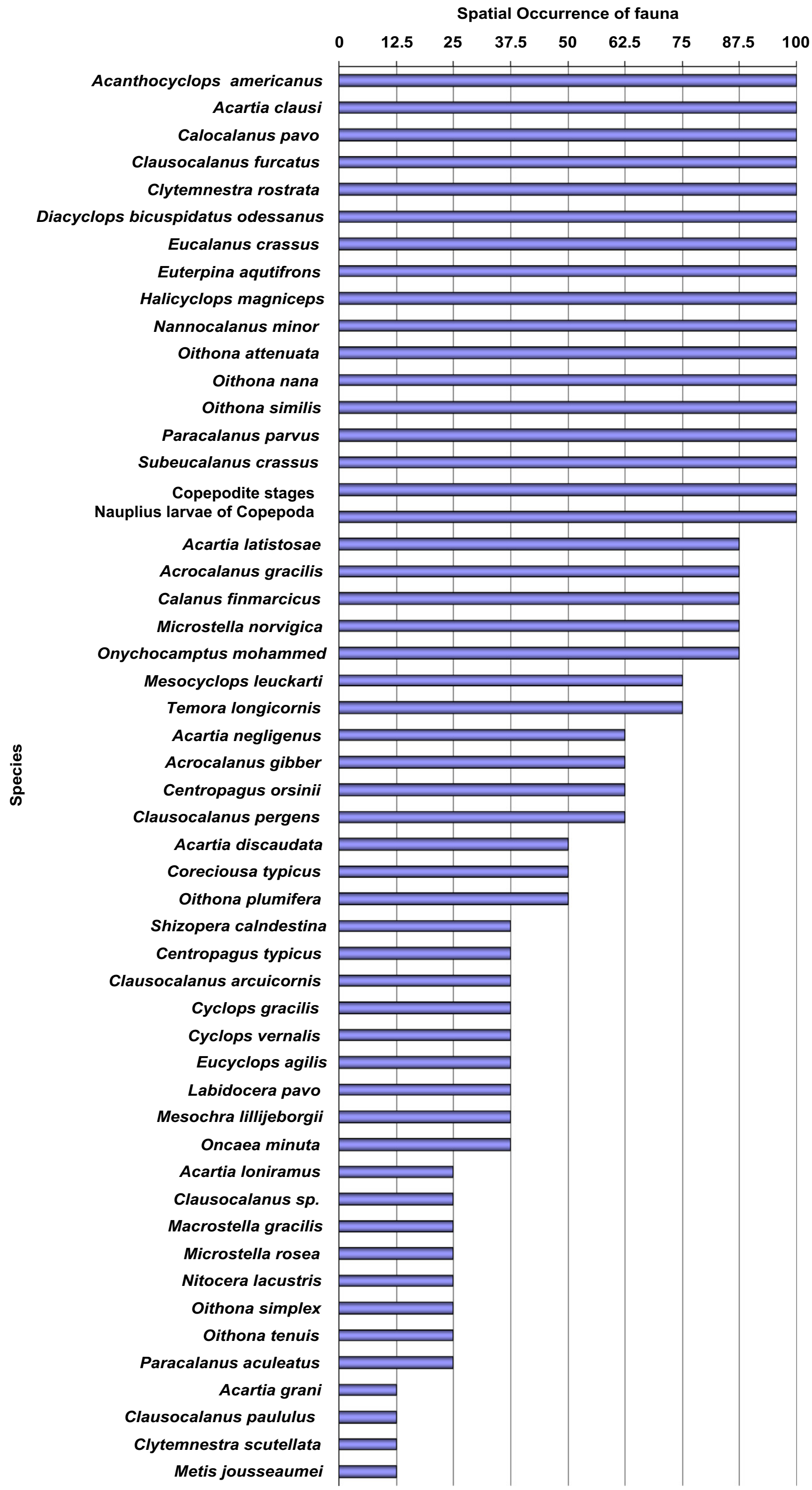

Figure 12 Histogram showing the frequency of occurrence of Copepoda at different stations.

water temperatures between 14.39 and 30.68 °C with water salinity between 10.82‰ and 28.53‰. The highest seasonal abundance of total copepods was in autumn 2012 where total individual number was 99,878 and 12,485 organisms/m^3 with 31 species where water temperature was between 16 and 18 °C and salinity reached its maximum of 25.03–33.50‰.

