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Zooplankton composition and distribution in a stressed environment (El Dekhaila Harbour), South-Eastern Mediterranean Sea, Egypt

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Abstract

This study focused on the spatial and temporal distribution, composition and abundance of zooplankton in El Dekhaila Harbour. Zooplankton samples were carried out seasonally during 2012 on nine sampling stations. Zooplankton diversity and physico-chemical parameters were studied to adjudge the health and potential threats of the harbour waters. Copepods represented the dominant component (46.45% of the total community), followed by Protozoa (28.95%) while other groups collectively formed about 24.6% of the total zooplankton population. Winter was the most productive season. Zooplankton community comprised 75 species and diversity index was found to be quite high. The uniformity of zooplankton composition clearly appeared in the different stations, especially evident in the two dominant groups; Copepoda and Protozoa, where relative importance of the individual species showed characteristic high ranking of *Oithona nana* and *Schmidingerella serrata*. Protozoa was the richest group having 31 species followed by Copepoda (19). Shannon diversity index, Pielou evenness and species richness were used to describe temporal variations of zooplankton diversity. Zooplankton numerical variability primarily responded to seasonal variation in water temperature, but no obvious effect of salinity on zooplankton abundance. The results discriminated perturbed by anthropogenic inputs (polluted), had high chlorophyll *a* levels, high nutrient concentrations and low zooplankton abundance signifies towards eutrophic condition.

Keywords: Zooplankton, Physico-chemical parameters, Diversity index.

Introduction

El-Mex Bay is a relatively large coastal embayment west of Alexandria, at longitude 29° 45‛ and 29° 54‛ E and latitude 31° 07‛ and 31° 15‛ N, with an average depth of about 10 m and surface area of about 19.4 km^2 (El-Sherif, 2006). The bay occupies the south-eastern corner of the Mediterranean. It is an important fishery ground as well as recreation area. It includes both the Western Harbour and El-Dekhaila Harbour. The bay is one of heavily polluted areas on the Egyptian Mediterranean coast, receiving huge amount of agricultural, industrial, and sewage wastes from adjacent Lake Mariut through El-Umoum Drain. According to different estimations, the bay receives about 2.547 x 10^9 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 x 10^6 m^3 y^{-1} via E l- Umum Drain Halim et al. (1995). The rate of dispersion of pollutants in such waters makes the systems highly variable, where changes influences induce high temporal variability on scales ranging from hours to seasons (Walsh, 1988). This variability may be reflected in the dynamics of the zooplankton thriving in these areas. The residence time of El-Mex Bay water was found to be around 28 days (Halim et al. (1995).

Abo-Taleb et al. (2015) studied the water quality of El-Mex Bay and found that the water salinity in the bay fluctuated between a minimum of 6.2 PSU in front of El-Umoum Drain and a maximum of 33.5 PSU. The pH values fluctuated between 4.51 and 8.01; while dissolved oxygen ranged between 2.52 and 9.11 mg l^1. As for concentration of nutrient salts it ranged between 0.23-15.17; 0.11 -20.09 µg.l^{-1} for nitrite and nitrate, respectively. The mean concentration of phosphorus ranged between 0.84 and 3.34 µg.l^{-1} (Okbah and Tayel, 1999; Said et al., 1991), while Abo-Taleb et al. (2015) registered high values of 9.09 and 10.14 µg.l^{-1} in front of El-Umoum Drain. On the other hand, Chlorophyll *a* reached 34.38 and 29.92 µg/L in summer and autumn 2012 (Abo-Taleb et al. (2015).

El Dekheila Harbour is located in the western side of El-Mex Bay and is one of the commercial harbours in Egypt. It is a semi-enclosed basin constructed recently, after 1986, and it occupies the western part of El- Mex Bay (Figure 1). Its water depth ranges between 6 and 19 m with an average of 12.4 m. The harbour's water is subjected to several sources of wastewaters coming from El-Mex Bay through El-Umoum drain (Abdalla et al. (1995) and Fahmy et al. (1997). The marine environment in the harbour is affected largely by anthropogenic factors, which cause alternate inhibition and promotion of the plankton growth (Abdel-Aziz, 2001 and Ismael and Dorgham, 2003).

Numerous studies have been carried out on the physical, chemical (Fahmy et al. (2004); Abo-Taleb et al. (2015); Shaltout and Abd-El-Khalek, 2014) and biological characteristics of El-Mex Bay and El Dekheila Harbour (Aboul Ezz et al. (2014); Abdel-Aziz and Dorgham 2001; Abdel-Salam and Ramadan, 2008; Zakaria et al. (2007); Ismael and Abdel-Aziz, 2003).

The main aim of this study is to assess the diversity, abundance, community composition and seasonal and spatial distribution of zooplankton in El Dekheila Harbour situated in a hot spot area subjected to various kinds of discharged waters, and to address the main environmental factors which have influenced their community structure. Data are compared with previous results obtained in other Egyptian Mediterranean harbours.

