Oceanologia (2015) 57, 61—70

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/oceano

ORIGINAL RESEARCH ARTICLE

Potential effects of abiotic factors on the abundance and distribution of the plankton in the Western Harbour, south-eastern Mediterranean Sea, Egypt

Ahmed M.M. Heneash, Hermine R.Z. Tadrose, Maged M.A. Hussein, Samia K. Hamdona, Nagwa Abdel-Aziz, Samiha M. Gharib *

National Institute of Oceanography and Fisheries (NIOF), Alexandria, Egypt

Received 5 September 2014; accepted 19 September 2014
Available online 25 October 2014

KEYWORDS
Phytoplankton;
Zooplankton;
Environmental variables;
Diversity index;
Western Harbour

Summary Samples were collected seasonally from Western Harbour during winter 2012—winter 2013 to examine spatial and temporal variability in phytoplankton and zooplankton abundance in relation to physicochemical parameters. Water was alkaline and well oxygenated. Nutrient concentrations were generally high and related to inflow of discharged waters. A total of 157 and 106 of phytoplankton and zooplankton species were recorded, respectively. The average plankton population was 4×10^6 cells l^{-1} in terms of phytoplankton and 24×10^3 ind. m^{-3} in terms of zooplankton. Seasonal differences in the quantitative and qualitative composition of both communities in the different stations were marked. *Eutreptiella* belonging to class Euglenophyceae overwhelming during spring, reaching an average of 17×10^6 cells l^{-1}. The genus previously was recorded as rare form in the Egyptian waters and may have been introduced via ballast water. Except in spring, copepods were the most abundant group and tintinnid abundances generally increased in spring. The ranges of Shannon diversity indices indicate disturbance level and sometimes high productivity. Salinity, dissolved oxygen and pH may be responsible for the variations in phytoplankton and zooplankton community structure. The results indicate that not only the discharged water make the harbour at risk, but also the ballast water is not less dangerous, and so, we emphasize the need for activation of the ballast water management IMO Ballast Water Management Conventions to reduce the risk of future species invasions.

---

* Corresponding author at: Alexandria, 21556, Egypt. Fax: +20 034801443.
E-mail address: gharibsamiha@hotmail.com (S.M. Gharib).

Peer review under the responsibility of Institute of Oceanology of the Polish Academy of Sciences.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.oceano.2014.09.003

1. Introduction

Egypt's Mediterranean coastline occupies the south-eastern corner of the Mediterranean. The coastal zone of Egypt is of great economic and environmental significance, and it combines localities of intensive socio-economic activities and urbanized areas. The Mediterranean Sea has many ports open for international shipping. The Western Harbour (WH) is the first Egyptian harbour and used for commercial shipping, serving about three quarters of Egypt's international trade. It is the most polluted spot in the Egyptian northern coast (Shriadah and Tayel, 1992; Tadros and Nessim, 1988). The harbour is subjected to multiple sources of pollutant interacting in proper combination leading to the development and persistence of nuisance algal blooms and having also a severe effect on the water quality and the associated aquatic ecosystem (Saad et al., 1993).

Elevated inputs of nutrients can produce eutrophication (Newton et al., 2003) with its associated problems, such as harmful algal blooms (HABs) and deterioration of water quality (Domingues et al., 2011). It also must be taken into account that ships facilitate the transfer of aquatic organisms across natural boundaries (Gollasch, 2002) when the ballast water discharged, and the non-indigenous species are released at the port of destination, and they may become established in the recipient ecosystem and spread (Kolar and Lodge, 2001). These invasive species can pose a risk to biodiversity (McGeoch et al., 2010) and, in some cases, also to human health (Ruiz et al., 2000).

Numerous studies have been carried out on the physical, chemical (Farag, 1982; Shriadah and Tayel, 1992; Saad et al., 2003) and biological characteristics of the WH. (Abdel-Aziz, 2002; Dorgham et al., 2004; Gharib and Dorgham, 2006; Nessim and Zaghloul, 1991; Zaghloul, 1994, 1996).

The main objectives of this study were to analyze the variations in the phytoplankton, zooplankton communities as a response to physical and chemical water variables during the different seasons and to understand which species could be used as indicators of HABs.

2. Material and methods

2.1. Study area

The WH is approximately a closed elliptical shallow basin with an area of 7.4 km^2 and depth range of 5.5—16 m, connected to the sea through a small opening of less than 100 m width at its southwestern side. Inside the harbour, there are several small basins delivered for different maritime activities. The harbour receives directly freshwater from Noubaria Canal at its southern part and indirectly waste waters from Umoum Drain at its western side (Fig. 1) (Dorgham et al., 2004).

2.2. Methods

Study at eleven stations was carried out seasonally from winter 2012 to winter 2013. Specifically, in February 2012, April, September, November and February 2013, these samplings were designated as: winter 2013, spring, summer, autumn and winter 2013 monitoring, respectively. Station 1 was located outside of the harbour, station 2 at the entrance of the harbour to the sea, stations 3 and 4 at the southwestern side, stations 5, 6 and 11 at the heart of the harbour and stations 7, 8, 9 and 10 at the northeastern side of the harbour.

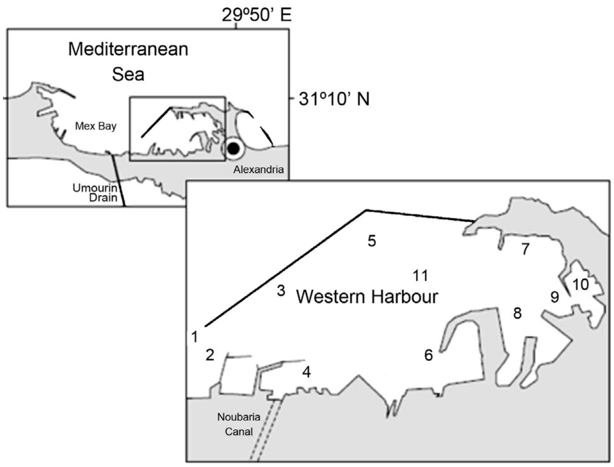

Figure 1 Western Harbour and location of sampling stations.

Samples of hydrological and chemical parameters and phytoplankton were taken seasonally from surface water between winter 2012 and winter 2013, while zooplankton samples were taken for four seasons during the year 2012 and collected with a 55 μm mesh Nansen net (30 cm diameter) by consecutive vertical hauls from near-bottom to the surface at a speed of 0.5 m s^{-1}. Net collections were preserved in 2.5% formaldehyde-seawater solution. Abundances were expressed as the number of individuals per cubic metre (ind. m^{-3}).

Water temperature was measured with a thermometer sensitive to 0.1°C, the pH using a pocket pH meter (model 201/digital pH meter), and the water salinity using a Beckman salinometer (Model NO.R.S.10); dissolved oxygen, dissolved inorganic nitrogen (DIN; nitrate, nitrite, ammonia), soluble reactive phosphorus (SRP) and reactive silicate (RS) were performed according to standard methods described in APHA (1995).

The phytoplankton samples were immediately fixed with 4% formaldehyde for laboratory analysis. Phytoplankton samples were counted and identified using 2-ml settling chambers with a Nikon TS 100 inverted microscope at 400× magnification using Utermöhl's (1958) method, and the zooplankton samples were preserved in 5% neutralized formalin and after settling they were concentrated to 100 ml.

