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FULL LENGTH ARTICLE

Environmental assessment of El-Mex Bay, Southeastern Mediterranean by using Rotifera as a plankton bio-indicator

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Abstract Rotifers are one of the most common, abundant components of plankton in the coastal waters of the Mediterranean Sea, which means that they can be used as bio-indicators and provide useful information on the long-term dynamics of the El-Mex Bay ecosystem. Rotifera species were quantitatively and qualitatively assessed in the El-Mex Bay, west of Alexandria at eight stations to study spatial, temporal, dominance, and abundance of the rotifer community and their relation with changes in environmental conditions. Samples were collected seasonally from autumn 2011 to autumn 2012. Ecological parameters were determined and correlated with total rotifers abundance to gain information about the forces that structure the rotifer community in this dynamic environment. A total of 38 rotifer species were identified belonging to 16 genera within 12 families and 3 orders under one class and contributed about 12.1% of the total zooplankton in the study area with an average of 1077 specimens/m^3. Maximum density was observed in summer 2012 with an average of 1445 specimens/m^3. During autumn 2011 rotifers appeared in low density (434 specimens/m^3). The predominant species *Ascomorpha saltans*, *Brachionus urceolaris, Synchaeta oblonga, Synchaeta okai, Synchaeta pectinata* and *Synchaeta tremula* were recorded in all study stations of the bay. Salinity, temperature, depth, and chlorophyll-*a* concentration were the most important environmental factors co-related with the abundance of rotifers in the El-Mex Bay. A significant positive

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correlation between the total rotifer abundance and chlorophyll-*a* was observed during winter 2012 and summer 2012 ($r = 0.763$ and $r = 0.694$, respectively, at $p \leqslant 0.05$).

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Introduction

Zooplankton species succession and spatial distribution result from differences in ecological tolerance to abiotic and biotic environmental factors (Marneffe et al., 1998). According to Rocha et al. (1997), to understand such changes and its impact on natural systems, some knowledge of the structure of the community and of the main processes involved in nutrient cycling and production is required.

Rotifers are important components of planktonic communities because of their rapid heterogenetic reproduction. They are the first metazooplankters to cause an impact by grazing on the phytoplankton. Furthermore, rotifers influence various interactions within the microbial food-web which occurs at several trophic levels (Arndt, 1993). Rotifers are microscopic herbivores, common in the plankton of freshwater habitats, which feed on single-celled algae and bacteria. Where food is abundant, they may exceed 5000 per liter of water (Wallace and Snell, 1991). Their abundance reflects eutrophication; for example, *Keratella cochlearis* and *Kellicottia quadrata* increase with an enhanced input of phosphorous (Edmondson and Litt, 1982).

In Egypt, after the construction of the Aswan High Dam and controlling of the Nile River water flow, the El-Umoum Drain became one of the main land based sources regularly discharging its waters directly to the Mediterranean sea at the El Mex Bay, west of Alexandria. Due to the domestic and industrial waste effluents discharging, the drain water is slightly brackish, does not exceed 5 psu, with dissolved oxygen ranging between 0.5 and 3.58 ml l^{-1}. Nutrient salts showed high levels up to 28, 346, 42 and 22 μM for phosphate, silicate, ammonia and nitrites, respectively; pH values fluctuated between 7.25 and 7.93 (Hossam and Petras, 1998; El-Rayis and Abdallah, 2006; Nessim et al., 2005, 2010; Hendy, 2013). The water characteristics, phytoplankton and zooplankton population of the El-Mex Bay and the El-Umoum Drain were previously studied (Soliman and Gharib, 1998; Gharib, 1998; El-Sherif, 2006; Hussein and Gharib, 2012) and showed that, the continuous discharge of polluted water into the bay caused massive development of algal blooms and a gradual deterioration of water quality. Also, (Zakaria et al., 2007) illustrate the influence of salinity variations on the abundance and community structure of zooplankton in the El-Mex Bay waters.

In this paper, we first describe the study, the material and the techniques used to collect the biological and physical data and after that, we show the correlations between the physico-chemical parameters, water temperature, salinity, and chlorophyll-*a* concentration. Moreover, we analyze the Rotifera community and the variability of the main groups observed in relation to the environmental variables and the hydrograph of the studied area is established. Finally, we notify the dramatic consequences that might be observed on rotifers species in the El-Mex Bay.

Material and methods

Area description

El-Mex Bay is bordering an industrial zone located west of Alexandria City, one of the most densely populated cities in Egypt with 6 million people (Fig. 1). This bay extends about 7 km between longitudes 29° 45′ and 29° 54′ E and latitudes 31° 07′ and 31° 15′ N, from the Agami headland (west) to the Western Harbor (east) and occupies an area of 19.4 km^2, with a mean depth of 10 m and a water volume of $190.3 \times 106\ m^3$.

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 waters of the El-Mex Bay receive huge amounts of untreated industrial wastes dumped directly into the southern part of the bay via pipelines. In addition, El-Dekhaila Harbor has been recently constructed at the western side of the El-Mex Bay.

The bay receives about $2.547 \times 10^9\ m^3\ y^{-1}$ of agricultural wastes mixed with water effluents (surplus water) from a neighboring sewage-polluted lake (Lake Mariut) with a rate of $262.8 \times 10^6\ m^3\ y^{-1}$ via the Omoum Drain. In addition, the bay receives $13 \times 10^6\ m^3\ y^{-1}$ of industrial discharge, as well as water from the Western Harbor amounting to $1.13 \times 106\ m^3\ y^{-1}$. The residence time of the El-Mex Bay water was found to be around 28 days. Accordingly, this bay is considered as an estuarine zone of the huge agricultural Omoum Drain (Halim et al., 1995).

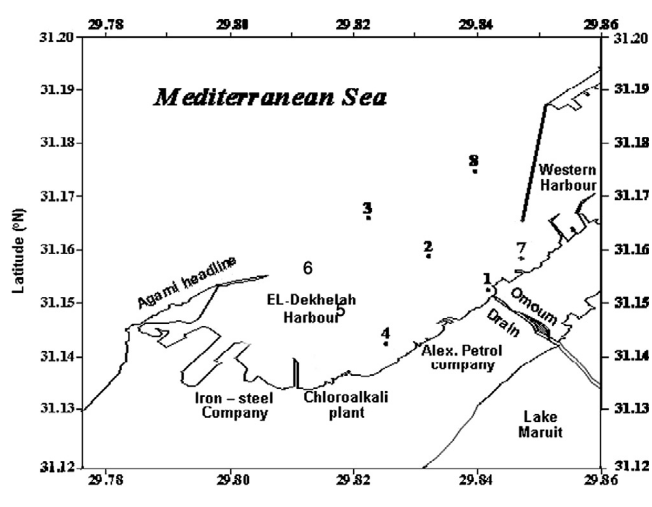

Figure 1 The location of stations in the El-Mex Bay.

Sampling design

Samples were collected seasonally during a complete year cycle (from autumn 2011 to autumn 2012) at the selected stations. The stations will be selected to cover all possible climatic and environmental characteristics of the different parts of the study area.

Eight stations were chosen in the El-Mex Bay for the present study, the locations of the sampling stations are shown in (Fig. 1).

Samples were collected vertically by using a standard plankton net (55 µm mesh size), lowered near the bottom and then pushed up to the water surface. The collected fauna which were retained in the net were then transferred into small glass bottles and preserved in 5% neutralized formalin solution and the sample volume was then adjusted to 100 ml. The samples were examined under a binocular research microscope. The identification was undertaken to species levels. For the estimation of standing crop, sub samples of 5 ml were transferred to a counting chamber (Bogorov chamber) using a plunger pipette. This operation was performed three times and the average of the three counts was taken. Rotifera 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 zooplankton per cubic meter. n: Average number of zooplankton in 1 ml of the sample. v: Volume of zooplankton concentrate (ml). V: Volume of total water filtered (L).

Additionally, at each station, water temperature was measured directly by usual thermometers, graduated to 0.1 °C, water transparency was measured using a white enameled Secchi disc with a diameter of 30 cm and the water salinity was measured by a salinometer. The phytoplankton biomass (Chlorophyll-*a*) was measured according to procedures described by Strickland and Parsons (1972).