Materials and Methods

Study area

El-Mex bay is a semi-enclosed basin subjected to several sources of wastewaters discharged into the bay through El-Umoum drain (Abdalla et al. (1995) and Fahmy et al. (1997). El-Dekhaila Harbour occupies the western side of El-Mex Bay (Figure 1) is a commercial harbour constructed recently, after 1986, for the export of manufactured iron and steel and the import of coal. It also plays an important role in the export and import of other goods such as minerals, ores, fertilizers, salts and grain. In addition, maritime activities, the loading and unloading of unpacked grains and fertilizers on to and from ships, are a cause of direct pollution in the harbour (Abdel-Aziz, 2001). El-Dekhaila Harbour, like other harbours, is also affected by shipping activities. The degree of water contamination of the harbour water from the wastewaters depends on water circulation in the bay. The marine environment in the harbour is affected largely by anthropogenic factors, which cause alternate inhibition and promotion of the plankton growth (Abdel-Aziz, 2001 and Ismael and Dorgham, 2003). The harbour has a surface area of about 12.5 km2 and a water depth ranging from 4 to 20 m with an average of 12.4 m.

Methods

Water samples were collected four times per the year 2012, the chosen periods corresponding to winter (January), spring (April), summer (August) and autumn (November). The samples were collected at a depth of 0.5 m at the studied stations. A simple mercury thermometer was used to measure water temperature. Salinity was measured using a Beckman induction salinometer (Model RS-7B).

The zooplankton samples were collected by filtering 50 liters of the harbour water through a small standard plankton net (mesh size 55 µm) using a plastic container of liters capacity. The collected samples were preserved directly with 4% neutral formalin solution in 250 ml polyethylene bottles. The volume of each sample was concentrated to 100 ml and the whole sample was examined in a Petri dish under a research binocular microscope. For zooplankton enumeration purposes, at least two aliquots (2 ml of well shaken suspension) were withdrawn from each sample using a graduated pipette, placed in a counting chamber and the number of individuals of each species was counted. The average number of duplicate examination for each sample was estimated and the counts were expressed as number of individuals per cubic meter.

Statistical analysis

Three indices were used to obtain the estimation of species diversity (Shannon and Weaver 1963), species richness (Margalef, 1978) and species evenness (Pielou, 1975). The Pearson's Correlation Coefficient (r) was used for the simple relationship analyses with the variables (N=36) with SPSS 8.0 Statistical Package Program.

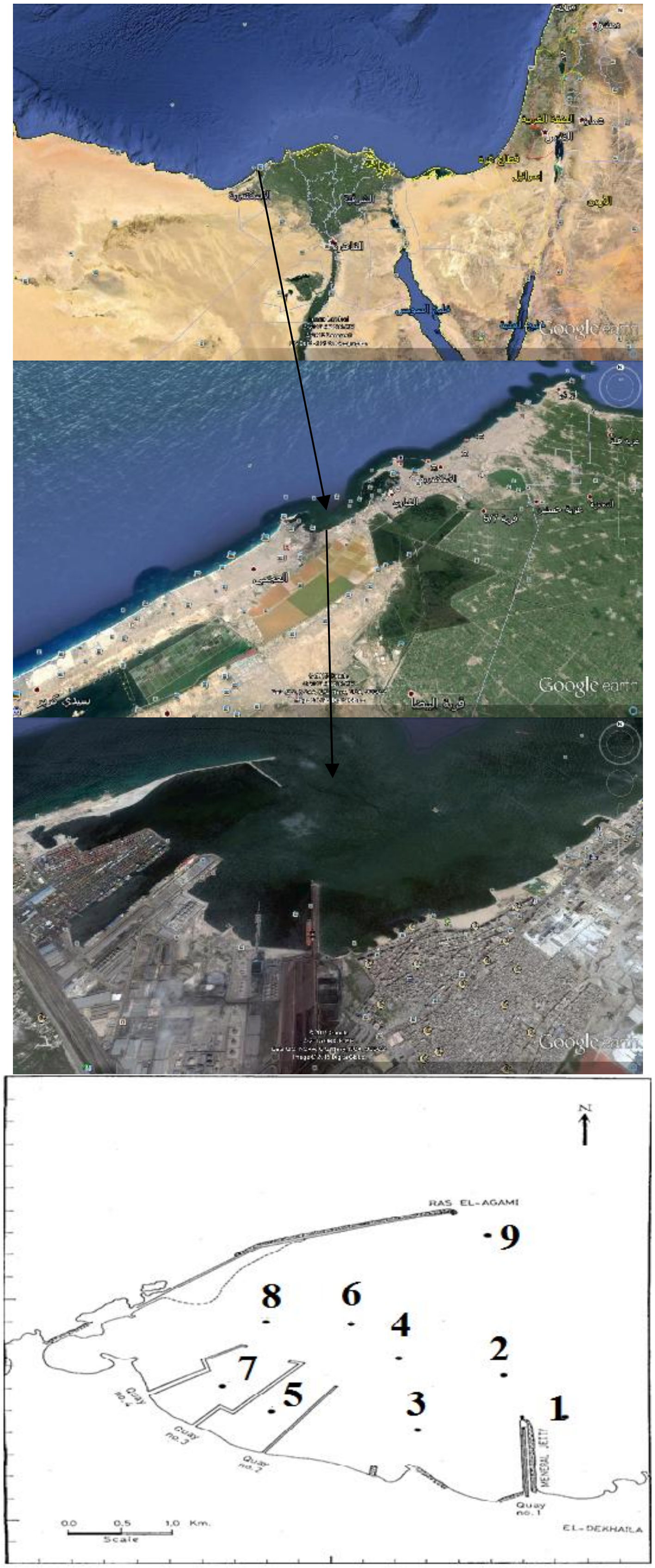

Figure 1. El-Dekhaila Harbour occupies the western side of El-Mex Bay

Results

Hydrographic conditions:

The measured physicochemical parameters were published by Shaltout and Abd-El-Khalek , 2014.