2.3. Statistical analysis

Diversity (H') (Shannon and Wiener, 1963) was used to estimate the community structure for both phytoplankton and zooplankton. The Spearman rank correlation (r) was used to evaluate the relations between environmental variables and both of phytoplankton abundances (N = 54) and zooplankton (N = 43) at each sampling station with the SPSS 8.0 Statistical Package Program.

Table 1 The average seasonal physicochemical parameters from winter 2012 to winter 2013 at the Western Harbour.

Season/parameter	Winter 2012	Spring 2012	Summer 2012	Autumn 2012	Winter 2013
pH	8.11 ± 0.02	8.93 ± 0.27	8.21 ± 0.20	8.40 ± 0.06	8.11 ± 0.01
DO [mg l^{-1}]	12.14 ± 1.99	17.04 ± 3.23	9.44 ± 3.16	10.67 ± 1.20	11.48 ± 1.18
Salinity [PSU]	38.22 ± 0.26	27.73 ± 3.64	37.09 ± 0.76	38.30 ± 0.59	36.42 ± 0.72
SST [°C]	16.68 ± 0.24	24.36 ± 0.42	29.19 ± 0.16	23.61 ± 0.13	17.17 ± 0.19
NO_3 [μM]	4.29 ± 3.67	2.57 ± 4.42	21.97 ± 10.16	7.27 ± 12.99	2.64 ± 1.38
NO_2 [μM]	0.63 ± 0.20	0.25 ± 0.18	15.62 ± 9.98	21.18 ± 6.31	0.79 ± 0.59
NH_4 [μM]	2.08 ± 2.01	2.71 ± 1.32	3.91 ± 0.57	5.22 ± 4.30	17.25 ± 4.84
PO_4 [μM]	0.99 ± 1.11	0.85 ± 0.47	5.93 ± 2.07	1.89 ± 2.65	2.51 ± 0.73
SiO_2 [μM]	12.44 ± 3.29	4.87 ± 2.70	28.95 ± 14.13	4.85 ± 7.20	16.14 ± 3.25

3. Results

3.1. Hydrographic conditions

The seasonal average physicochemical parameters of the different stations from winter 2012 to winter 2013 are shown in Table 1.

Water temperatures followed the expected annual dynamics with winter 2012 minima (16.68 ± 0.24°C) and summer maxima (29.19 ± 0.16°C). No spatial variation in water temperature could be detected. Salinity exhibited seasonal fluctuations and reached maximum values (38.22 ± 0.26 PSU; 38.30 ± 0.59 PSU) in winter and autumn 2012, respectively, whereas the lowest values (27.73 ± 3.64 PSU) were measured in spring. Lowest values were observed at stations 1 and 2 due to the freshwater discharged. Minimum pH value (8.11) was recorded in winter 2012, 2013, while the highest value (8.40) was measured in autumn. The harbour's water was always well-oxygenated and reached maximum values in spring (17.04 ± 3.23 mg l^{-1}) and minimum values in summer (9.44 ± 3.16 mg l^{-1}).

The concentration of DIN, SRP, and RS varied widely and showed excess nutrient during autumn and high concentrations in summer with an apparent excess of SRP. Seasonal and spatial variation of nutrient concentrations showed that highest values of DIN were observed in summer (41.50 ± 10.13 μM) and lowest registered in spring (5.52 ± 5.20 μM). Stations 1, 9 and 10 usually presented peaks of DIN. Nitrate was the most dominant nitrogen form in winter and summer 2012 (55.89%; 52.97%, respectively) with maximum values observed at stations 1, 9 and 10. Ammonium was the dominant nitrogen form in spring and winter 2013 (57.40; 83.20%, respectively) with maximum values registered at stations 1, 7 and 9. Nitrite was the dominant during autumn (69.22%) with maximum values recorded at stations 6, 7 and 8.

The highest SRP concentrations were measured in summer (5.93 ± 2.07 μM) and lowest in spring (0.85 ± 0.47 μM). Station 6 reached maximum values, 9.75 μM in summer and 9.60 μM in autumn. Highest values of RS were observed during summer (28.95 ± 14.13 μM) with maximum values at stations 1 and 2.

The DIN/SRP ratio changed both seasonally and spatially. In general, DIN/SRP were lower than the algal N/P (Redfield ratio) throughout most of the harbour stations, increasing to >16:1 only at station 1 (summer and autumn) and stations 9 and 10 (summer). Low DIN:SRP ratios (<5) during spring and winter 2013 suggested that nitrogen could be the principal limiting nutrient. The RS/SRP ratio underwent more complex seasonal changes. Except in winter 2012, the ratio RS/SRP was <16:1 all the year round. Higher ratios were observed in winter 2012, suggesting less demand for RS relative to SRP. This is consistent with high proportions of Si-requiring diatoms in the phytoplankton community during spring-winter 2013 and primarily non-siliceous forms in spring.

3.2. Phytoplankton community structure and composition

From the analysed data, a visible change in phytoplankton community with regard to numerical abundance and species composition was evident among stations and in the seasonal cycle. A total of 157 phytoplankton species were quantified through the analysis of the 54 samples collected from eleven stations in 5 seasons. Bacillariophyta made up the highest number (37 genera, 87 species), but with a remarkably low abundance (8.1%), followed by Pyrrophyta (15 genera, 31 species). Chlorophyta, Cyanophyta and Euglenophyta were represented by 18, 10 and 10 species, respectively. Silicoflagellates was represented by only one species. On the other hand, Euglenophyta was the first group quantitatively (86.8%). Many species (38) were rare, having a frequency of occurrence of about 1.85%, but they were very important because they controlled the levels of species diversity. The total number of species on the sampled stations demonstrated more pronounced variations at the spatial scale than the temporal one. A high diversity (100 species) was recorded at station 1, followed by 66 species at station 2, and approximately similar numbers of species (57—59 species) were recorded at stations 3, 5 and 9, while a conspicuously smaller numbers (47—52 species) were found at stations 4, 6, 7, 8, 10 and 11.

The numbers of phytoplankton species recorded in winter, spring, summer, autumn 2012 and winter 2013 were 51, 44, 59, 72 and 74 respectively. In spite of the large number of species, only ten were perennial: *Chaetoceros affinis* Lauder, 1864, *Cyclotella kützingiana* Thwaites, *Leptocylindrus danicus* Cleve, 1889, *Skeletonema costatum* (Greville) Cleve, 1873, *Exuviaella marina* Cienkowski, 1881, *Oxytoxum sceptrum* (Stein) Schroder, 1906, *Prorocentrum micans* Ehrenberg, 1834, *Prorocentrum triestinum* J. Schiller, 1918, *Scrippsiella trochoidea* (Stein) Balech ex Loeblich III, 1965 and *Chlorella marina* Butcher R. W., 1952.