Identification of different rotifer species was carried out according to Edmondson (1959), Berzins (1960), Hutchinson (1967), Pontin (1978), Guerguess (1979), Soliman (1983) and WORMS database.

All collected data in the present study were tabulated and appropriate graphs were constructed. Data were statistically treated to find biological indices. The diversity index was calculated according to Shannon and Weaver (1963). Correlation coefficient (*r*) and multiple regression analysis were computed using MINITAP 14 program for rotifers with the ecological measured parameters and chlorophyll-*a* concentration at $p \leqslant 0.05$.

Results

Environmental parameters

In the El-Mex Bay a clear seasonal pattern of water temperature and salinity was observed during the period of the five seasons, with the highest values observed in summer 2012.

Water temperature varied from a minimum of 14.4 °C in winter 2012 to a maximum of 30.7 °C in summer 2012 (Fig. 2). Generally, differences in water temperature were statistically significant between seasons. Moreover, sampling stations did not show significant temperature differences during the same season.

The high salinity value was recorded during autumn 2012, (28.53‰). On the other hand the minimum salinity value was noticed during winter 2012 (10.82‰) where water temperature recorded the lowest value during the period of study at 14.39 °C (Fig. 2).

The levels of chlorophyll-*a* are shown in Fig. 3. Its concentration showed a wide fluctuation which ranged from 0.27 to 52.65 µg/l with an average of 18.77 µg/l. As regards the spatial distribution of chlorophyll-*a*, the results showed that the station in front of the El-Umoum Drain had the highest concentration (52.65 µg/l), whereas, the lowest concentration was recorded at station IV (0.27 µg/l).

Seasonal variations of chlorophyll-*a* concentrations in the El-Mex Bay showed a wide range. It ranged from minimum concentrations during autumn 2011, winter 2012, and spring 2012 (11.35 µg/l, 10.62 µg/l and 10.14 µg/l), respectively, for the three seasons to its maximum concentrations during summer 2012 and autumn 2012 (34.38 µg/l and 32.98 µg/l), respectively, for the two seasons (Fig. 4).

Rotifer species assemblage

From the analyzed data, Rotifera contributed about 12.1% (average of 1077 specimens/m^3) to the total zooplankton

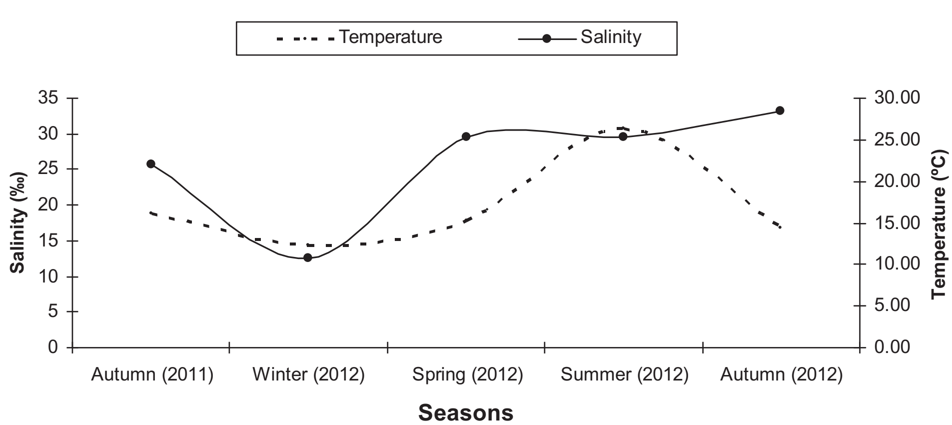

Figure 2 Seasonal mean water temperature and salinity values during the study period in the El-Mex Bay.

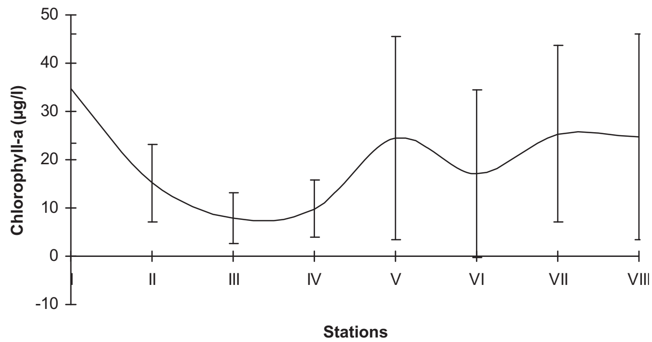

Figure 3 Spatial distribution of concentration of chlorophyll-*a* during the study period.

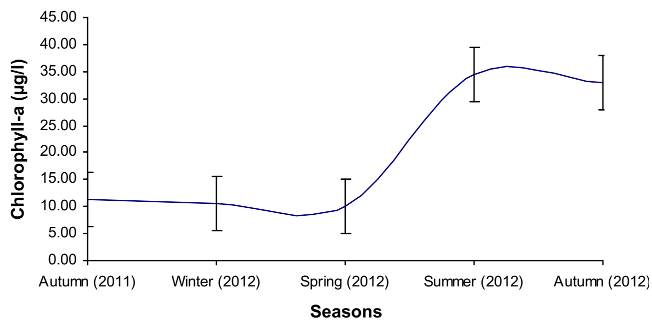

Figure 4 Temporal distribution of concentration of chlorophyll-*a* during the study period.

counts in the study area. Thirty-eight rotifer species belonging to 16 genera within 12 families and 3 orders were classified under one class. The three orders are:

The first order was Plomia (Hudson and Gosse, 1886) represented by 9 families and 13 genera and 35 species.

The second order was Floscularіaceae (Harring, 1913) represented by 2 families, 2 genera and 2 species.

The third order was Bdelloidea (Hudson, 1881) represented by 1 family and 1 genus and 1 species (Table 1, Plates I–IV).

Kingdom: Animalia
Phylum: Rotifera Cuvier, 1817
Class: Eurotatoria De Ridder, 1957
Subclass: Monogononta Plate, 1889

During autumn 2012; 13 species, 1353 specimens/m^3 were recorded. The number of species increased to a maximum during winter 2012 reaching 34 species (1421 specimens/m^3). On the other hand, the remaining seasons autumn 2011, spring 2012 and summer 2012 recorded 19 species (434 specimens/m^3), 17 species (734 specimens/m^3), and 21 species (1445 specimens/m^3), respectively (Table 2 and Fig. 5).

The spatial distribution of rotifer species (Table 3 and Fig. 6) showed that 32 species (955 specimens/m^3) were recorded at station I, while station VII recorded a high density with 2508 specimens/m^3 (24 species). Station II recorded 22 species (673 specimens/m^3), station III recorded 14 species (596 specimens/m^3), station IV recorded 20 species (1332 specimens/m^3), station V recorded 18 species (558 specimens/m^3), station VI recorded 18 species (798 specimens/m^3), and station VIII recorded 16 species (1200 specimens/m^3).

Results of the occurrence and distribution of rotifer species during different seasons are presented in Fig. 7. The frequency occurrence of rotifer species varied from season to season during the study period, where the highest occurrence value (100%) was observed for *Brachionus urceolaris*, *Synchaeta oblonga, Synchaeta okai, Synchaeta pectinata,* and Metamorphosis of rotifers (immature forms); while the lowest occurrence value (20%) was for *Brachionus dimidiatus*, *Epiphanes senta*, *Euchlanis dilarara, Pompholyx complanata, Synchaeta stylata*, and *Synchaeta triophthalma*.

On the other hand, data showed that 13 species were present during two seasons of the study which were *Trichocerca* sp., *Argonothora foliacea, Brachionus ibericus, Brachionus quadridentatus, Colurella adiatica, Filinia longiseta, Habotrocha rosa, K. cochlearis, Keratella tropica, Keratella valga, Lophocharis oxisternons, Rhinoglena frontalis,* and *Synchaeta clave*.