Surface water temperature in El Dekheila Harbour varied from a minimum of 16.19°C in winter to a maximum of 28.66°C in summer, but it mostly recorded negligible thermal difference among the sampling stations (0.44-1.88°C). The surface salinity fluctuated between 28.89 and 35.58 PSU with an average annual of 33.90±1.77 PSU. Lowest values were recorded at station 6 (32.49±2.42) and highest at station 3 (34.92±1.26). The seasonally average salinity showed significantly lower values than those usually recorded in Egyptian coastal waters (>38 PSU).

Zooplankton community structure and composition

A total of 75 species of zooplankton and their different developmental stages in addition to the larvae of some zooplankton groups were recorded in El Dekheila Harbour. The adult forms of zooplankters belong to two major groups namely: Protozoa; the protozoan community comprised 31 species: tintinnids (17species), non-tintinnid ciliates (2 species) foraminiferans (11 species) and amoebozoans (one species), and copepods represented by nineteen species, belonging to four orders, out of which six species were from both of calanoida and harpacticoida. The order poicilostomatoida and cyclopoida were represented only by 3 and 2 species, respectively. Besides eight minor groups: Decapoda, Ostracoda, Rotifera, Cladocera, Amphipoda, Mollusca , Annelida and Cnidaria. (Figure. 2).

In spite of the large number of species, only 21 were perennial: *Branchioecetes* sp., *Schmidingerella serrata* (Möbius, 1887) Agatha and Strüder-Kypke, 2012, *Tintinnopsis beroidea* Stein, 1867, *Tintinnopsis compressa* Daday, 1887, *Tintinnopsis cylindrica* Daday, 1887, *Cycloforina contorta* (d'Orbigny, 1839), *Globorotalia truncatulinoides* (d'Orbigny, 1839), *Acartia clausi* Giesbrecht, 1889, *Acartia grani* Sars, 1904, *Acartia latisetosa* (Kritchagin, 1873), *Centropages kroyeri* Giesbrecht, 1893, *Canthocamptus gracilis* Sars , 1863, *Euterpina acutifrons* (Dana, 1847), *Onychocamptus mohammed* (Blanchard & Richard, 1891), *Oithona nana* Giesbrecht, 1893, *Oithona plumifera* Baird, 1843, *Ergasilus sieboldi* Nordmann, 1832, *Oncaea venusta* Philippi, 1843, *Cypridina mediterranea* Costa, 1845, *Moina micrura* KURZ, 1874 and *Obelia* sp.

Table (1): Mean relative abundance of total zooplankton components (ind.m^3) in El Dekhaila Harbour during 2012

Taxa	Mean relative abundance (ind.m^3)	%
Copepod	602	46.41
Protozoa	376	28.99
Decapoda	55	4.24
Ostracoda	27	2.08
Cirripedia	42	3.24
Cladocera	42	3.24
Amphipoda	18	1.39
Mollusca	16	1.23
Nematode	8	0.62
Annelid	46	3.55
Rotifer	27	2.08
Cnidaria	21	1.62
Fish Larvae	17	1.31
Total	1297	100.00

The annual average zooplankton abundance was 1297 ind.m^{-3}, with highest density (1657 ind. m^{-3}) recorded at station 7, and lowest (953 ind. m^{-3}) recorded at station 4, where copepods were by far the predominant component made up 46.45% of the total zooplankton population. Copepoda Calanoida presented 18.72 % of the total abundance, cyclopoida 34.92%, harpacticoida 22.37% and poicilostomatoida 10.56% of total copepods. Their larval stages (nauplii and copepodites) respectively, made up 13.44 and 6.24%