The most representative genera were: *Skeletonema*, *Asterionellopsis*, *Cyclotella*, *Pseudo-nitzschia* and *Leptocylindrus* from diatoms, *Prorocentrum*, *Exuviaella* and *Gyrodinium* from

Pyrrophyta, and *Protoperidinium* from heterotrophic dinoflagellate. The most dominant genus of Euglenophyta was *Eutreptiella*. The most dominant in frequency were the diatom, *Skeletonema costatum* and the Pyrrophyta *Exuviaella marina* (86% and 83% occurrence, respectively), *Prorocentrum micans*, *Prorocentrum triestinum*, *Scrippsiella trochoidea* and *Cyclotella kützingiana* appeared in more than 50% of the samples. Chlorophytes and cyanophytes did not contribute greatly to the abundance of total phytoplankton and had average annual 4863 and 178 cells l^{-1}, respectively.

In Shannon Wiener legislation, the lowest and highest species diversities were 0.02 (St. 6, spring) and 3.03 (St. 1, winter, 2013). Generally, lowest phytoplankton diversity was observed in spring (0.404 ± 0.45) whereas higher values were recorded in winter 2013 (2.076 ± 0.384). The correlation between phytoplankton density and diversity was strongly negative ($r = -0.478$, $p < 0.001$), and it is apparent that minimum diversity means that a stress increases with poor water quality, whereas the opposite is true for maximum diversity results with favourable condition.

3.3. Seasonal dynamics of phytoplankton community

The average phytoplankton abundance was 4×10^6 cells l^{-1} and the highest values were registered in spring (Fig. 2) and lowest values were registered in winter 2012. There was a high variability in cell abundance when the temporal distribution of phytoplankton groups was examined. Generally, diatoms registered the highest values in winter 2012, autumn and winter 2013. Pyrrophyta abundance was in summer, while Chlorophyta and Cyanophyta cell densities were usually lower than 1% of the total density.

During winter 2012, the seasonal mean total phytoplankton cell abundance was $5.74 \pm 5.20 \times 10^4$ cells l^{-1}. It was represented mainly by diatoms which represented 92% of cell abundance. The most dominant taxa were *Asterionellopsis glacialis* (Castracane) Round, 1990 (48.3%) and *Skeletonema costatum* (15.7%), and in terms of frequency, *Chaetoceros socialis* H.S. Lauder, 1864 and *Ch. affinas*. *Scrippsiella trochoidea* and *Archaeperidinium minutum* (Kofoid) Jörgensen, 1912 were the most abundant Pyrrophyta.

During spring, the seasonal mean total phytoplankton cell abundance reached $17 \pm 20.6 \times 10^6$ cells l^{-1}. Phytoplankton was showing overwhelming dominance of Euglenophyta which reached 96.6% of cell abundance. The most dominant species was *Eutreptiella* sp. Pyrrophyta formed 2% and *Exuviaella marina* was the dominant.

During summer, the seasonal phytoplankton mean was $56.80 \pm 69.50 \times 10^4$ cells l^{-1}. The community began recovering and the more resistant group Pyrrophyta increased to reach 75.4%, while the diatoms showed a slight increase to reach 12.6%. The most abundant and frequent species were *Cyclotella kützingiana* (58.7%), *Skeletonema costatum* (49.1%), while the most abundant dinoflagellate genus was *Gyrodinium* (61.1%) and the most frequent was *Prorocentrum triestinum* and *Scrippsiella trochoidea*. At station 9, the percentage composition of Chlorophyta reached maximum (14.9%).

During autumn, the seasonal phytoplankton mean was $1.14 \times 10^6 \pm 65.0 \times 10^4$ cells l^{-1}. Diatoms achieved the highest percentage (95.3%), while the Pyrrophyta dropped to 3.7%. *Skeletonema costatum* was the leader forming 91.5% of the total abundance. Euglenophyta achieved lowest number and disappeared from most stations.

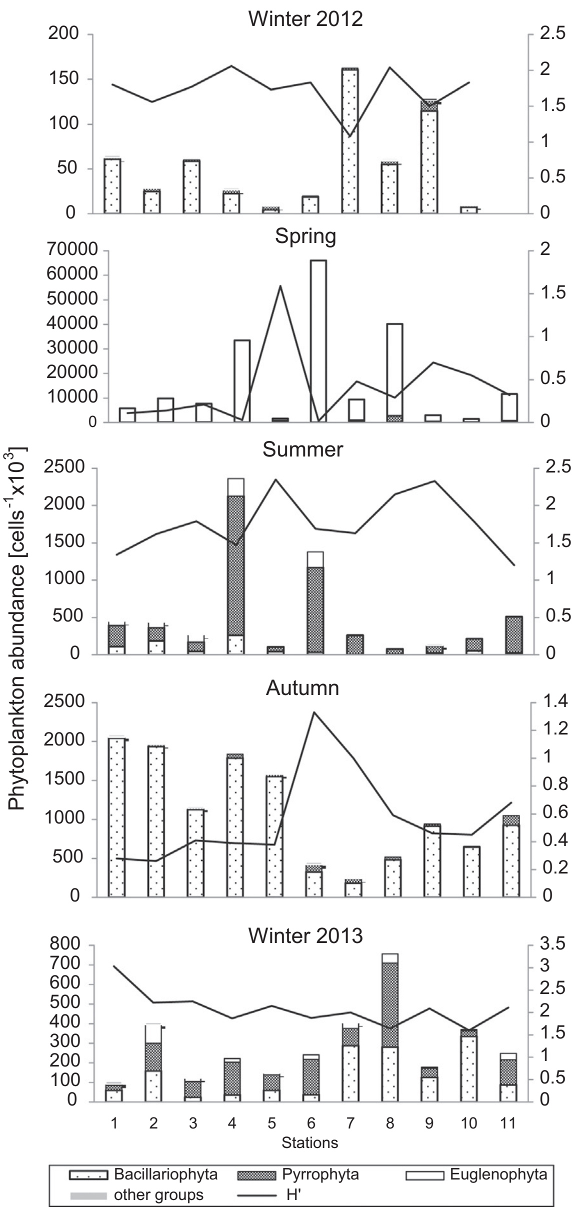

Figure 2 Seasonal variations of phytoplankton abundance subdivided by groups and species diversity index (H') of the Western Harbour from winter 2012 to winter 2013.

During winter 2013, the seasonal phytoplankton mean was $29.2 \pm 18.8 \times 10^4$ cells l^{-1}. The percentage of diatoms deceased (46.5%), while the percentage of Pyrrophyta increased (43.3%). Euglenophyta accounted for 9.1%, while Chlorophyta and Cyanophyta were 1.0% and 0.1%, respectively. The most abundant species was the diatom *Skeletonema costatum* (42.2%) but the most frequently occurring species were the Pyrrophyta *Prorocentrum triestinum* (39.7%) followed by *Exuviaella marina* (36.8%). The percentage composition of Chlorophyta at station 1 was considerably higher (12.1%), than all other sites and same was true for Cyanophyta (0.9%).

3.4. Relations between abiotic parameter and phytoplankton community

Spearman Rank correlation analyses were performed on environmental parameters and phytoplankton groups in order to examine significant relationships. Phytoplankton cell abundance had a strong positive correlation with dissolved oxygen and pH values, and weakly positive with percentage of ammonia. On the other hand, the phytoplankton density was negatively correlated with salinity. Euglenophyta showed significantly positive correlations with pH values, dissolved oxygen and ammonia percentage, while showed negative correlation with DIN and salinity. Diatoms showed significantly positive correlations with DIN and DIN: DIP ratio, and showed negative correlation with RS:DIN. Pyrrophyta presented a moderately positive correlation with temperature and pH values, and showed negative correlations with salinity.