Data showed that another 8 species were present in three seasons which were *Brachionus budapestinensis*, Brachionus caudatus, *Brachionus plicatilis*, *K. quadrata*, *Polyarthra vulgaris*, *Synchaeta kitina*, *Synchaeta longipes,* and *Synchaeta tremula*. The remaining rotifer species such as *Ascomorpha saltans, Brachionusangularis, Brachionus calyciflorus, Brachionus rotundiformis, Brachionus rubens, Proalis daphnicola, Synchaeta grandis,* and eggs of rotifers were present in four seasons with an occurrence value of 80%.

The spatial distribution of data presented in (Table 4 and Fig. 8) showed that 6 species were recorded in all stations, among them *A. saltans*, *B. urceolaris, S. oblonga, S. okai, S. pectinata*, and *S. tremula*. In contrast, 6 species were found at one station only, which were *A. foliacea, B. dimidiatus, E. dilarara, P. complanata, S. stylata*, and *S. triophthalma*. On the other hand, 5 species were recorded at two stations among them *E. senta, F. longiseta*, *H. rosa, K. cochlearis*, and *L. oxisternons*.

Ten species were found at three stations like *B. budapestinensis*, *B. caudatus*, *B.ibericus*, *K. quadrata*, *K.valga*, *R. frontalis*, *S. clave*, *S. kitina*, *S. longipes*, and *Trichocerca* sp., while six species namely; *B. quadridentatus*, *Brubens*, *C. adiatica*, *K. tropica*, *P. vulgaris*, and *P.* daphnicola were present at four stations.

B. plicatilis and *S. grandis* were found at six and five stations (75% and 62.5%), respectively. On the other hand, 3 species were recorded at 7 stations among them *B. angularis*, *B. calyciflorus*, *B. rotundiformis* in addition to eggs and metamorphosis of Rotifera.

Diversity index, correlation, regression, step-wise regression analysis, and cluster analysis

Diversity measures

Diversity index varied distinctly along the El-Mex Bay during the five seasons. Winter 2012 tended to present a higher Shannon Diversity of 3.14. On the other hand, spring 2012 showed, generally, a lower diversity of 0.34.

In general, during the study period the community changed. There is a number of species that appeared in the beginning of the study (autumn 2011) and disappeared at the end (autumn 2012) among them *B. dimidiatus*, *C. adiatica*, *K. tropica*, and *K. valga* (Table 5).

Table 1 Systematic list of 38 rotifer species.

Family	Genus	Species
Brachionidae Ehrenberg, 1838	*Argonotholca* Gosse, 1886	***foliacea*** Ehrenberg, 1838
		Accepted as:
		Notholca foliacea Ehrenberg, 1838
	Brachionus Pallas, 1766	***angularis*** Gosse, 1851*
		budapestinensis Daday, 1885
		calyciflorus Pallas, 1766*
		caudatus Barrois and Daday, 1894
		dimidiatus Bryce, 1931
		ibericus Ciros-Peréz, Gómez & Serra, 2001
		plicatilis Müller, 1786
		quadridentatus Hermann, 1783*
		rotundiformis Tschugunoff, 1921
		rubens Ehrenberg, 1838*
		urceolaris Müller, 1773*
	Keratella Bory de St. Vincent, 1822	***cochlearis*** Gosse, 1851*
		quadrata Müller, 1786*
		tropica Apstein, 1907*
		valga Ehrenberg, 1834*
Epiphanidae Harring, 1913	***Epiphanes*** Ehrenberg, 1832	***senta*** Muller, 1773
	Rhinoglena Ehrenberg, 1853	***frontalis*** Ehrenberg, 1853
Euchlanidae	***Euchlanis*** Ehrenberg, 1832	***dilatata*** Ehrenberg, 1832
Gastropodidae Harring, 1913	***Ascomorpha*** Perty, 1850	***saltans*** Bartsch, 1870
Lepadellidae Harring, 1913	***Colurella***, Bory De St. Vincent, 1824	***adriatica*** Ehrenberg, 1831
Mytilinidae Harring, 1913	***Lophocharis*** Ehrenberg, 1838	*oxisternons* Gosse, 1851
Proalidae Harring & Myers, 1924	***Proales*** Gosse, 1886	***daphnicola*** Thompson, 1892
Synchaetidae Hudson & Gosse, 1886	***Polyarthra*** Ehrenberg, 1834	***vulgaris*** Carlin, 1943*
	Synchaeta Ehrenberg, 1832	***clave*** Ruttner-Koliske, 1960
		grandis Zacharias, 1893
		kitina Rousselet 1902
		longipes Gosse, 1887*
		oblonga Ehrenberg, 1832*
		okai Sudzuki, 1964
		pectinata Ehrenberg, 1832*
		stylata Wierzejski, 1893*
		tremula Muller, 1786*
		triophthalma Lauterborn, 1894*
Trichocercidae Harring, 1913	***Trichocerca*** Lamarck, 1801	sp.
Trochosphaeridae Harring, 1913	***Filinia*** Bory de St. Vincent, 1824	***longiseta*** Ehrenberg, 1834*
Testudinellidae Harring, 1913	***Pompholyx*** Gosse, 1951	***complanata*** Gosse, 1851
Habrotrochidae	**Habrotrocha** Donner, 1949	***rosa*** Donner, 1949

Correlation analysis

A significant positive correlation between the total rotifer abundance and chlorophyll-a was observed during winter 2012 and summer 2012 (r = 0.763 and r = 0.694, respectively at $p \leqslant 0.05$) and there was a significant negative correlation between total rotifer abundance and depth that was observed during autumn 2011, spring 2012, and autumn 2012 (r = −0.809, r = −0.769, and r = −0.851, respectively).

Multiple regression analysis

Multiple regression analysis of total Rotifera versus Visibility, Depth, Salinity (‰), pH, Temp., DO (mg/l) and Chlorophyll-a (μg/l) result in the following equations. The stepwise regression analysis was performed to exclude parameters that were insignificantly correlated with total rotifers (p > 0.05) from the equations.

Regression equations were constructed for estimating the relationships between total rotifer numbers (standing crop) and all the measured environmental factors of the bay. Regression analysis helps to understand how the typical value of the dependent (Total rotifer numbers)variable changes when any one of the independent variables is varied, it is widely used for prediction and forecasting. The resulting prediction equations for estimating the total number of rotifers resulted in some errors and the exact number of these errors can be minimized by using stepwise regression equations which exclude parameters that were not strongly correlated (not significant) with the total numbers of rotifers at $p \leqslant 0.05$.

Autumn (2011)

Total Rotifera = −12,366 − 238 Visibility − 34.0 Depth − 27.0 Salinity (‰) − 491 pH + 1025 Temp. − 127 DO (mg/l) − 54.8 Chlorophyll-a (μg/l).

Stepwise Regression equations:Total Rotifera = 1067 − 54 Depth.