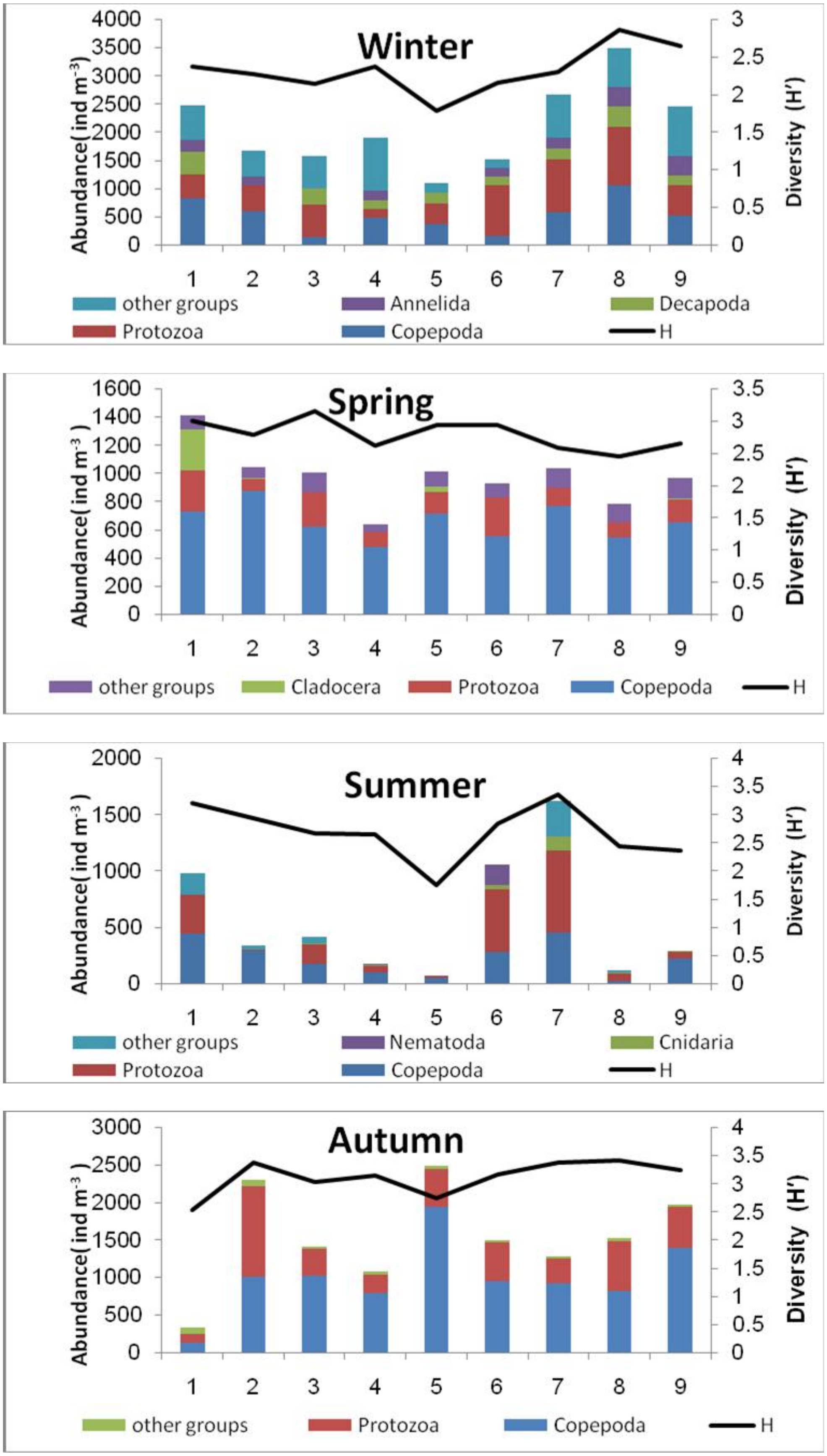

Fig. 2 Distribution of zooplankton density and Shannon-Wiener diversity (H') in Western Harbour.

of the total copepods and total zooplankton. The highest copepod densities were observed at station 5 (768 ind. m^{-3}) and lowest (462 ind. m^{-3}) at station 4. *Oithona nana* was the most dominant copepod species (30.89 and 14.35% of the total copepods and total zooplankton, respectively). Other species as: *Euterpina acutifrons*, *Microsetella rosea*, *Onychocamptus mohammed*, *Oithona plumifera* and *Corycella carinata* were frequently recorded (about 4% of the total copepods).

Protozoa formed the second most important group, comprising about 28.95% of the total zooplankton count with an annual average of 376 ind.m^{-3}. Protozoans were mostly represented by tintinnids, forming 69.0% and 20.0% of the total protozoans and total zooplankton, respectively. Foraminifera second in importance constituted 14.16 and 4.10% of the total protozoans and total zooplankton, respectively. Non tintinnids and Amoebozoa formed respectively, 8.97, 2.6% and 7.88, 2.28% of the total protozoans and total zooplankton. The highest Protozoan densities were observed at station 7 (539 ind. m^{-3}) and lowest (144 ind. m^{-3}) at station 4. *Schmidingerella serrata* was the most dominant species forming 33.01% and 9.56% of the total protozoans and total zooplankton, respectively. Although rotifers were represented by 7 species, collectively they formed only about 2.11% of the total zooplankton.

Decapoda came in the third position (4.23%) and showed higher percentage at station 1 (8.17%) and station 3 (6.51%), decreased to reach minimal at station 2 (0.15%), and was represented by *Porcellana platycheles* (Pennant, 1777) and Mysis stages of Decapoda. Annelida contributed as little as 3.53% of the total count.

Zooplankton samples collected at station 7 were richer in species (70 species) than those collected at stations 2 and 6 (58 species) and station 1 (55 species). Approximately similar numbers of species (51—53 species) were recorded at stations 3, 4, 8 and 9, while a conspicuously smaller number (48) was found at station 5. Greatest taxon richness was recorded in summer (68) and lowest number was recorded in winter (42).

As a result, Shannon index of diversity (H‛) values generally increased in parallel to the number of species throughout the study period. The highest diversity (H‛ =3.42 bits) was observed in autumn at station 8, while the lowest (H‛ =1.75 bits) was recorded in summer at station 5. The overall mean were 2.324±0.302 (winter), 2.796±0.234 (spring), 2.687±0.482 (summer), 3.118±0.307 (autumn). Diversity index values were generally higher during autumn with parallel lower values of dominance at all stations. Station 7 attained higher values than those of the other stations. Species evenness (J) was high and quite homogeneous varied between 0.864± 0.050 in autumn and 0.986 ±0.012 in winter, with relatively higher values generally sporadically recorded, indicating a reduction in the degree of dominance.