3.5. Zooplankton community structure and composition

In total, 106 zooplankton species were identified, including the larval stages of different groups. Most of them were protozoans (54 species: 13 non tintinnid ciliates, 29 tintinnids and 12 species foraminiferans). Copepods formed 19 species, rotifers 8 species and nematodes 5 species. Cnidarians, annelids and chaetognaths were represented by 3 species each. Decapoda and Larvaceae were represented by 2 species each, while Cladocera, Ostracoda, Amphipoda, Mollusca and Echinodermata were represented by only one species each.

A high diversity (64 species) was recorded at station 1, followed by 58 species at station 3 and approximately similar number of species (48—51 species) were recorded at stations 2, 4, 5, 7 and 9, while a conspicuously smaller numbers (45—46 species) were found at stations 6, 8, 10 and 11. Greatest taxon richness was recorded in summer (61) and lowest number was recorded in autumn (36).

Out of 106 species recorded, only 11 species could be encountered as perennially existing during the four seasons. These species were: *Adelosina elegans* (Williamson, 1848), *Tintinnopsis cylindrica* Daday, 1887, *T. beroidea* Stein, 1867, *Synchaeta okai* Sudzuki, 1964, *Dorylamus* sp., *Paracartia grani* Sars G.O., 1904, *Paracartia latisetosa* (Kritchagin, 1873), *Euterpina acutifrons* (Dana, 1847), *Oithona nana* Giesbrecht, 1893, *Oithona plumifera plumifera* Baird, 1843 and *Paracalanus parvus* (Claus, 1863).

The annual average zooplankton abundance was 23.9×10^3 ind. m^{-3}, where copepods were by far the predominant component made up 52.2% of the total zooplankton population. Their larval stages (nauplii and copepodites) respectively, made up 42.1 and 22.0% of the total copepods and total zooplankton. Among the most dominant copepod species were *Oithona nana* and *O. plumifera* (29.6, 15.4 and 11.3, 5.9% of the total copepods and total zooplankton, respectively). Protozoa formed the second most important group, comprising about 35.5% of the total zooplankton count with an annual average of 8.5×10^3 ind. m^{-3}. Protozoans were mostly represented by tintinnids, forming 99.1% and 35.2% of the total protozoans and total zooplankton, respectively. *Schmidingerella serrata* (Möbius, 1887) Agatha and Strüder-Kypke, 2012 was the most dominant species forming 70.5% and 25.1% of the total protozoans and total zooplankton, respectively. Although rotifers were represented by 8 species, collectively they formed only about 4.6% of the total zooplankton, with relatively high numbers of *Synchaeta okai* at stations 1, 3, 4 during summer.

The diversity index value (H') of the zooplankton community ranged between 0.66 and 2.16. The overall mean were 1.82 ± 0.26 (winter), 1.18 ± 0.37 (spring), 1.90 ± 0.15 (summer), 1.90 ± 0.15 (autumn). Diversity index values were generally higher during summer and autumn with parallel lower values of dominance at all stations. Station 1 attained higher values than those of the other stations.

3.6. Spatial distribution of the zooplankton standing crop

Highest density (annual average: 41.6×10^3 ind. m^{-3}) was recorded at station 3, and lowest recorded at stations 6 and 7 (annual averages: 17.3×10^3 and 17.5×10^3 ind. m^{-3}, respectively).

Copepods were strongly dominant, making up the bulk of the zooplankton population. The highest copepod densities were observed in stations 6, 7, 5, 10 and 11. Copepod larval stages represented high percentage, fluctuated between 23.9% (station 6) and 65.9% (station 9) with an annual average of 42.1% of the total copepods.

Protozoans were the most dominant group at stations 1, 2, 3 and 8, fluctuating between 37.2% (station 1) and 54.8% (station 3). Their abundance decreased to minimal at stations 6 and 7 (12.7% and 11.4%). *Schmidingerella* spp. were the most dominant fluctuating between 67.4% (station 1) and 96.2% (station 8).

Rotifers were third in abundance (4.6%), and showed higher percentage at station 1 (12.0%) and decreased to reach minimal at stations 5 and 8. Cirripeds were relatively abundant in station 1 (10.3%), whereas in the other stations they accounted for only 0.3—2.7% of zooplankton numbers. Larvaceans contributed as little as 1.7% of the total count.

3.7. Seasonal distribution of the zooplankton standing crop

The zooplankton standing crop was the smallest during winter (average: $11 \pm 10.6 \times 10^3$ ind. m^{-3}). The contribution of copepods to the total zooplankton has been represented by 69.5% with an increase of their larval stages (45.8%). Moreover, the dominant adult species was *Oithona nana* (19.0% of the total zooplankton). Protozoans were the second most abundant group making up 11.0% of the total zooplankton count. They were dominant by *Schmidingerella serrata* and *Tintinnopsis campanula* Ehrenberg, 1840, representing respectively, 7.7% and 1.2% of the total zooplankton (Fig. 3). During this season, cirripedes were represented by nauplii, which contributed 10.7% of the total count. Annelida constituted 6.3% of the total zooplankton with Spionid and Trochophore larvae were the dominant.

In spring, the zooplankton crop was larger than other seasons (average: $31.3 \pm 21.5 \times 10^3$ ind. m^{-3}). It was the most productive season for protozoans, representing 78.2% of the total zooplankton. They were represented by

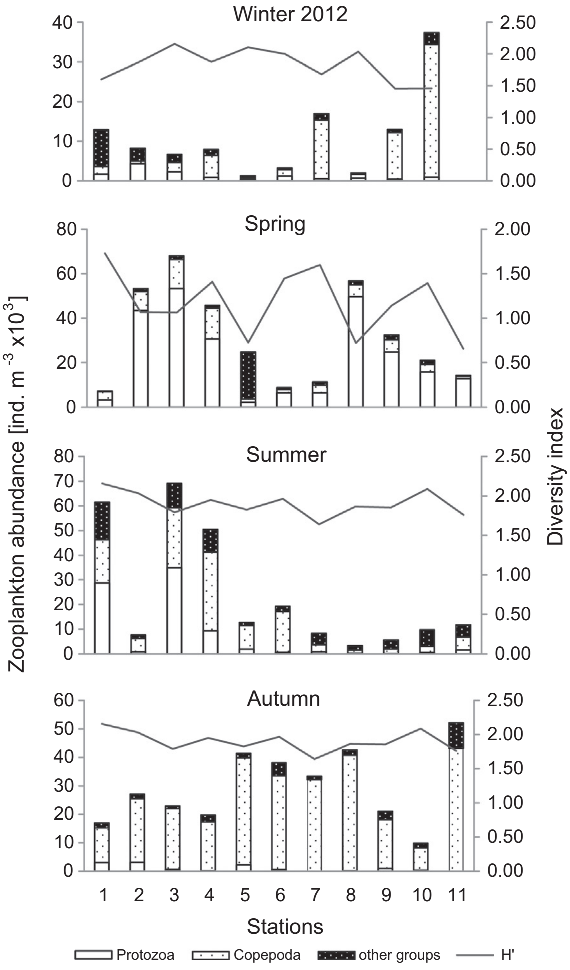

Figure 3 Seasonal variations of zooplankton abundance subdivided by groups and species diversity index (H') of the Western Harbour from winter to autumn 2012.