Planktonic Copepod larvae and copepodite stages formed the main bulk being 36.7% of the total copepods in the El-Mex Bay contributing an average of 1866 organisms/m^3. This is in agreement with Dowidar and El-Maghraby (1970a,b, 1973), Hussein (1977), Samaan et al. (1983). Copepoda was represented by 33 species belonging to 22 genera from three orders, Calanoida, Cyclopoida, and Harpacticoida. Most of them were cosmopolitan, neritic temperate and warm water forms (Rose, 1933; Sewell, 1948). Five copepod species were the most dominant and they represented

Table 1 Correlation matrix between the total copepods, different Copepod orders and the environmental parameters.

Seasons	Categories	Parameters											
		Depth (m)	Total dissolved solids TDS (g/l)	Temperature (°C)	pH	Conductivity (mS)	Salinity (‰)	chlorophyll-*a* (μg/l)	Total Copepoda	NO_2(μM)	Larvae and copepodite stages	Harpacticoida	Poecilostomatoida
Autumn 2011	Total Copepoda	−0.87											
	Cyclopoida								0.70				
	Harpacticoida						−0.72						
	Larvae and copepodite stages	−0.82							0.87				
Winter 2012	Cyclopoida				−0.69	−0.73				0.74			
	Calanoida								0.94		0.76		
	Larvae and copepodite stages								0.92				
Spring 2012	Total Copepoda	−0.76											
	Cyclopoida			0.68									
	Calanoida								0.87			0.82	
	Harpacticoida	−0.79							0.70				
	Larvae and copepodite stages	−0.69						−0.91	0.89				
Summer 2012	Total Copepoda		−0.71										
	Cyclopoida								0.83				
	Calanoida		−0.67					−0.75	0.68				
	Harpacticoida								0.78		0.79		
	Larvae and copepodite stages		−0.69						0.68				
‘Autumn 2012	Total Copepoda	−0.69		0.86									
	Cyclopoida			0.68					0.91	−0.75			
	Calanoida									−0.85			
	Harpacticoida		−0.73			−0.72							−0.75
	Larvae and copepodite stages	−0.72		0.80	0.69				0.76				

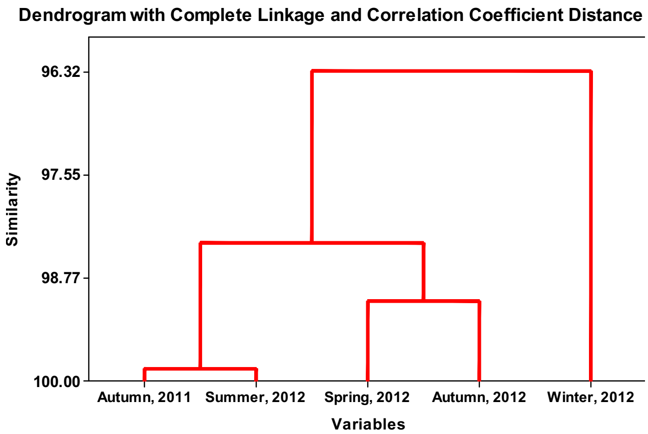

Figure 13 Dendrogram showing the similarity between different studied stations according to correlation coefficient and complete linkage.

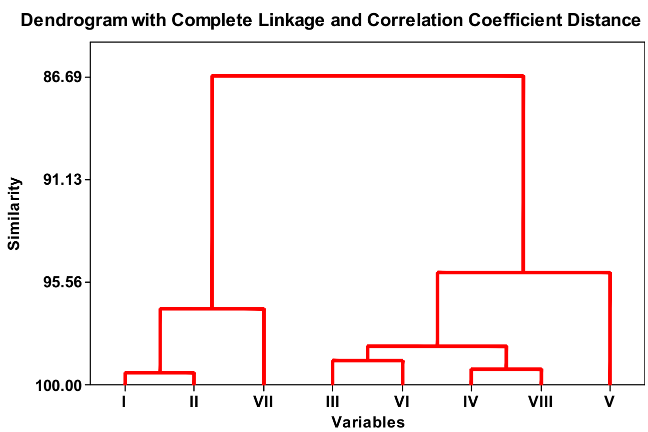

Figure 14 Dendrogram showing the similarity between different investigation seasons according to correlation coefficient and complete linkage.