On the other hand, diversity and richness followed the same trend at most stations. High diversity was associated with high richness. Evenness showed a different trend, decreasing with increasing diversity and richness. The increase in richness was associated with increasing salinity ($r=0.398$, $p < 0.05$). Higher values of diversity and richness indices occurred at station 7, whereas highest evenness at station 1.

The correlations of zooplankton abundance with species diversity indices were insignificant ($r = 0.165$, $p = 0.337$). Changes in species diversity were greatest across regions, and smallest on seasonal scales, in contrast to abundance patterns, suggesting that zooplankton diversity may be a more sensitive indicator of ecosystem response to regional variation and to less extent zooplankton abundance. This appeared from the insignificant correlation between the abundance of total zooplankton and number of species ($r = 0.090$, $p = 0.601$).

Seasonal variations of the zooplankton standing crop

Total zooplankton abundance was highly variable within the study period, ranging between 68 and 3504 ind. m^{-3}, with an average of 1297±804 ind.m^{-3}. The highest value was recorded in winter at station 8, and the lowest was recorded in summer at station 5.

Zooplankton flourishes during winter to reach an average of 2098 ± 743 ind. m^{-3}. The density fluctuated between 1099 ind. m^{-3} (station 5) and 3504 ind. m^{-3} (station 8). The community was dominated by protozoans (28.64%). *Schmidingerella serrata* formed 46.98% of the total Protozoa and 13.45% of the total zooplankton. Copepods were the second most abundant group making up 25.01% of the total zooplankton count. They were dominant by *Oithona nana* (36.93% and 9.24% of the total copepods and total zooplankton, respectively). Other species as *Acartia latisetosa* from Calanoida and *Canthocamptus gracilis*, *Onychocamptus mohammed* from

Harpacticoida represented about 4% of the total copepods for each. Copepod juveniles (nauplii and copepodids) formed 25.63 and 6.41% of the total copepods and total zooplankton, respectively. Decapoda third in importance (10.12%) in which Porcellana platycheles (Pennant, 1777) and Mysis stages of Decapoda were the only present. Annelida and Cirripedia constituted 8.27 and 6.33% of the total, respectively. Winter was the most productive season for rotifers, represented 4.34% of the total zooplankton and represented mainly by *Synchaeta pectinata* Ehrenberg, 1832, *Synchaeta okai Sudzuki*, 1964, *Keratella hiemalis* Carlin, 1943.

In spring, the zooplankton standing crop dropped to reach an average of 982 ±212 ind. m^{-3}. It showed high fluctuation between 638 ind. m^{-3} (station 4) and 1416 ind. m^{-3} (station 1). The contribution of copepods to the total zooplankton has been represented by 67.3%, in which nauplius larvae and copepodite stages formed 11.81% of the total copepods. Moreover, the dominant adult species was the cyclopoid *Oithona nana* (26.06% of the total copepods). Other species as Paracalanus parvus (Claus, 1863) (9.82%) from Calanoida, *Onychocamptus mohammed* (8.13%) from Harpacticoid and *Corycella carinata* (Giesbrecht, 1891) (7.81%) from Poecilostomatoida were presented with 8-10% of the total copepods. Cladocera appeared at station 1 with 292 ind. m^{-3}.

The zooplankton standing crop was the smallest during summer (average: 562 ± 537 ind. m^{-3}) ranging between 68 ind. m^{-3} (station 5) and 1630 ind. m^{-3} (station 7). Copepoda and Protozoa had the similar values (40.0% of the total zooplankton). *Schmidingerella serrata* (29.58 and 11.92% to Protozoa and total zooplankton, respectively) and *Oithona nana* (27.56 and 11.00% to copepods and total zooplankton, respectively) were the most dominant species. Nematoda and Cnidaria making up about 4% of the total zooplankton count and were represented by nematod larvae and *Obelia* sp., *Ectopleura dumortieri* (van Beneden, 1844) and *Phialidium hemisphaericum* (Linnaeus, 1767).

In autumn, the zooplankton crop was larger than the last two seasons (average: 1546 ± 655 ind. m^{-3}). The density ranged between 330 ind. m^{-3} (station 1) and 2495 ind. m^{-3} (station 5). It was the most productive season for copepodans, represented 64.67% of the total zooplankton. Moreover, the dominant adult species was *Oithona nana* (31.65% of the total copepods and 20.47% of the total zooplankton), with a decrease of their larval stages (7.85% to the total group). Protozoans were the second most abundant group making up 32.40% of the total zooplankton count, *Schmidingerella serrata* was leading with 20.17% to the total group and 6.54% to the total zooplankton. The other groups either disappeared or rarely represented.

Correlation analysis

The statistical relationships were performed between different environmental variables, phytoplankton biomass and zooplankton abundance and dominant groups.

Total zooplankton abundance was correlated neither with water salinity nor with Chl *a*. Zooplankton was negative correlated with water temperature ($r=-0.607$, $p<0.001$). With regard to the different zooplankton groups, temperature was negatively correlated with Protozoa ($r =- 0.341$, $p<0.05$) especially *Schmidingerella serrata* ($r=-0.570$, $p<0.001$). Other significant correlations with temperature were also found for Decapoda ($r=-0.659$, $p<0.001$), Ostracoda ($r=-0.659$, $p<0.001$), with Annelida ($r=-0.577$, $p<0.001$) and with Rotifera ($r=-0.434$, $p<0.05$). Copepoda did not show any clear relationship with either temperature or Chl *a*.