22 species (1 non tintinnid ciliates, 16 tintinnids and 5 foraminiferans) with the dominance of *Schmidingerella serrata* (73.9% of the total zooplankton). Copepods were the second dominant group, accounting for 17.6% of the total count. Regarding species composition, copepods were represented by 8 species. *Oithona nana* made up 34.43% of the total copepods and *O. plumifera* 12.78%. Rotifers contributed 1.0% to the total community.

During summer, the zooplankton community (average: $23.5 \pm 24.3 \times 10^3$ ind. m^{-3}) was dominated by copepods (45.8%), protozoans (30.9%) and rotifers (16.3%). The leading species were the copepod *Oithona nana* and *O. plumifera* (17.7% and 9.8%, respectively), as well as the protozoans *Favella ehrenbergii* (Claparède and Lachmann, 1858) Jörgensen, 1924 (21.0%) and the rotifer *Synchaeta okai* (12.1%).

In autumn, the average zooplankton community count was $29.6 \pm 13.1 \times 10^3$ ind. m^{-3}. Copepods clearly dominated the zooplankton assemblages, accounting for more than 87%. They were represented by 9 species. *Oithona nana*, *O. plumifera*, *Paracalanus parvus* and *Euterpina acutifrons* were the dominant species at all stations, constituting respectively, 22.2, 7.2, 12.8 and 12.4% of the total zooplankton. Protozoa was the second group, making up 3.6% of the total zooplankton count. It was dominated by *Eutintinnus* sp. and *Favella ehrenbergii*.

3.8. Zooplankton structure and environmental conditions

Analysis of the main environmental influences on zooplankton abundances showed that pH and dissolved oxygen were the most important parameters, which positively affected the variation of zooplankton ($r = 0.461$; $p < 0.05$ and $r = 0.320$; $p < 0.05$, respectively). In contrast, salinity exercised negative effects with total abundance and was not correlated with any of the groups except Protozoa. Shannon diversity showed significant positive correlations with the concentrations of nitrate, nitrite, ammonia, phosphate and silicate at $p < 0.05$ ($r = 0.392$; $r = 0.441$; $r = 0.333$; $r = 0.361$; $r = 0.400$, respectively).

4. Discussion and conclusion

The WH and adjacent marine environment are under risk of discharged wastewaters from both drains and ballast water. These pollutants cause dysfunctions in the food web that might lead a total ecosystem imbalance, especially because of the low water exchange rate with the open sea. The turnover time of the water in the harbour was estimated to be 30 days (Hassan and Saad, 1996).

Temperature fluctuations do not have an important effect on species composition, while salinity is the main physical parameter that can be attributed to the plankton diversity and acts as a limiting factor that influences the distribution of plankton community as reported by Sridhar et al. (2006). Large salinity oscillations in the harbour were recorded spatially and temporally, ranging from 22.7 PSU (St. 2) to 38.6 PSU (St. 7). Values were noticeably high in winter and autumn but drops in spring and causing a stress condition and a resultant loss of biodiversity. The marked reduction in salinity values may be due to the huge quantities of discharged water, or may be due to the disposal of ballast water. This appeared by the lowest average salinity values recorded at stations 1 and 2, both under direct wastewaters influence, while the highest average salinity values were generally recorded at stations 5 and 10. In the long term, average salinity decreased from 37.0 PSU in 1985 (Nessim and Tadros, 1986) to 35.3 PSU in 1999—2000 (Dorgham et al., 2004), and still as the latter average value during the present study.

The low oxygenation of the harbour has been a characteristic feature for a long time (Dorgham et al., 2004; Farag, 1982), but the present study showed that water was well-oxygenated all the year round and no anoxic phenomenon was observed. Oxygen concentrations generally ranged between 5.34 and 22.08 mg l^{-1}, corresponding to 71% and 266% O_2 saturation, respectively. Peak O_2 saturation observed during spring (average: 205%) could be a direct indication of high phytoplankton density. This is well known from the strong positive correlation with phytoplankton counts ($r = 0.703$, $p < 0.001$). Oxygen solubility was strongly negatively influenced by water salinity and all nutrient salt concentrations.

The nutrient concentration 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). Sometimes nitrate concentrations exceed a factor of 5, the low limit of eutrophication criteria (4 μM) as adopted by Marchetti (1984). According to these values, the Western Harbour could be classified as eutrophic.

The temporal fluctuations of nutrients are considered to reflect phytoplankton consumption as well as water discharged. Generally, lowest nutrient concentrations were recorded during spring due to intensive uptake by the abnormal phytoplankton blooms. DIN values (average: 9.215 μM) exceeded that reported by Nessim and Tadros (1986) and Dorgham et al. (2004) who recorded 4.06 and 5.73 μM, respectively. Higher nitrite values during summer could be due to oxidation of ammonia and reduction of nitrate and also due to bacterial decomposition of planktonic detritus (Govindasamy et al., 2000). The influence of water discharged was apparent during summer (15.616 μM). Low ammonia concentrations (3.61 μM) were recorded when compared with earlier studies (Dorgham et al., 2004; Nessim and Tadros, 1986). Station 1 is positioned between El-Naubaria Canal and Umum Drain, and so it sustained higher DIN concentrations during spring and autumn.

Phosphate concentrations were high (annual average: 2.409 μM) as compared to 0.84 μM, 0.46 μM and 1.18 μM recorded by Nessim and Tadros (1986), Zaghloul (1996) and Dorgham et al. (2004), respectively. While silicate concentrations gradually increased from 3.04 μM (Zaghloul, 1996) to 9.03 μM (Dorgham et al., 2004), it reached to 12.895 μM in the present study. In spite of diatoms are responsible for regulating silicate level because it is a fundamental nutrient for building diatom skeletons. It was observed that low concentrations of silicate during spring were accompanied by dense bloom of euglenoids and not of diatoms. In summer, silicate reached maximum levels in parallel with low diatom counts.

Minimum nutrient salts concentrations were recorded in spring, coinciding with reduced salinity, indicating that nitrogen and phosphorus were regulated by the quick phytoplankton uptake. Except in winter 2012, RS:DIN ratios tend to be lower than 1, indicating a potential limitation for diatom growth, and suggesting a possible advantage for dinoflagellate growth (Anderson et al., 2002). Calculations of potential nutrient limitation in the harbour waters suggest no limitation by PO_4.

Fluctuations in nutrient over time may cause significant changes in phytoplankton community and structure (Reynolds, 2006; Rojas-Herrera et al., 2012). Under very specific environmental conditions, some algae species may proliferate massively, forming harmful algal blooms. This phenomenon occurs near coasts, usually during warm seasons (Gárate-Lizárraga et al., 2008). They can be caused by increased nutrient discharge and also transport of toxigenic species in ship ballast water (Bauman et al., 2010).