collectively 44% of the total copepod counts. The first most dominant one was *O. nana* which comprised 16% with total numbers being 31,875 individuals and an average of 839 organisms/m^3, followed by *E. subcrassus* 11% and with a total count of 21,997 individuals (917 organisms/m^3). *P. parvus* and *E. crassus* ranked as the third most dominant copepod species with total counts being 13,161 and 11,463 individuals and average numbers were 252 and 425 organisms/m^3 respectively, each of the two species represented 6% of the total copepod counts on its own. *E. acutifrons* ranked the fifth dominant copepod species in the El-Mex Bay and formed 5% of total copepod counts with a total of 10,154 individuals and 308 organisms/m^3. They were previously recorded as dominant species along the Mediterranean coasts by Dowidar and El-Maghraby (1970a,b) and Nour El-Din (1987). The high count at station 4 (average 16,573 organisms/m^3) was due to the increased number of *O. nana*, *Euterpina acutifrons*, and *P. parvus* which flourished at temperatures between 19.8 and 28.0 °C and salinity of 20.0–28.89 ppt. Similar observations were found in the Egyptian Mediterranean coast (Dowidar and El-Maghraby 1970a,b; Hussein 1977; Samaan et al.,1983; Nour El-Din 1987; Hussein, 1997).

Mahmoud et al. (2009) and Zakaria et al. (2007) stated that based on salinity, the El-Mex Bay was occupied by four water types, they were the mixed land drainage (L) water type that occurred near the El-Umum Drain outlet (Salinity < 10 ppt), the mixed water (M) occupied the southern half of the bay (Salinity 10–30 ppt), the diluted seawater (D) type reported at the northern part (Salinity 30–38.5 ppt), and the Mediterranean Sea water (S) reported at the western part (Salinity > 38.5 ppt). Zakaria et al. (2007) found the influence of salinity variations on the zooplankton community in the El-Mex Bay and stated that copepod in the water type (M) was the third important group after Rotifer and Protozoa, it constituted about 13.45% to the total zooplankton counts. In water type (D), Copepoda and their larval stages were the most dominant zooplankton groups, where they constituted 51% to the total zooplankton. Also in the Mediterranean water type (S), Copepoda and their larvae were the most dominant zooplankton group, they formed 49.5% of the total zooplankton. *O. nana*, *A. clausi* and *P. parvus* dominated the copepod population. This being in agreement with the results of the present study which showed that copepods constituted 57% of the total zooplankton counts and formed the most prevailing group in the El-Mex Bay.

El-Sherif (2006) found that Copepoda was represented in the study area by 22 species, only one of them (*A. americanus*) belongs to the freshwater form. Other recorded species, *A. clausi*, *A. latisetosa*, *P. parvus*, *O. nana* and *E. acutifrons* are eurythermal and euryhaline species. They are common in the near shore waters west of Alexandria (Hussein, 1997; Abdel Aziz, 2002).

Conclusions

El-Mex Bay is located under stressful conditions due to the discharge of untreated domestic, industrial and agricultural effluents, and also due to the effect of ships' movements to and from the harbors. Therefore, the conditions in this bay are eutrophic and completely different from the open sea water.

El-Mex Bay is regarded among the eutrophic marine habitats on account of the magnitude of the standing crop of copepod that reach an annual average of 5083 organisms/m^3. The copepod populations appeared to be highly diversified with increasing temperature and salinity. Great fluctuations in the quantitative and qualitative composition of copepods in different stations over the seasons were mainly due to several environmental factors, which vary in different seasons and regions. This kind of cyclic change in the species composition of copepods was a characteristic feature of the Alexandrian coastal area. The results showed that the area is lightly to moderately polluted. The results also emphasized the need to use the copepod community as an index of water quality. Accordingly, it is recommended that the waste water should be treated and/ or recycled before discharge into this naturally aquatic body.

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