The environmental variables that positive correlated with the zooplankton patterns were NO_3 and NO_2 ($r = 0.607$, $p < 0.001$ and $r = 0.379$, $p < 0.05$, respectively), and the negative correlated were pH ($r = -0.383$, $p < 0.05$). The dominant group Copepoda performed significant negative relationship with pH ($r = -0.349$, $p < 0.05$) and a strong positive correlations with total dissolved nitrogen; NH_4 ($r = 0.471$, $p < 0.05$); NO_3 ($r = 0.565$, $p < 0.001$); NO_2 ($r = 0.554$, $p < 0.001$). While Protozoa performed significant negative relationship with temperature ($r = -0.341$, $p<0.05$) and positive with NO_3 ($r = 0.520$, $p < 0.05$) and NO_2 ($r = 0.338$, $p < 0.05$). Salinity has not been proved as an influencing parameter for zooplankton population and their dominant groups. No significant correlation was observed between zooplankton population density and other environmental variables.

Discussion

Water temperature in the harbour did not deviate from the normal seasonal fluctuations on the southeastern coast of the Mediterranean Sea (16-30°C). The difference in temperatures at different stations (reached 1.88°C in spring) was due to the different times of sampling with stations sampled early in the morning recording lower temperatures. Salinity oscillations in the harbour fluctuated between 28.89 and 36.58 PSU. Comparison between the water qualities of the two harbours located in El Max Bay illustrated that the Western Harbour is more affected by the diluted discharged water than El-Dekhaila Harbour. This is appeared clearly from the lower salinity values and higher concentrations of nutrient salts in the Western Harbour (Heneash et al. (2015) than that recorded in El-Dekhaila Harbour (Shaltout and Abd-El-Khalek, 2014).

Concentrations of chlorophyll *a* varied between 2.4 µg l^{-1} in autumn and 158 µg l^{-1} in spring, with annual average 58 µg l^{-1}. The Mediterranean Sea is generally considered to be a poor productive oligotrophic sea and mean chlorophyll *a* concentration values vary from 0.1 to 0.5 µg l^{-1} indicate moderate phytoplankton development in the water column (Jacques & Tréguer, 1986). These authors state that values of 1.0 – 1.5 µg l^{-1} off-shore, except in some bays and ports where nutritional anthropic inputs may favor the growth of phytoplankton and zooplankton. Although Fahmy et al., 2004 in 1998-99 did not note a significant development of phytoplankton and a risk of eutrophication, their values of Chlorophyll *a* in El Dekhaila Harbour (average 107 µg l^{-1}) were much higher than recorded in the present study (58 µg l^{-1}) by Shaltout and Abd-El-Khalek, 2014.

Except of the autumn period which dissolved oxygen averaged 2.65 mg l^{-1}, the harbour water was well oxygenated all the year round and no anoxic phenomenon was observed. Peak O_2 concentrations were observed during winter (average 6.66 mg l^{-1}) means that temperature had a direct indication on oxygen solubility ($r=-0.473$, $p<0.05$) and not phytoplankton biomass ($r=0.317$, $p=0.060$). For most zooplankton species 2.3 mg l^{-1} of oxygen is the limiting amount for survival (Dodson, 2005) and the minimum oxygen concentration needed for the survival of copepods (2 mg l^{-1}) (Roman et al., 1993). Thus, this parameter is not the cause of the difference in the zooplankton structure in the studied harbour, whereas, copepods constituted > 60% of the total zooplankton abundance during autumn.

Nutrient concentrations at El Dekhaila Harbour were higher than in other areas along the Egyptian coast. For instance, in the study area, nitrate, nitrite, ammonia, phosphate and silicate concentrations, respectively, varied in the ranges 0.4–14.9; aver.6.54 µM, 0.17–12.50; aver.3.53 µM, 1.7–51.15; aver.15.66 µM, 0.09–17.1, aver.5.77 µM and 10.3–77.3; aver 34.72 µM, as reported by Shaltout and Abd-El-Khalek, 2014. Whereas in the Western Harbour, previous nitrate, nitrite, ammonia, phosphate and silicate concentrations varied in the ranges 2.64–21.97 µM, 0.63–21.18 µM, 2.08–17.25 µM, 0.85–5.93 µM and 4.85–28.95 µM, respectively, (Heneash et al., 2015). The ranges reported as criteria of eutrophication in coastal waters were: 1.15—2 µM for NH_4, 0.53—4 µM for NO_3 (Ignatiades et al., 1992) and >0.15— 0.34 µM for PO_4 (Ignatiades et al., 1992; Marchetti, 1984). According to these values of nutrient salt concentrations, El Dekhaila Harbour could be classified as eutrophic.

To study the relative effect of some environmental factors, correlation analyses were made between zooplankton and other physic-chemical parameters. Zooplankton showed negative and significant correlation with water temperature ($r=-0.607$). This indicated that the decrease in temperature leads to an increase in total zooplankton population. The conditioning effect of temperature on zooplankton groups is documented in large investigations (e.g. Marques et al., 2006). Other observation was recorded by Ismael and Dorgham, 2003 who found a positive correlation between temperature and zooplankton in El-Dekhaila Harbour and illustrated this to the increase of phytoplankton and algae which provide food resources for zooplankton.