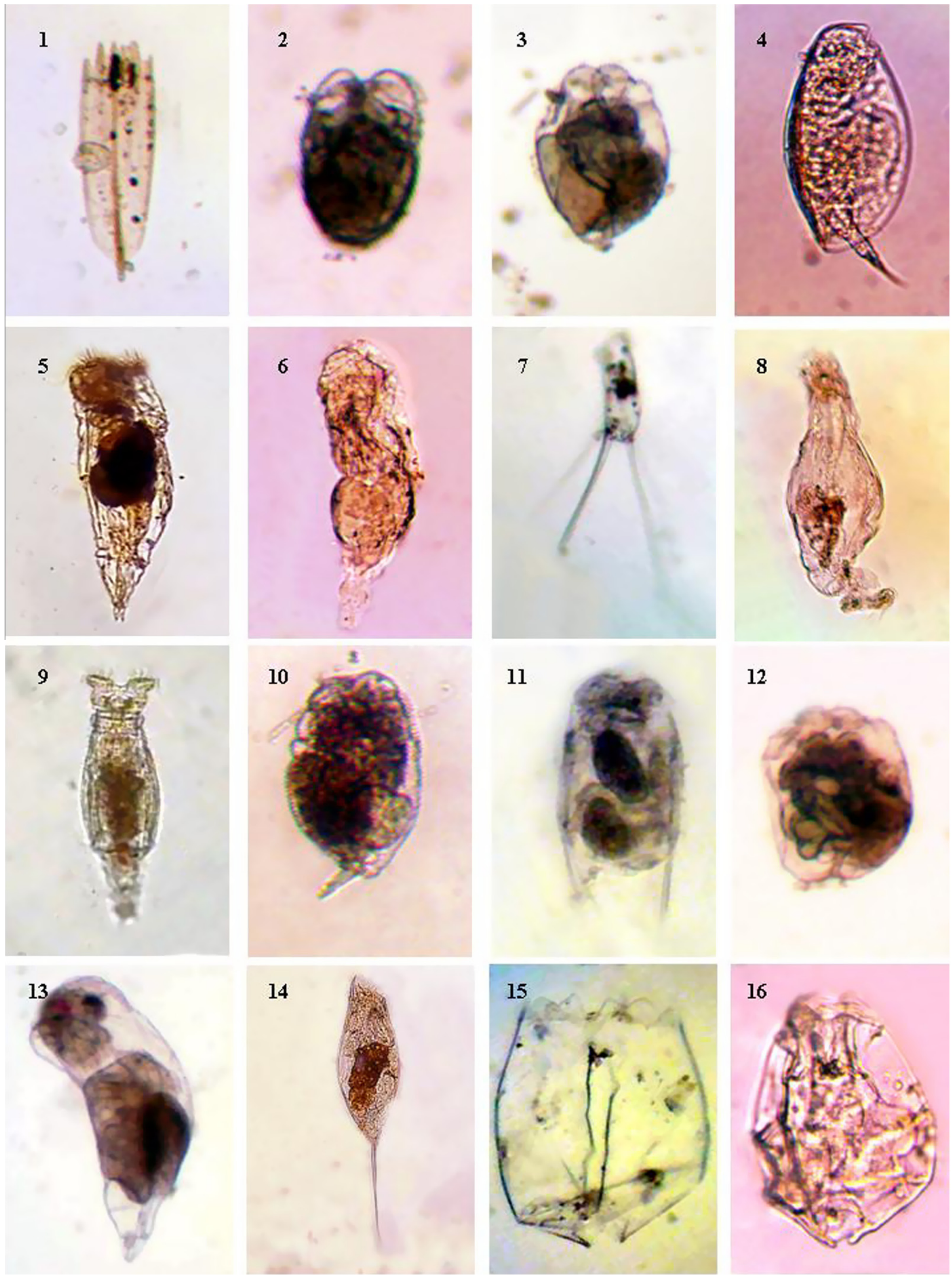

Plate I (1) *Argonotholca foliacea*, (2 and 3) *Ascomorpha saltans*, (4) *Colurella adriatica*, (5) *Epiphanes senta*, (6) *Euchlanis dilarara*, (7) *Filinia longiseta*, (8) *Proalis daphnicola*, (9) *Habrotrocha rosa*, (10) *Lophocharis oxisternons*, (11) *Polyarthra vulgaris*, (12) *Pompholyx complanata*, (13) *Rhinoglena frontalis*, (14) *Trichocerca* sp., (15) *Brachionus ibericus* and (16) *Brachionus angularis*.

Winter (2012)

Total Rotifera = 35,642 + 5077 Visibility – 440 Depth + 1381 Salinity (‰) – 6510 pH – 182 Temp. – 439 Chlorophyll-*a* – 824 DO (mg/l).

Stepwise Regression equations:Total Rotifera = −236.6 + 183 Chlorophyll-*a*.Total Rotifera = 9180.9 + 364 Chlorophyll-*a* – 921 Temp + 203 Salinity.

Spring (2012)

Total Rotifera = 7498 + 1808 Visibility – 199 Depth – 332 Salinity (‰) – 201 pH + 120 Temp. – 85.6 Chlorophyll-*a* + 361 DO (mg/l).

Stepwise Regression equations: Total Rotifera = 2599 – 173 Depth.

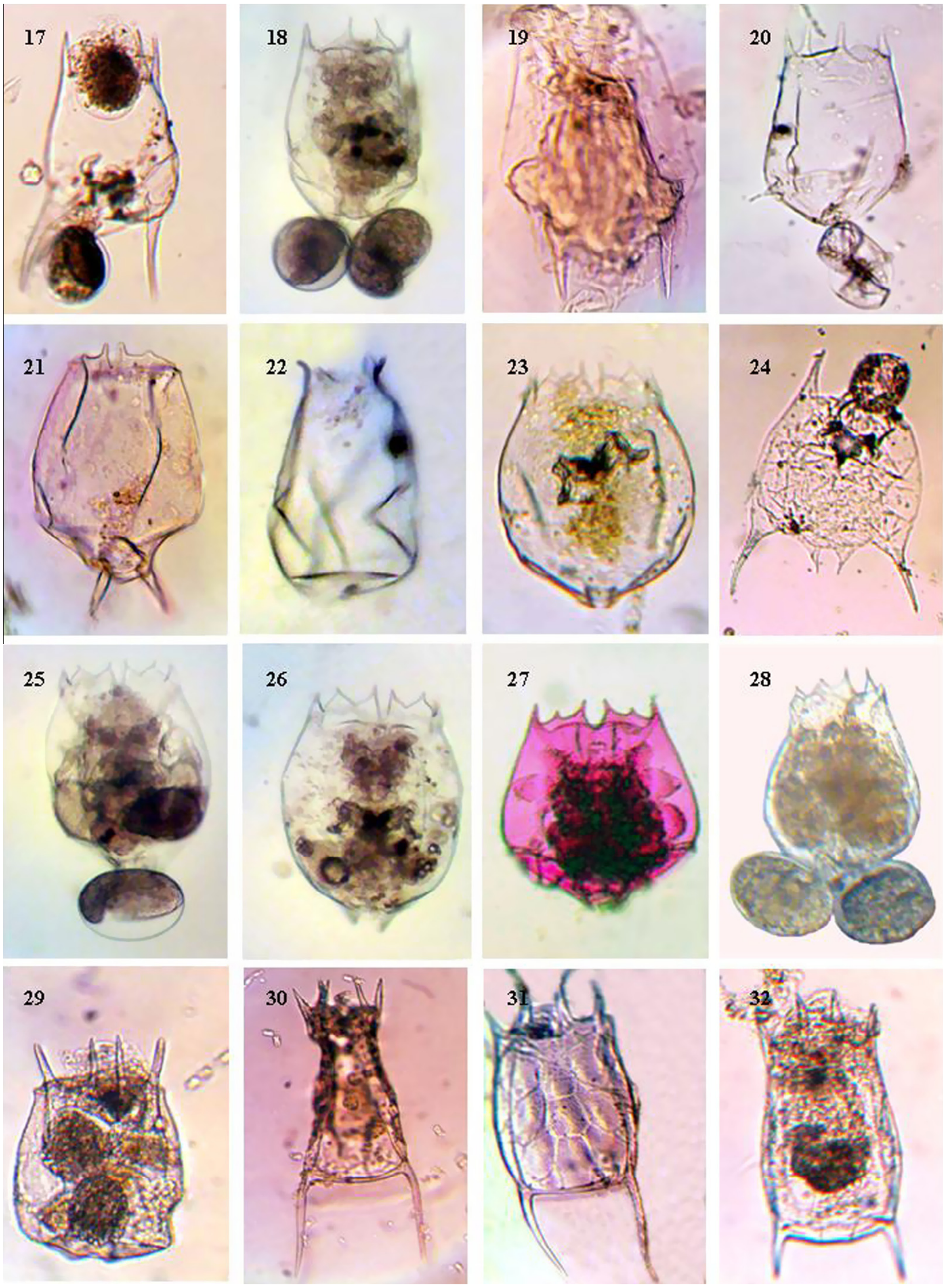

Plate II (17–20) *Brachionus calyciflorus*, (21) *Brachionus caudatus*, (22) *Brachionus dimidiatus*, (23) *Brachionus plicatilis*, (24) *Brachionus quadridentatus*, (25 and 26) *Brachionus rotundiformis*, (27) *Brachionus rubens*, (28) *Brachionus urceolaris*, (29) *Brachionus budapestinensis* and (30–32) *Keratella quadrata*.

Summer (2012)

Total Rotifera = −40,229 + 3139 Visibility − 118 Depth− 129 Salinity (‰) + 1639 pH + 1168 Temp. + 12.2 Chlorophyll-*a* − 851 DO (mg/l).