In the WH quite a unique situation was observed in spring at all stations, this was the presence of a potentially harmful bloom of euglenoid flagellates *Eutreptiella*. More than 80% of the phytoplankton cell counts corresponded to *Eutreptiella*, except in station 5 (51.0%). On this occasion, minimum concentrations of *Eutreptiella* had already been detected in station 5, from which salinity recorded maximum value (34.2 PSU) and co-occurred with minimum of nutrient salt concentrations. During the days prior to event, gusty winds occurred, with a temperature range of 24.1—25.6°C and salinity range of 22.7—34.2 PSU, as well as green sea water discoloration. *Eutreptiella* sp. bloom reached a maximum concentration of 66×10^6 cells l^{-1} at station 6, with 99.8% dominance and no human health effects or intoxication was associated with this event, i.e., no fish death was observed. The genus comprises nine known species (Stonik, 2007) and is neritic worldwide, belonging to the marine or brackish water (Throndsen, 1993). Bravo-Sierra (2004) described the genus as coastal in polluted areas with high organic contamination, with no outbreaks or associated toxicity. No harmful bloom of *Eutreptiella* has been seen on Egyptian coastal waters before. It was previously recorded as a rare form in the Eastern Harbour southeastern Mediterranean Sea during 1997—1999 (Labib, 2002). The species was possibly new in the Mediterranean Sea, and so may have been introduced via ballast water. The findings of the genus during this study underline that ballast water releases may have been the likely introduction vector. The genus was also recorded in Kuwait's waters (Al-Kandari et al., 2009). It is common in the Baltic coastal waters, but rarely in high numbers (Olli et al., 1996), in Japan Sea (Konovalova, 2003) and in Turkish Seas (Turkoglu and Koray, 2004; Turkoglu, 2008). In 1990, it formed a bloom along the north shore of Nassau County, New York (Anderson et al., 2000).

In contrast to the vernal bloom of euglenoids, the zooplankton abundance increased with the dominance of tintinnid ciliates. This may be explained by the general inability of ciliates to feed on *Eutreptiella*. Ciliates mainly feed on nanosized prey, preferably nanoflagellates (Paranjape, 1990; Sherr and Sherr, 1994). Euglenoids are generally considered to be poor food items for zooplankton because their reserve product, paramylon, is rarely digestible for the grazers (Walne and Kivic, 1990). Although the cells may have been grazed by zooplankton, the paramylon grains passed undigested through the gut, thus diminishing the nutritional gain. Also, increases in jellyfish numbers have been observed, and this may be the result of planktonic food available in greater abundance (Mills, 2001).

Different species dominated in any season, indicating wide variability in species composition over time. Diatoms were found to be dominant during winter and autumn, which could be due to the fact that diatoms can tolerate the widely changing hydrographical conditions (Sushanth and Rajashekhar, 2012). *Asterionellopsis glacialis* and *Skeletonema costatum* were dominant during winter 2012 and the latter species formed >90% of the total abundance during autumn. These two dominant species appear to be confined to coastal Egyptian waters (Gharib et al., 2011; Gharib, 2006). The occurrence of *Skeletonema costatum* is as an indicator of eutrophication (Moncheva et al., 2001). The dominance of any species in the polluted water may be considered as an indicator species (Dorgham et al., 1987). During winter 2013, diatoms abundance was nearly similar to that of dinoflagellates. Dinoflagellates are better adapted to the oceanic environment, while diatoms are more adapted to coastal environments (Peña and Pinilla, 2002). The presence of variation in the seasonally cell abundances of these two groups suggests that environmental conditions in Western Harbour change during the year in response to variations in several physicochemical parameters.

Gyrodinium sp. was largely responsible for the notable increase in dinoflagellate abundance during summer. Jeong et al. (2011) found that *Gyrodinium* sp. has considerable potential grazing impact on the populations of the euglenophyte *Eutreptiella*, and this explains the blooming of *Gyrodinium* during summer after overwhelming of *Eutreptiella*.

Total phytoplankton richness (157 species) and diversity values (0.02—3.03) registered in the study area were higher than ranges previously reported (Gharib and Dorgham, 2006; Zaghloul, 1994), in spite of the seasonal sampling during the present study against monthly one in the previous study, with approximately complete replacement of the dominant species. The leader species were: *Cyclotella meneghiniana*, *Pseudonitzschia delicatissima*, *Prorocentrum cordatum* and *P. micans* during 1989 (Zaghloul, 1994) and altered to *Alexandria minutum*, *Skeletonema costatum*, *Prorocentrum triestinum*, *Pseudonitzschia seriata*, *Scripsiella trochoidea*, *Asterionella japonica* and *Prorocentrum micans* during 1999—2000 (Gharib and Dorgham, 2006).

As in many coastal zones and harbours of the Mediterranean basin, two peaks (spring and autumn) in zooplankton abundance are usually observed (Vasilievich et al., 2003). Higher diversity in the zooplankton population recorded at stations 1 and 2 were related to the existence of fresh and brackish water forms as the result of increased inflow of wastewater from Noubaria Canal.

Analysis of the main environmental influences on zooplankton abundances showed that pH and dissolved oxygen were the most important parameters, which positively affected the variation of zooplankton. In contrast, salinity exercised negative effects with Protozoa. Temperature does not appear to directly correlate with total zooplankton abundance. The conditioning effect of temperature on zooplankton groups is documented in large investigations (e.g. Marques et al., 2006). A total of 106 species were recorded in the present study, and this is slightly lower than the number recorded by Abdel-Aziz (2002) which amounted to 111 species.

Except in spring, copepods were the most abundant group and their average abundance value was >52% of total zooplankton and maximum value reached in autumn. The abundance of copepods steadily increased during winter and autumn with rising trend of salinity. Biodiversity of the copepod community was not adversely affected by the differences in the average nutrient load in the investigated area.

Oithona nana emerged as the most successfully adapted copepod species at both seasonal and spatial scales because it has the ability to consume a much wider range of food than the other copepods (Lampitt and Gamble, 1982), and it is very important in many neritic regions that are exposed to eutrophication (Richard and Jamet, 2001). The average abundances of this species ranked first among adult copepods in winter (78.1%), spring (66.9%), summer (60.7%) and autumn (39.9%). Apart from *Oithona nana*, among the top 4 species throughout the investigated area were *Oithona plumifera*, *Euterpina acutifrons* and *Paracalanus parvus*. *Oithona* spp., *Paracalanus parvus* and *Euterpina acutifrons* are the most ubiquitous and abundant copepods in the coastal Mediterranean (Gallienne and Robins, 2001). One of the characteristic features of the present observation was the relatively large occurrence of copepod nauplii (22.0% of the total zooplankton) which could be attributed to high density of older stage copepods (Uye et al., 2000).

Tintinnids had the highest species richness (29 spp.); meanwhile, they occupied the second order of abundance after copepods, forming 35.23% of the total count. Its predominance during spring could be due to their high reproductive capacity and euryhaline nature (Govindasamy and Kannan, 1991). *Schmidingerella serrata* was the dominant and attained abnormally higher counts in spring as compared to other seasons, which means that this species prefers salinity <30.0 PSU.

In other coastal waters of similar conditions like Abu Qir Bay and Dekhaila Harbour, tintinnids formed 27.8% and 65% of total zooplankton respectively, with the dominance of *Favella markuzowskii*, *Stenosemella nivalis*, in Abu Qir Bay (Abdel-Aziz, 2001) and *Favella serrata*, *Tintinnopsis lata* in Dekhaila Harbour (Abdel-Aziz, 2000). Rotifers attained their maximum abundance during summer, constituting 16.3% of the total zooplankton at water temperature of 28°C, salinity 37.0 PSU and pronounced high concentrations of nutrient salts.