Also, zooplankton recorded positive correlation with nitrate and nitrite ($r=0.607$ and 0.379, respectively at $p<0.05$) while it recorded a significant negative correlation with pH ($r=-0.383$, $p<0.05$). Salinity has already been proved as an influencing parameter for zooplankton population (Padmavati and Goswami, 1996; Sridhar et al. (2006) but in the present study, however, no definite correlation was discernible between salinity and zooplankton, but at the group scale, salinity affected negatively with Rotifera ($r=-0.334$, $p<0.05$) and Annelida ($r=-0.551$, $p<0.001$).

The results of present study showed that zooplankton abundances were governed by water temperature, pH, nitrate and nitrite. A long term study in seasonal aspect is needed to understand the effect of other ambient water quality parameters on zooplankton species composition and distribution of El Dekheila Harbour waters. The present study on zooplankton will act as baseline information for future environmental assessment purpose as this kind of studies is meager in this Harbour.

Phytoplankton biomass as Chlorophyll a appears to have had no effect on the abundance of zooplankton during the present study, as abundance did not show a clear seasonal pattern following the phytoplankton bloom. This clearly appear from the insignificant correlation between zooplankton abundance and Chlorophyll *a* ($r=-0.182$, $p= 0.288$) or between other zooplankton groups. In spring, when maximum values of Chlorophyll a were reached, zooplankton abundance was also at maximal (Shaltout and Abd-El-Khalek, 2014).

About 75 zooplanktonic species are reported for El Dekhaila Harbour, including some brackish and freshwater organisms, this value was lower than that recorded by Ismael and Abdel-Aziz, 2003 which amounted to 92 species, this may be due to the previous study done by Ismael and Abdel-Aziz, 2003 during 1998-99 was based on monthly sampling, while the present study was done seasonally, which means lacking of some species on the missed months.

Zooplankton abundance during 1998-99 (Ismael and Abdel-Aziz, 2003) was much high (mean $>100\text{x}10^3$ ind. m^{-3}). While in the present result the value diminished to a mean of 1297 ind.m^{-3}. The differences in the abundance of zooplankton observed in the two periods are thus probably due to ecological factors, such as the low levels of Chlorophyll *a*, and perhaps by predation by fishes or other unknown factors.

In El-Mex Bay, Abou Zaid et al. (2014) registered an average zooplankton abundance amounted to 8918 ind. m^{-3} during the present period 2012. In other inshore Egyptian waters, Nour El-Din (1987) recorded the mean zooplankton abundance during 1970–71 was 3.7×10^3 ind. m^{-3}, and during 1984–85 was 2.0×10^3 ind. m^{-3}, in which Copepoda predominated by approximately 87% of the total zooplankton.

Copepods were the dominant group contributed numerically 46.45% of the total zooplankton counts with an average of 602 ind. m^{-3}. During spring and autumn copepods were the most abundant group, as elsewhere in the Mediterranean Sea (Abou Zaid et al. (2014; Abdel-Aziz and Aboul-Ezz, 2003; Abdel Aziz, 2002; Aboul Ezz et al. (2014); Vidjak et al. (2012) and their percentages were >65% of total zooplankton. The abundance of copepods steadily increased during spring with rising trend of Chlorophyll *a*.

Oithona nana emerged as the most successfully adapted copepod species at both seasonal and spatial scales (30.89 and 14.35% of the total copepods and total zooplankton, respectively). This is because it has the ability to consume a much wider range of food than the other copepods (Lampitt and Gamble, 1982) and have a low metabolic rate, suggesting that these adaptations constitute the strategy whereby *O. nana* maintains its population levels throughout the year. The species is very important in many neritic regions that are exposed to eutrophication (Richard and Jamet, 2001). Yamazi, 1956, 1964 and Gaudy, 1971 reported that this cyclopedia also occurs in brackish and polluted waters, and it is so, consider as an euryhaline species with a wide ecological tolerance (Lampitt & Gamble, 1982; Johan et al. (2002). Interestingly, most of the studies in the Mediterranean report a maximum abundance of the genus *Oithona* in the winter and beginning of spring (Vives, 1966; Seguin, 1981; Gaudy, 1984).

The average abundances of *Oithona nana* ranked first among adult copepods in winter (36.93%), spring (26.06%), summer (27.56%) and autumn (31.65%). One of the characteristic features of the present observation was the relatively low occurrence of copepod nauplii (10.51% of the total zooplankton) which could be attributed to low density of older stage copepods (Uye et al. (2000).

Protozoa (Amoebozoa, Foraminifera, non-tintinnid ciliates and tintinnids) was the highest species richness (31 spp.); meanwhile, they occupied the second group of abundance after copepods, forming 28.95% of the total count. It was the dominant group during winter and summer, forming, respectively, 28.64 and 40.28% of the total zooplankton counts. Tintinnids were the richness order (17 spp.) constituting 69.0 and 20.0% of the total protozoans and total zooplankton counts, respectively. *Schmidingerella serrata* was the dominant species forming 33.01 and 9.56% of the total Protozoa and total zooplankton abundance. Abdel-Aziz, 2000) recorded *Schmidingerella serrata* and *Tintinnopsis lata* as the dominant tintinnids in Dekhaila Harbour. *Schmidingerella serrata* showed a negative correlations with both water temperature and water salinity ($r=-0.570$, $p<0.001$ and $r=-0.342$, $p<0.05$, respectively), which means that it is very sensitive to salinity variations.