Stepwise Regression equations: Total Rotifera = −271.9 + 50 Chlorophyll-*a*.

Autumn (2012)

Total Rotifera = −80,169 − 2499 Visibility + 567 Depth − 119 Salinity (‰) + 5332 pH + 3258 Temp. − 628 DO (mg/l) − 105 Chlorophyll-*a* (μg/l).

Stepwise Regression equations: Total Rotifera = 6128 − 477 Depth.

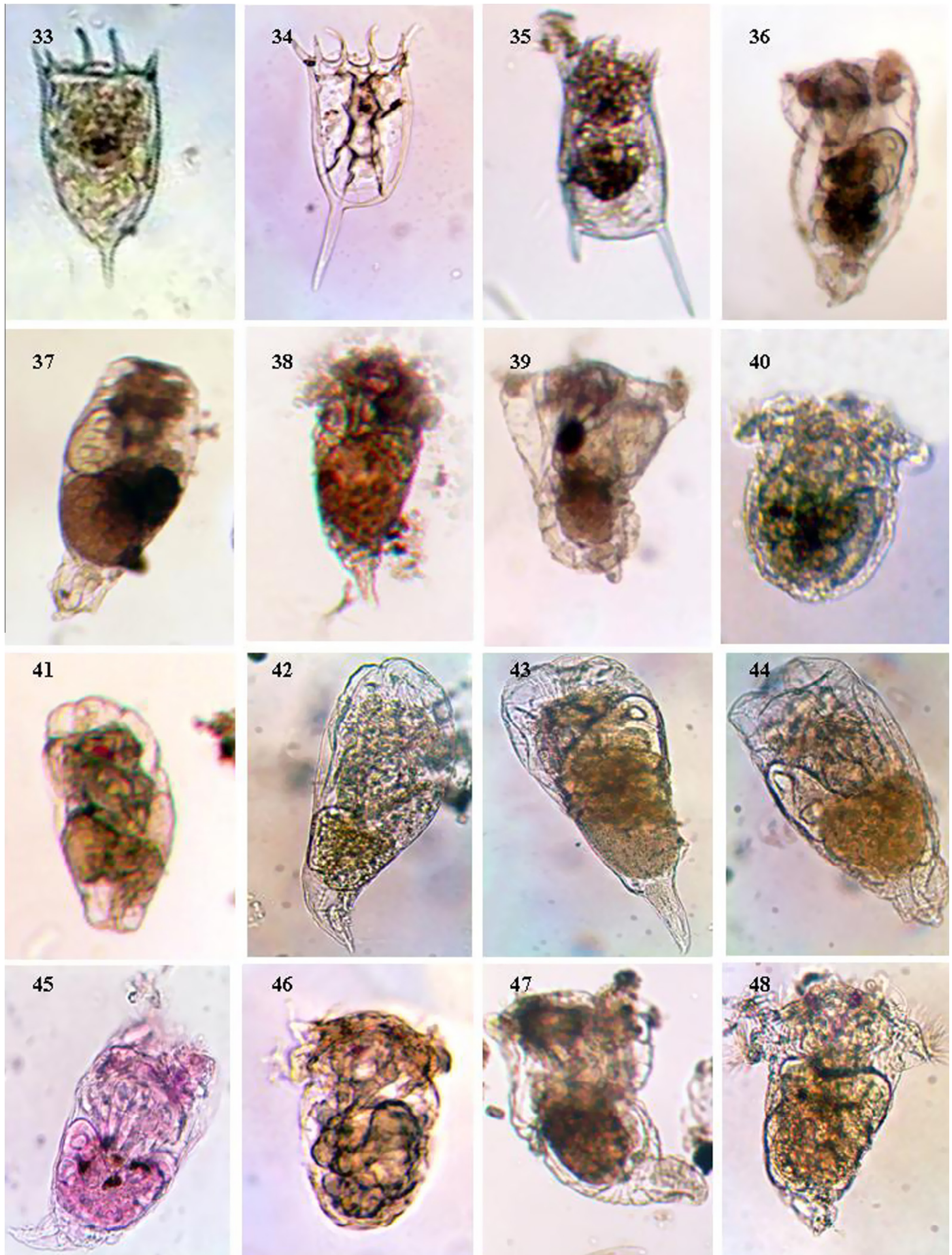

Plate III (33) *Keratella cochlearis*, (34) *Keratella tropica*, (35) *Keratella valga*, (36 and 37) *Synchaeta clave*, (38) *Synchaeta grandis*, (39) *Synchaeta kitina*, (40) *Synchaeta longipes*, (41–44) *Synchaeta okai* (45–47) *Synchaeta oblonga* and (48) *Synchaeta pectinata*.

Similarity analysis

In order to seek the similarities between different seasons and between the sampling stations, two hierarchical dendrograms were constructed from simultaneous rotifer species diversity and density. The environmental parameters were measured.

Results reflected that two major clusters were constructed between different seasons with only 59.75% similarity between them, the first cluster separates the summer 2012 season. The second cluster is divided into two sub-clusters with a similarity of 72.95% between them, the first sub-cluster separates autumn 2011 and the second sub-cluster contains the remaining three seasons. The highest similarity of 93.25% was between winter and autumn 2012, followed by the similarity between winter and spring 2012 (85.65%) (Fig. 9).

The analysis of similarity between the studied stations indicated in the dendogram (Fig. 10) showed that locations were divided into two major clusters with 75.47% similarity between them, the first cluster separates station IV from all stations. The second cluster includes the rest of seven surveyed stations. The second cluster is divided into two sub-clusters with 86.43% similarity between them. The first sub-cluster separates

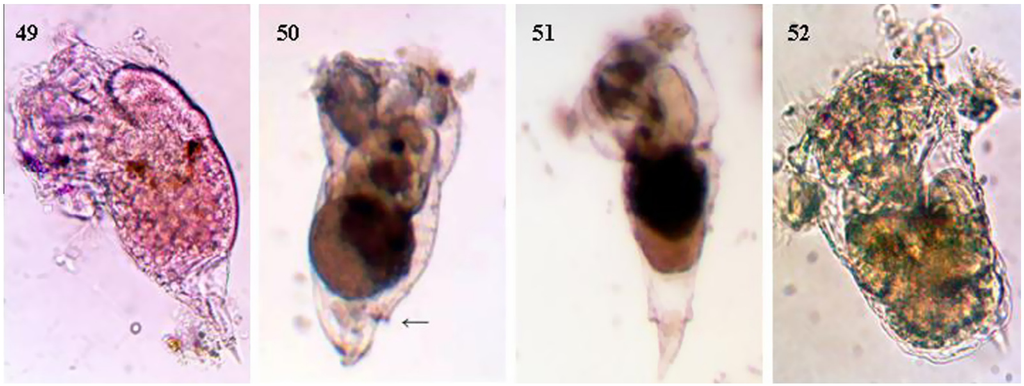

Plate IV (49) *Synchaeta stylata*, (50 and 51) *Synchaeta tremula*, and (52) *Synchaeta triophthalma*.

Table 2 Seasonal changes of species diversity and density of Rotifera in the El-Mex Bay through the period of autumn 2011 to autumn 2012.

Seasons	Autumn 2011	Winter 2012	Spring 2012	Summer 2012	Autumn 2012
No. of species	19	34	17	21	13
No. of specimens/m^3	434	1421	734	1445	1353

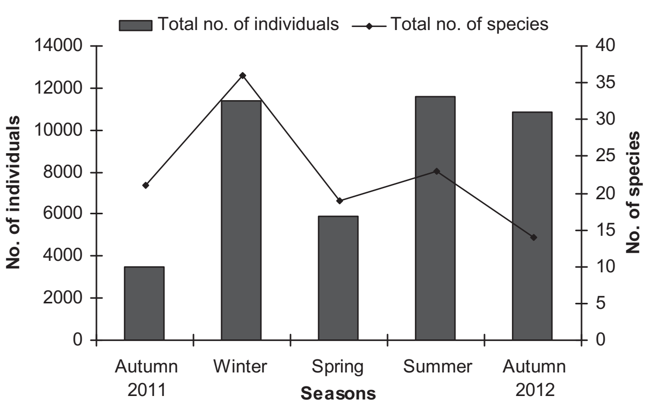

Figure 5 Seasonal variations in species diversity and density of Rotifera in the El-Mex Bay through the period of autumn 2011 to autumn 2012.

station V from the remaining six stations, while the second sub-cluster is divided into two clusters with a similarity of 87.86% between them. One contained stations I, II and III 16 which were located in one section in the bay and the second includes the remaining three stations represented by the second section. The highest similarity was 97.51% between stations VI and VIII, followed by the similarity of 97.32% between stations II and III (Fig. 10).