Zooplankton diversity was positively correlated with both salinity and nutrient salt concentrations. These relationships suggest that low salinity and low nutrient concentrations decreases zooplankton.

In conclusions, not only the discharged water from canals and drains make the harbour at risk, but also the ballast water not less dangerous, and so, we emphasize the need for ballast water management to reduce the risk of future species invasions and further studies should be carried out frequently to monitor any change in species composition since ships arriving at the Western Harbour are increasing annually and also these concerns emphasize the need for activation of the ballast water management IMO Ballast Water Management Conventions to reduce the risk of future species invasions.

Acknowledgements

The authors are indebted to National Institute of Oceanography and Fisheries, Egypt on the financing of the project "Microbial and plankton estimation in the Western Harbour in relation to some environmental parameters". They also thank Prof. Manal El Nagar, head of Marine Microbiology Department, for supporting the research project.

References

Abdel-Aziz, N.E., 2000. Zooplankton dynamics and ecology of an eutrophic area, Egypt. Arab Gulf J. Sci. Res. 18 (2), 110—121.

Abdel-Aziz, N.E., 2001. Zooplankton in beach waters of the southeastern Abu Qir Bay. J. Egypt Acad. Soc. Environ. Dev. 2 (4), 31—53.

Abdel-Aziz, N.E., 2002. Impact of water circulation and discharged wastes on zooplankton dynamics in the Western Harbour of Alexandria, Egypt. Egypt J. Aquat. Biol. Fish. 6 (1), 1—21.

Al-Kandari, M., Al-Yamani, F., Al-Rifaie, K., 2009. Marine Phytoplankton Atlas of Kuwait's Waters. Kuwait Institute for Scientific Research, ISBN: 99906-41-24-2.

Anderson, D.M., Glibert, P.M., Burkholder, J.M., 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries 25, 704—726.

Anderson, D.M., Hoagland, P., Kaoru, Y., White, A.W., 2000. Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the Unites States. Woods Hole Oceanographic Institution, Woods Hole, MA.

APHA, 1995. Standard Methods, 19th ed. American Public Health Association, Washington, DC.

Bauman, A.G., Burt, J.A., Feary, D.A., Marquis, E., Usseglio, P., 2010. Tropical harmful algal blooms: an emerging threat to coral reef communities? Mar. Pollut. Bull. 60, 2117—2122.

Bravo-Sierra, E., 2004. Potentially toxic and harmful phytoflagellates from the Mexican Pacific coasts. Rev. Biol. Trop. 52, 5—16.

Domingues, R.B., Anselmo, T.P., Barbosa, A.B., Sommer, U., Galvão, H.M., 2011. Nutrient limitation of phytoplankton growth in the freshwater tidal zone of a turbid, Mediterranean estuary. Estuarine Coast. Shelf Sci. 91 (January (2)), 282—297 ISSN: 0272-7714.

Dorgham, M.M., Abdel-Aziz, N.E., El-Deeb, K.Z., Okbah, M.A., 2004. Eutrophication problems in the Western Harbour of Alexandria, Egypt. Oceanologia 46, 25—44.

Dorgham, M.M., EL-Samra, M.I., Mostafa, Th., 1987. Phytoplankton in an area of multi-polluting factors, west of Alexandria, Egypt. Qatar Univ. Sci. Bull. 7, 393—419.

Farag, M., 1982. Circulation patterns and hydrographic structure of El-Mex and Western Harbour area. M.Sc. Thesis, Fac. Sci., Alexandria Univ., Egypt.

Gallienne, C.P., Robins, D.B., 2001. Is Oithona the most important copepod in the world's oceans? J. Plankton Res. 23 (12), 1421—1432.

Gárate-Lizárraga, I., Pérez-Cruz, B., Díaz-Ortíz, J., Band-Schmidt, C. J., 2008. Microalgas y biotoxinas marinas en las costas mexicanas. Conversus 9, 22—26.

Gharib, S.M., 2006. Effect of freshwater flow on the succession and abundance of phytoplankton in Rosetta Estuary, Egypt. Int. J. Ocean Oceanogr. 1, 207—225.

Gharib, S.M., Dorgham, M.M., 2006. Eutrophication stress on phytoplankton community in the Western Harbour of Alexandria, Egypt. Int. J. Ocean Oceanogr. 1 (1), 261—273.

Gharib, S.M., El-Sherif, Z.M., Abdel-Halim, M., Radwan, A., 2011. Phytoplankton and environmental variables as a water quality indicator for the beaches at Matrouh, south-eastern Mediterranean Sea, Egypt: an assessment. Oceanologia 53 (3), 819—836.

Gollasch, S., 2002. The importance of ship fouling as a vector of species introductions into the North Sea. Biofouling 18, 105—121.

Govindasamy, C., Kannan, L., 1991. Ecology of rotifers of the Pichavaram mangroves (Southeast coast of India), a hydrographical approach. Mahasagar 24, 39—45.

Govindasamy, C., Kannan, L., Jayapaul, A., 2000. Seasonal variation in physico-chemical properties and primary production in the coastal water biotopes of Coromandel coast, India. J. Environ. Biol. 21, 1—7.

Hassan, M.H., Saad, N.N., 1996. Some studies on the effect of Alexandria Western Harbour on the coastal waters. In: Sixth International Conf. on "Environmental Protection is a Must", Alexandria, Egypt, 464—478.

Ignatiades, L., Karydis, M., Vounatsou, P., 1992. A possible method for evaluating oligotrophy and eutrophication based on nutrient concentrations. Mar. Pollut. Bull. 24 (5), 238—243, http://dx.doi.org/10.1016/0025-326X(92)90561-J.

Jeong, H.J., Kim, T.H., Yoo, Y.D., Yoon, E.Y., Kim, J.S., Seong, K.A., Kim, K.Y., Park, J.Y., 2011. Grazing impact of heterotrophic dinoflagellates and ciliates on common red-tide euglenophyte Eutreptiella gymnastica in Masan Bay, Korea. Harmful Algae 10, 576—588.

Kolar, C.S., Lodge, D.M., 2001. Progress in invasion biology: predicting invaders. Trends Ecol. Evol. 16, 199—204.

Konovalova, G.V., 2003. State of research on flagellate algae in the Russian waters of the Far Eastern seas. Int. J. Algae 5, 33—46.

Labib, W., 2002. Phytoplankton variability in the Eastern Harbour (Alexandria, Egypt). Egypt J. Aquat. Biol. Fish. 6 (2), 75—102.

Lampitt, R.S., Gamble, J.C., 1982. Diet and respiration of the small planktonic marine Copepod Oithona nana. Mar. Biol. 66, 185—190.

Marchetti, R., 1984. Quadro analitico complessivo del risultati delle indagini condotte negli anni 1977—1980. II.In: Problema dell'eutrofizzazione delle acque costiere dell'Emilia Romagna: situazione ipotesi di intervento, Regione Emilia Romagna, Bologna, p. 308.