In other coastal waters of similar conditions like Abu Qir Bay and Western Harbour, tintinnids formed 27.8% and 35.2% of total zooplankton, respectively, with the dominance of *Favella markuzowskii*, *Stenosemella nivalis*, in Abu Qir Bay (Abdel-Aziz, 2001) and *Schmidingerella serrata* in the Western Harbour (Heneash et al. (2015). Tintinnids richness in Dekhaila Harbour is apparently higher than those of other inshore areas of the Egyptian Mediterranean coasts, where 13 tintinnid species were recorded by Hussein, 1997 and 6 tintinnids by Soliman (2006).

Rotifera contributed 2.11% (average of 27 ind. m^{-3}; 7 species) to the total zooplankton counts. The frequency of rotifers alongside other organisms during winter (4.34%) could be an indicator to the level of contamination in this season. Aboul Ezz et al. (2014) recorded 38 rotifer species with an average of 1077 ind. m^{-3} (12.1%) in El-Mex Bay during 2012; the same sampling period of this study. El-Shabrawry and Khalifa (2002) mentioned that the presence of rotifers such as *B. calcifloris*, *Polyarthra vulgaris* and *K. cochlearis* are eutrophic indicators, revealed to effect of eutrophication. This eutrophication affects zooplankton composition, shifiting the dominance from large species (Copepoda) to smaller species (Rotifera) (El- Shabrawry, 2000). Rotifers are known to be excellent indicators of organic pollution as they thrive better in organically rich environment. The rarity present of Rotifera and the higher values of water salinity (28.9-36.58 PSU) may be due to the diminish effect of discharged water reached the harbour.

Ostracoda was represented only by *Cypridina mediterranea*. It contributed least to total zooplankton (2.1%). Though this is benthic in nature but become planktonic as disturbances in water which brings them to surface.

The diversity and equitability values should reflect the current environmental conditions. Diversity indicates the degree of complexity of the community structure. It is a function of two elements, one being the number of species (richness), and the other the equitability (evenness) with which individuals are distributed among species (e.g. Omori and Ikeda, 1984). Thus, high values should indicate the presence of "stable" and "pristine" conditions. High diversity values in El Dekhaila Harbour have been recorded in autumn (mean 3.12) and lowest in winter (mean 2.32). The diversity index was low owing to the dominance of just a single or few species. In the present study, the highest species diversity, found in autumn, was attributed to a relatively balanced distribution of abundance among species. The present study found that the diversity and abundance of zooplankton species varied seasonally. Although this study failed to conclusively support this variation with statistical significance, it is believed that other factors were responsible for the noted seasonal variation. Balloch et al. (1976) and Ismael and Dorgham, 2003 advocated that the diversity index (Shannon's) was found to be a suitable indicator for water quality assessment.

General speaking, the water quality was detected and measured using various physical, chemical and biological methods. The biological analysis, i.e. the analysis of zooplankton communities was carried out in support of the interpretation of the results obtained from the physicochemical analysis of the water as well as phytoplankton biomass as Chlorophyll a which were taken at the same time as the zooplankton samples (Shaltout and Abd-El-Khalek, 2014). The monitoring of zooplankton is of great importance because monitoring based solely phytoplankton or physicochemical analysis is sometimes insufficient.

Three classes of water quality were defined for the Shannon–Weaver diversity index by Wilhm (1975), who implied that a high H′ value suggested a rich diversity and therefore a healthier ecosystem (less pollution), whereas a low H′ value suggested poor diversity and thus a less healthy ecosystem (more pollution). In terms of H′ values, the water of El Dekhaila Harbour can be fluctuated between moderately polluted and clean water.

According to Scotto di Carlo and Ianora, 1983; Vasilievich et al. (2003); Kovalev et al. (2003); Estrada et al. (1984), Mediterranean zooplankton is characterized by two abundance maxima: one in late winter or early spring and a second peak in autumn, related to the corresponding phytoplankton maxima, this is agree with the present study which showed a pronounced increase in winter and autumn.

In the study area as a whole, the standing crop of the total zooplankton (average 1297 ind. m^{-3}) is much lower than that recorded by Ismael and Abdel-Aziz, 2003 during 1998-99 at the same area (>100 x 10^3 ind. m^{-3}) and by Aboul Ezz et al., (2014) in El-Max Bay during 2012 (8918 ind. m^{-3}) and by Heneash et al.(2015) during 2012 in the Western Harbour (24 x 103 ind.m-3) and also with earlier data of Hussein, 1977 and Nour El-Din, 1987 in the Egyptian waters of the Eastern Mediterranean (3700 and 2010 ind. m^{-3}, respectively). This may be due to the decreased fresh water influx from El-Umoum Drain which appeared clearly from salinity values that never decreased from 29 PSU and the diminished percentage of freshwater groups, especially Rotifera that constituted 2.11% of the total zooplankton abundance and completely absent during spring. Relatively higher diversity and equitability indices (1.75 - 3.42; average 2.73 and

0.78-1; average 0.91, respectively) and the absence discernible correlation between salinity and zooplankton or other major zooplankton groups, emphasise that water quality in the harbour is in recovery state.

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