Discussion

The rotifers' diversity in the El-Mex Bay was rich (38 species), perhaps due to the effect of the mixture of freshwater and marine species and the high trophic levels of the system which agree with recordings of El-Sherif (2006) who mentioned that the bay was subjected to highly tropic conditions. The majority of the species were euryhaline marine forms (21 species) and the rest of the species were freshwater forms (17 species). Throughout the present investigation, the total percentage of genus *Synchaeta* was 51.3% of the total rotifer numbers followed by *Brachionus* with 19.1% and *Keratella* with 4.5%.

The water temperature did not deviate from the normal seasonal fluctuations on the southeastern coast of the Mediterranean Sea (15–30 °C) (Boyd, 1979). El-Mex Bay demonstrated wide range 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 28.53‰ in the open part of the sea which reflects the effect of land drainage.

The continuous discharge of polluted water into the El-Mex Bay caused a massive development of algal blooms and a gradual deterioration of water quality. (Hussein and Gharib, 2012).

Table 3 Spatial changes in species diversity and density of Rotifera in the El-Mex Bay at different stations over all of the investigation period.

Stations	I	II	III	IV	V	VI	VII	VIII
No. of species	32	22	14	20	18	18	24	16
No. of specimens/m^3	955	673	596	1332	558	798	2508	1200

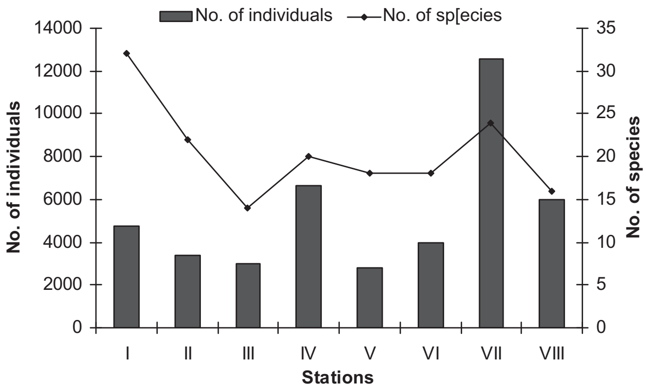

Figure 6 Spatial changes in species diversity and density of Rotifera in the El-Mex Bay at different stations.

The land-runoff discharges from human settlements, certain industries and agricultural activities are largely the cause of man-made eutrophication in the Egyptian Mediterranean coastal waters of Alexandria. Controlling fertilization, mainly by nitrogen and phosphorous of infertile marine systems increases primary production, which can have consequences for fishery yield. Conversely, uncontrolled eutrophication of productive systems can lead to undesirable consequences (Hussein and Gharib, 2012).

Eutrophication accelerates the development of massive algal blooms; including those visible (red tides), not only for the richness of the organic substances and nutrients in the discharged waters, but ultimately for the potential role of stabilizing the water column. Although algal blooms are natural, a higher frequency of their occurrence in the past twenty years indicates an unstable ecosystem. The frequency of toxic blooms has recently increased, with a direct effect on the organisms that feed on them.

The high concentration of Chl-*a* content recorded in water has coincided with the low salinity and high values of nutrient salts, which reflect 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.

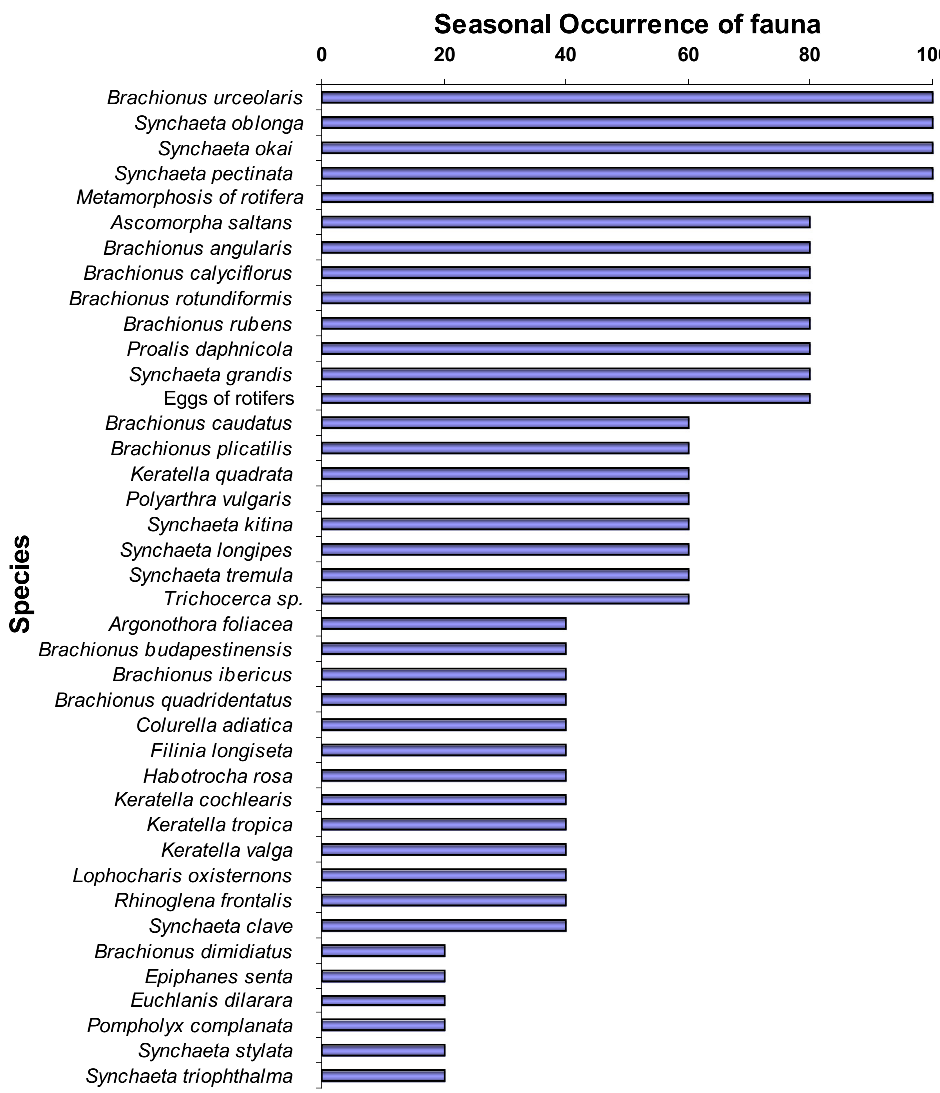

Figure 7 Histogram showing the frequency of occurrence of Rotifera during different seasons.

Table 4 Spatial distribution and frequency of occurrence (%) of Rotifers in the El-Mex Bay.