Marques, S.C., Azeiteiro, M.U., Marques, J.C., Neto, J.M., Pardal, M. Â., 2006. Zooplankton and ichthyoplankton communities in a temperate estuary: spatial and temporal patterns. J. Plankton Res. 28, 297—312.

McGeoch, M.A., Butchart, S.H.M., Spear, D., Marais, E., Kleynhans, E. J., Symes, A., Chanson, J., Hoffmann, M., 2010. Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. Divers. Distrib. 16, 95—108.

Mills, C.E., 2001. Jellyfish blooms: are populations increasing globally in response to changing ocean conditions? Hydrobiologia 451, 55—68.

Moncheva, S., Gotsis-Skretas, O., Pagou, K., Krastev, A., 2001. Phytoplankton blooms in black sea and Mediterranean coastal ecosystems subjected to anthropogenic eutrophication: similarities and differences. Estuarine Coast. Shelf Sci. 53, 281—295.

Nessim, R.B., Tadros, A.B., 1986. Distribution of nutrient salts in the water and pore water of the Western Harbour of Alexandria, Egypt. Bull. Natl. Inst. Oceanogr. Fish. (Egypt) 12, 165—174.

Nessim, R.B., Zaghloul, F.A., 1991. Nutrients and chlorophyll in the polluted Kait Bey region, Alexandria. In: Proc. Symp. Mar. Chem. in the Arab Region, Suez, April 1991, 71—80.

Newton, A., Icely, J.D., Falcao, M., Nobre, A., Nunues, J.P., Ferreira, J.G., Vale, C., 2003. Evaluation of the eutrophication in the Ria Formosa coastal lagoon, Portugal. Cont. Shelf Res. 23, 1945—1961.

Olli, K., Heiskanen, A.S., Seppälä, J., 1996. Development and fate of Eutreptiella gymnastica bloom in nutrient-enriched enclosures in the coastal Baltic Sea. J. Plankton Res. 18, 1587—1604.

Paranjape, M.A., 1990. Microzooplankton herbivory on the Grand Bank (Newfoundland Canada): a seasonal study. Mar. Biol. 10, 321—328.

Peña, V., Pinilla, G.A., 2002. Composiciòn, distribuciòn y abundancia de la comunidad fitoplanctònica de la Ensenada de Utria, Pacifica colombiano. Rev. Biol. Mar. Oceanogr. 37, 67—81.

Reynolds, C.S., 2006. Ecology of Phytoplankton. Cambridge University Press.

Richard, S., Jamet, J., 2001. An unusual distribution of Oithona nana Giesbrecht (1892) (Crustacea: Cyclopoida) in a bay: the case of Toulon Bay (France, Mediterranean Sea). J. Coast. Res. 17, 957—963.

Rojas-Herrera, A.A., Violante-González, J., García-Ibáñez, S., Sevilla-Torres, V.M.G., Gil-Guerrero, J.S., Flores-Rodríguez, P., 2012. Temporal variation in the phytoplankton community of Acapulco Bay, Mexico. Microbiol. Res. 13—19.

Ruiz, G.M., Fofonoff, P.W., Carlton, J.T., Wonham, M., Hines, A.H., 2000. Invasion of coastal marine communities in North America, apparent patterns, processes, and biases. Annu. Rev. Ecol. Syst. 31, 481—531.

Saad, S.G., Abouzid, G., Saad, L.M., Mitwally, H., 1993. Impact of pollution in Alexandria Harbour. Bull. High Inst. Publ. Health 23 (3), 627—642.

Saad, M.A.H., Beltagy, A.I., Mahmoud, W.M., 2003. Total dissolved and particulate lead in the Western Harbour of Alexandria, a Mediterranean basin under stress. Mar. Pollut. Bull. 47 (Spec. Issue), 52—58.

Shannon, C.E., Wiener, 1963. The Mathematical Theory of Communications. University of Illinois, Urbana, 117 pp.

Sherr, E.B., Sherr, B.F., 1994. Bacterivory and herbivory: key roles of phagotrophic protists in pelagic food webs. Microb. Ecol. 28, 233—235.

Shriadah, M.M., Tayel, F.T., 1992. Environmental conditions of the Western Harbour of Alexandria, I-Physico-chemical characteristics. Bull. High Inst. Publ. Health, Alexandria, Egypt 22 (3), 213—228.

Sridhar, R.T., Thangaradjou, S., Senthil, K., Kannan, L., 2006. Water quality and phytoplankton characteristics in the Palk Bay, southeast coast of India, J. Environ. Biol. 27, 561—566.

Stonik, I., 2007. Species of the genus Eutreptiella (Eugleno-phyceae) from Russian waters of East/Japan Sea. Ocean Sci. J. 42, 81—88.

Sushanth, V., Rajashekhar, M., 2012. Seasonal variation in diatoms in response to physico-chemical characteristics of coastal waters of Uttara Kannada district, West Coast of India. Int. J. Environ. Sci. 2, 1543—1552.

Tadros, A.B., Nessim, R.B., 1988. The occurrence and distribution of some trace elements in Alexandria Western Harbour. In: 2nd Chemistry Conference, Fac. of Sci. Alex. Univ. 221—239.

Throndsen, J., 1993. The planktonic marine flagellates. In: Thomas, C.R. (Ed.), Marine Phytoplankton: A Guide to Naked Flagellates and Coccolithophorids. Academic Press Inc., London, 7—145.

Turkoglu, M., 2008. Synchronous blooms of the coccolithophore *Emiliania huxleyi* (Lohmann) Hay & Mohler and three dinoflagellates in the Dardanelles (Turkish Straits System). J. Mar. Biol. Assoc. UK 88 (3), 433—441.

Turkoglu, M., Koray, T., 2004. Algal blooms in surface waters of the Sinop Bay in the Black Sea, Turkey. Pak. J. Biol. Sci. 7, 1577—1585.

Utermöhl, H., 1958. Zur Vervollkommnung der quantitativen phytoplankton — methodik. Mitt. Int. Ver. Theor. Angew. Limnol. 9, 1—38.

Uye, S., Shimazu, T., Yamamuro, M., Ishitobi, Y., Kamiya, H., 2000. Geographical and seasonal variations in mesozooplankton abundance and biomass in relation to environmental parameters in Lake Shinji—Ohashi River—Lake Nakaumi brackish—water system. Jpn. J. Mar. Syst. 26, 193—207.

Vasilievich, A., Mazzocchi, M.G., Kideys, A.E., Toklu, B., Skryabin, V. A., 2003. Seasonal changes in the composition and abundance of zooplankton in the seas of the Mediterranean Basin. Turk. J. Zool. 27, 205—219.

Walne, P.L., Kivic, P.A., 1990. Phylum *Euglenida*. In: Margulis, L., Corliss, J.O., Melkonian, M., Chapman, D.J. (Eds.), Handbook of Protoctista. Jones and Bartlett Publishers, Boston, 270—287.

Zaghloul, F.A., 1994. Phytoplankton dynamics in the Western Harbour of Alexandria Egypt. Bull. Nat. Inst. Oceanogr. Fish. 20 (1), 107—117.

Zaghloul, F.A., 1996. Further studies on the assessment of eutrophication in Alexandria harbours Egypt. Bull. Fac. Sci. (Alexandria Univ.) 36 (1), 281—294.