Species	Stations								Average ± SE
	I	II	III	IV	V	VI	VII	VIII	
Ascomorpha saltans	+	+	+	+	+	+	+	+	789 ± 315
Brachionus urceolaris	+	+	+	+	+	+	+	+	445 ± 144
Synchaeta oblonga	+	+	+	+	+	+	+	+	418 ± 137
Synchaeta okai	+	+	+	+	+	+	+	+	1634 ± 355
Synchaeta pectinata	+	+	+	+	+	+	+	+	431 ± 140
Synchaeta tremula	+	+	+	+	+	+	+	+	108 ± 38
Brachionus angularis	+	+	+	+	+		+	+	75 ± 13
Brachionus calyciflorus	+	+	+	+	+	+	+		159 ± 38
Brachionus rotundiformis	+		+	+	+	+	+	+	71 ± 8
Eggs of Rotifea	+	+	+	+	+		+	+	118 ± 18
Metamorphosis of Rotifera	+	+	+	+	+	+	+		224 ± 78
Brachionus plicatilis	+	+	+	+		+	+		182 ± 95
Synchaeta grandis	+	+				+	+	+	112 ± 39
Brachionus quadridentatus				+	+		+	+	89 ± 18
Brachionus rubens	+			+		+		+	68 ± 12
Colurella adriatica	+	+	+			+			51 ± 9
Keratella tropica	+					+	+	+	90 ± 44
Polyarthra vulgaris	+	+				+	+		108 ± 18
Proales daphnicola		+		+		+	+		70 ± 16
Brachionus budapestinensis	+	+					+		87 ± 3
Brachionus caudatus				+	+	+			95 ± 45
Brachionus ibericus	+	+						+	75 ± 30
Keratella quadrata		+			+		+		380 ± 234
Keratella valga	+				+		+	+	82 ± 16
Rhinoglena frontalis	+			+	+				68 ± 14
Synchaeta clave	+				+	+			77 ± 15
Synchaeta kitina	+				+			+	77 ± 15
Synchaeta longipes		+		+			+		63 ± 13
Trichocerca sp.	+	+					+		61 ± 16
Epiphanes senta	+	+							43 ± 4
Filinia longiseta	+						+		131 ± 39
Habrotrocha rosa	+						+		66 ± 19
Keratella cochlearis	+			+					101 ± 38
Lophocharis oxysternon	+		+						41 ± 5
Argonotholca foliacea	+								97
Brachionus dimidiatus	+								42
Euchlanis dilarara		+							82
Pompholyx complanata					+				51
Synchaeta stylata				+					127
Synchaeta triophthalma	+								46

The long-term observations of the nutritional conditions demonstrated a wide variability in the spatial distribution in the bay, but the levels of all nutrient salts reflect a high eutrophication. The markedly high nutrients reported during 1995 and 1996 (Soliman and Gharib 1998; Gharib, 1998; Dorgham, 1997) reflect the large amounts of nutrients reaching the bay through the discharged wastewaters, since the maximum values were reported in front of the land runoff. In contrast, the comparatively low concentrations during 2003–2005 represented the amount of nutrients in the area especially in locations far from the entrance of the El-Umoum Drain. It is clear that the El-Mex Bay is characterized by a great load of organic matter on long-term scale. The phytoplankton demonstrated a pronouncedly intensive growth in the El-Mex Bay, maximizing the levels of eutrophication conditions, since the inter-annual records over the past three decades indicate a pronouncedly high chlorophyll-*a* concentration in the bay (Dorgham, 2011).

The ecological study of rotifer assemblages in different world regions indicated that some rotifers have the ability to exist in polluted waters and are considered as pollution bio-indicators, like *Brachionus* species and *Polyarthra* species (Klimowicz, 1961; Aboul Ezz et al., 1996; Abo-Taleb, 2010; Abdel-Aziz et al., 2011), or serve as indicators of the trophic nature of the environment (Arora, 1966). The presence of *Brachionus* species, *K. cochlearis* and *Filinia* species in any water body is an indicator of eutrophy (Pejler, 1957), while *F. longiseta* was considered among pollution indicators (El-Bassat, 1995). All the species mentioned above were found in the El-Mex Bay during the present study, thus confirming their classification as highly eutrophic and polluted waters.

Hussein (1997) found that among the eleven rotifer species recorded in the El-Mex Bay, three were dominant. They were namely; *S. oblonga, B. angularis,* and *B. calyciflorus.*

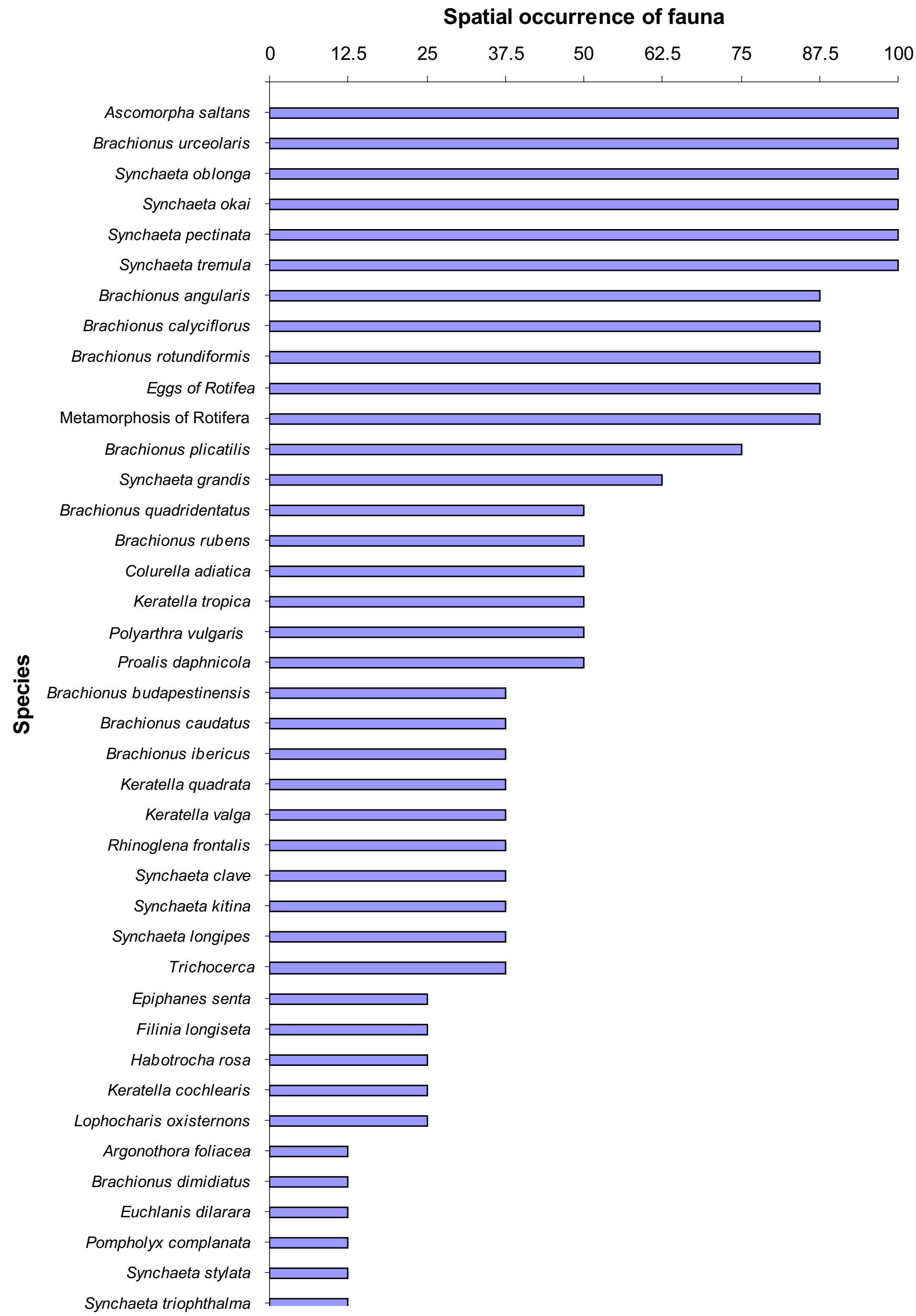

Figure 8 Histogram showing the frequency of occurrence of Rotifera at different stations in the whole of the study period.

Zakaria et al. (2007) stated that rotifers was the leading group at the mixed land drainage water type (L) < 10 ppt, which constituted 85.75% of the total zooplankton community. Sukumaran and Das (2004) mentioned that, the high rate of degradation of the organic matter in the aquatic ecosystem supports a dense load of bacterial population which in turn forms the chief components of the food of the rotifers. *B. Urceolaris* and *F. longiseta* were the dominant species contributing 68.39% and 14.63% to the total rotifer population, respectively. These two species were recorded among the most common rotifer species in Lake Maryout (Abdel-Aziz and Aboul Ezz, 2004).

In the El-Dekhalia Harbor, which is a part of the El-Mex Bay and lies on the western side of the Alexandria coast, rotifers were recorded sporadically, but mostly in low densities having an annual average of 103 organisms/m^3. However, *S. oblonga* was found most of the year with a relatively high density reaching the maximum in October (Abdel Aziz, 2000). The recent study in the El-Dekhalia Harbor showed that rotifers appeared in the greatest numbers during all months in the deeper layer. The great density of rotifers in the upper layer was associated with a markedly low surface salinity (19.28%) and a high production of phytoplankton. Heinbokel et al. (1988) noted that rotifers associated with phy-

Table 5 The change in faunal composition from the beginning to the end of the study.

Species	Autumn 2011	Autumn 2012
Ascomorpha saltans	+	+
Brachionus angularis	+	+
Brachionus budapestinensis	–	+
Brachionus calyciflorus	+	+
Brachionus caudatus	–	+
Brachionus dimidiatus	+	–
Brachionus ibericus	+	–
Brachionus plicatilis	–	+
Brachionus rotundiformis	+	+
Brachionus rubens	+	+
Brachionus urceolaris	+	+
Colurella adiatica	+	–
Eggs of Rotifers	+	–
C. adiatica	+	–
Keratella tropica	+	–
Keratella valga	+	–
Polyarthra vulgaris	+	–
Proalis daphnicola	+	+
Synchaeta grandis	+	–
Synchaeta oblonga	+	+
Synchaeta okai	+	+
Synchaeta pectinata	+	+
Trichocerca sp.	+	–
Metamorphosis of Rotifera	+	+

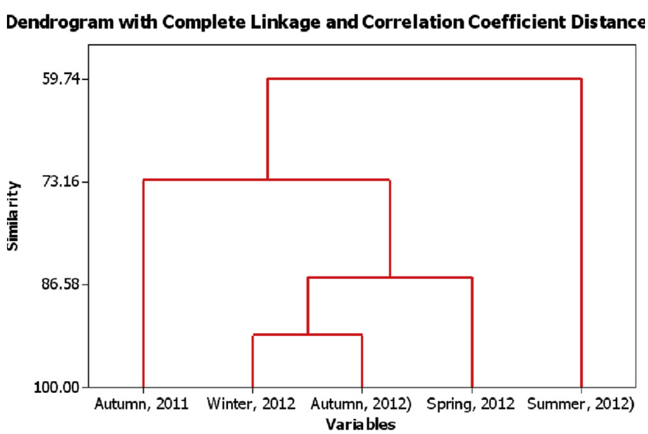

Figure 9 Dendrogram for the hierarchical clustering of seasons from autumn 2011 to autumn 2012 in the El-Mex Bay.

toplankton blooms often constitute the dominant grazers of dinoflagellates, and Gibert and Jack (1993) reported them as the main grazers of algae and small ciliates (Abdel Aziz, 2006).

According to Abdel Aziz (2004), the freshwater rotifers showed a marked abundance constituting 3.5–40% of the total zooplankton count during summer and early autumn due to the flourishing of *S. okai*. The abundance of this species may be attributed to the increase of the discharged sewage into the harbor during this season.

The contribution of some tolerant species including freshwater rotifers (e.g. *Keratella*) to the total zooplankton abundance and biomass in a variety of water masses is previously established in different areas by Wooldridge (1999),

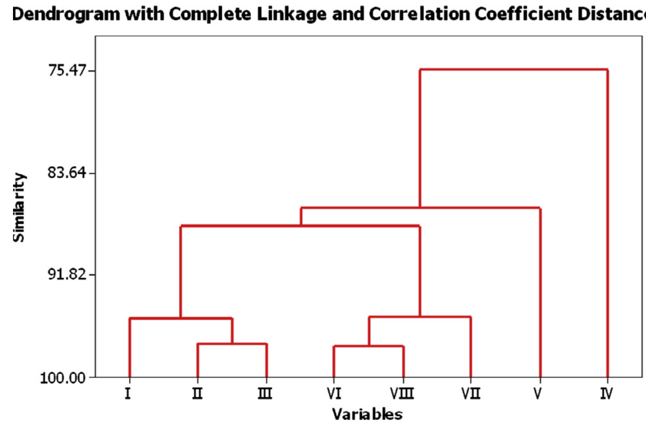

Figure 10 Dendrogram for the hierarchical clustering of different stations in the El-Mex Bay during the study period.

Froneman (2003), Kibirige and Perissinotto (2003). This species could be considered as a ubiquitous euryhaline species which is able to thrive in both marine and freshwater environments (Wooldridge and Bailey, 1982; Wooldridge, 1999).

Water temperature is known to be an important abiotic parameter that controls the population growth of rotifers (Radwan, 1984; Galkovskaja, 1987; Berzins and Pejler, 1989). During autumn 2011, the average water temperature was 18.75 °C with a salinity of 22.08‰ that correlated with the pronounced decrease in the total rotifer number to form 8% of the total zooplanktons. Most rotifer species prefer cold water (Guergues, 1993; El-Bassat, 1995). On the other hand, during autumn 2011 chlorophyll-*a* was low (7.5 μg/l); when the phytoplankton density was low and the majority of rotifers fed on the heterotrophic components of the microbial food-web, such as bacteria, hetertrophic flagellates and ciliates (Holst et al., 1998). During winter 2012, the average water temperature was 14.39 °C with a salinity of 10.82‰ that was correlated with the pronounced increase in the total rotifer number to form 26% of the total zooplankton. While, during summer 2012, the average water temperature was 30.68 °C with a salinity of 25.24‰ that was correlated with the pronounced increase in the total rotifer number to form 27% of the total zooplanktons.

The correlation coefficients and stepwise multiple regression analysis between the ecological parameters and the total rotifer abundance and depth and chlorophyll-*a* gave a more detailed picture about the most important factors co-related with rotifer abundance in the El-Mex Bay: Chlorophyll-*a* was the most effective factor during winter 2012 and summer 2012 ($r = 0.763$ and $r = 0.694$, respectively) and depth during autumn 2011, spring 2012, and autumn 2012 ($r = -0.809$, $r = -0.769$, and $r = -0.851$, respectively).

Finally, in the El-Mex Bay, the freshwater rotifers are more diversified and the predominant zooplankton component in the water mass is directly stressed by the El-Umoum Drain. Rotifers are also considered among the most abundant planktons in freshwater lakes, ponds and pools (Winner, 1975; Aboul Ezz et al., 1996), showing a wide distribution in inland waters of the world (Edmondson, 1959; Green, 1960; Hutchinson, 1967; Goldman and Heron, 1983; Wetzel, 1975; Mathew, 1977). Generally, they perform an important link in the food chain and constitute the main food items for a great variety of aquatic organisms, particularly fish larvae. They also share in the transfer of energy from primary producers to the higher tropic levels (Stemberger, 1990).

The Egyptian Mediterranean coast suffers from acute eutrophication, resulting from a great amount of anthropogenic nutrients entering the sea through numerous land runoffs distributed mainly off the Nile delta region and the Alexandria coast. These nutrients caused abnormally intensive phytoplankton blooms which together with great nutrient loads leads to the deterioration of the coastal waters to a degree not favorable for healthy populations of different biota. In addition, these conditions caused fundamental changes in the dynamics of the plankton community, including species composition, role of different groups, standing crop, seasonal cycles, and species dominance. Therefore, there is an importunate requirement to solve the problem of eutrophication not only in the Egyptian coasts but also everywhere in the aquatic habitats, through controlling the utilization of the chemical fertilizers in the cultivated lands and reducing the discharge of such fertilizers into the marine ecosystems (Dorgham, 2011).

Conclusion

Rotifer abundance is primarily controlled with fluctuations in physical environment, particularly depth and temperature which cause high seasonality among samples. Due to pollution and eutrophication, *Synchaeta* and *Brachionus* were favored. Chlorophyll-*a* was a limiting factor in the abundance of rotifers. It is clear that for a better understanding of the ecosystem of the El-Mex Bay, long-term monitoring of data on the important biological components and on the quality and quantity of zooplankton is essential.

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