ISSN 1996-3351

Asian Journal of Biological Sciences

http://knowledgiascientific.com

Knowledgia SCIENTIFIC
A Place to Publish Outstanding Research

OPEN ACCESS Asian Journal of Biological Sciences

ISSN 1996-3351
DOI: 10.3923/ajbs.2017.27.37

Research Article
Factors Regulating Composition and Abundance of Phytoplankton in El Dekhaila Harbor, South-Eastern Mediterranean Sea, Egypt

Hanan Mohamed Khairy and Samiha Mahmoud Gharib

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

Abstract
Background and Objective: The abundance and distribution of phytoplankton in harbors exhibits spatial and temporal variation. Many biotic and abiotic factors interact to regulate spatial and temporal variations in phytoplankton. This study was carried out to determine which factors can regulate the abundance and community structure of phytoplankton in El Dekhaila Harbor, South-Eastern Mediterranean Sea, Egypt. **Materials and Methods:** Samples of phytoplankton were gathered during 2012 in El Dekhaila Harbour, for statistical tests three indices were utilized to get the estimation of species diversity (H'), species richness (d) and species evenness (J) and also Pearson's Correlation Coefficient (r) was utilized for the simple relationship analysis with the variables. **Results:** Phytoplankton groups were essentially made out of Bacillariophyceae (84.58%) and also, have been determined as the richest group in species variety with 72 taxa. Summer had higher phytoplankton density, however autumn had higher richness and evenness. *Skeletonema costatum*, *Pseudo-nitzschia seriata*, *Chaetoceros curvisetus* and *Prorocentrum* spp. were frequently recorded. El Dekhaila Harbor suffered of high concentrations of both inorganic nitrogen and dissolved reactive phosphate. **Conclusion:** Zooplankton grazing activity on phytoplankton may assume a critical factor in regulating the phytoplankton community structure in El Dekhaila Harbor and not the concentrations of nutrient salts or their ratios.

Key words: Phytoplankton community, environmental factors, zooplankton grazing

Received: January 14, 2017 Accepted: February 28, 2017 Published: March 15, 2017

Citation: Hanan Mohamed Khairy and Samiha Mahmoud Gharib, 2017. Factors regulating composition and abundance of phytoplankton in El dekhaila harbor, South-Eastern Mediterranean Sea, Egypt. Asian J. Biol. Sci., 10: 27-37.

Corresponding Author: Samiha Mahmoud Gharib, Department of Hydrobiology, National Institute of Oceanography and Fisheries, Alexandria, Egypt
Tel: +201005369629

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Pollution in marine environments had turned out to be one of the troublesome problems and it has been developed wherever all through the system of the marine natural life. A large portion of the projects on the planet earth are settled in the water bodies of the countries, particularly, around significant commercial harbors because of simplicity of exchange, which adds to serious pollution.

Phytoplankton community structures are extremely complex qualitatively and quantitatively. Succession shifts in phytoplankton community structure are basically a result of changes in ecological factors (e.g., type, concentration and of nutrient salts limitation) as well as possibly moves in higher trophic levels (e.g., zooplankton)[1-4]. Recognizing the natural variables that manage phytoplankton community structure is essential for encouraging the elaboration of wide theories of pervasive ecological issues, for instance, eutrophication and harmful algal blooms[5,6].

El-Mex Bay is located in the southeastern side of the Mediterranean at longitude 29°45' and 29°54' E and latitude 31°07' and 31°15' N, with an average depth around 10 m and surface area of around 19.4 km^2. The bay is a very dynamic system and of extraordinary natural, since it receives a huge amount of agricultural, industrial and sewage wastes from the nearest Lake Mariut through El-Umoum Drain amounted 2.547×10^9 m^3 y^{-1}[7]. The discharged water input impact on all the water life, particularly the phytoplankton community structure.

El Dekhaila Harbor is located on the western side of El-Mex Bay and is considered one of the most famous commercial harbor in Egypt. The harbor's water is subjected to multisource of wastewaters beginning from El-Mex Bay through El-Umoum Drain[8,9], impacted to a great extent by anthropogenic components, which cause inhibition and promotion of the plankton development[10,11].

Few studies have been done on the physical and chemical characteristics of El Dekhaila Harbor water[8,12,13]. Several studies of phytoplankton community structure have been done in El-Mex Bay and the adjacent waters[14,15,11]. Zaghloul *et al.*[15] studied the phytoplankton in El Dekhaila Harbor and recorded *Merismopedia punctata*, *Ankistrodesmus falcatus*, *Euglena granulate*, *Skeletonema costatum*, *Nitzschia microcephala* and *Protoperidinium minutum* as the overwhelming species in the harbor during 1990-1991.

Ismael and Dorgham[11] detected the overwhelming species among 107 taxa were *Prorocentrum micans*, *Oscillatoria* sp., *Cerataulina smithii*, *Pseudonitzschia sigma*, *Spirulina* sp., *Gymnodinium minor*, *Coscinodiscus radiates, Euglena acus*, *Prorocentrum minimum*, *Protoperidinium curvipes, Chlorella* c.f. sp., *Cyclotella meneghiniana*, *Scrippsiella trochoidea*, *Prorocentrum triestinum*, *Cyclotella striata* and *Skeletonema costatum*.

Ismael and Abdel-Aziz[16] studied the relationship between phytoplankton and zooplankton in the harbor. Shaltout and Abd-El-Khalek[13] studied the chemical properties, while Heneash[17] investigated the zooplankton in the harbor during 2012, parallel to the present work and the collection of samples was at the same time and at same stations.

The objective of this study was to investigate the phytoplankton community structure, including the seasonal variation, species composition and cell densities and distribution. Ecological parameters controlling seasonal variety in the phytoplankton community are discussed, which will give knowledge into the relationships among physical, chemical and biological components in El Dekhaila Harbor.

MATERIALS AND METHODS

El Dekhaila Harbor is a semi-enclosed basin built after 1986. It expects an essential role in the export and import of products, as minerals, metals, manures, salts and grains. It involves the western part of El-Mex Bay (Fig. 1) and has a surface area of about 12.5 km^2 and a water depth ranging from 4-20 m with an average of 12.4 m.

Water samples were gathered four times per the year 2012 at nine stations with a Rüttner sampler. The chosen periods relating to winter (January), spring (April), summer (August) and autumn (November). Water samples were collected at a depth of 50 cm at the examined stations; the physicochemical parameters were measured and the results were published by Shaltout and Abd-El-Khalek[13] and the zooplankton was also studied and published by Heneash[17]. The gathered water samples were quickly fixed with 4% formaldehyde for phytoplankton examination. Phytoplankton was counted utilizing 2 mL settling chambers with a Nikon TS 100 inverted microscope at 400X magnification utilizing Utermohl's technique[18]. Identification of phytoplankton species was carried following previous studies[19-25].

A basic mercury thermometer was used to quantify water temperature. Saltiness was measured by a Beckman acceptance salinometer (Model RS-7B).

Statistical analysis: Three indices were used estimate species diversity (H)[26], species richness (d)[27] and species evenness (J)[28]. The Pearson's correlation coefficient (r) was utilized for the simple relationship analyses with the variables (N = 36) with SPSS 8.0 Statistical Package Program.

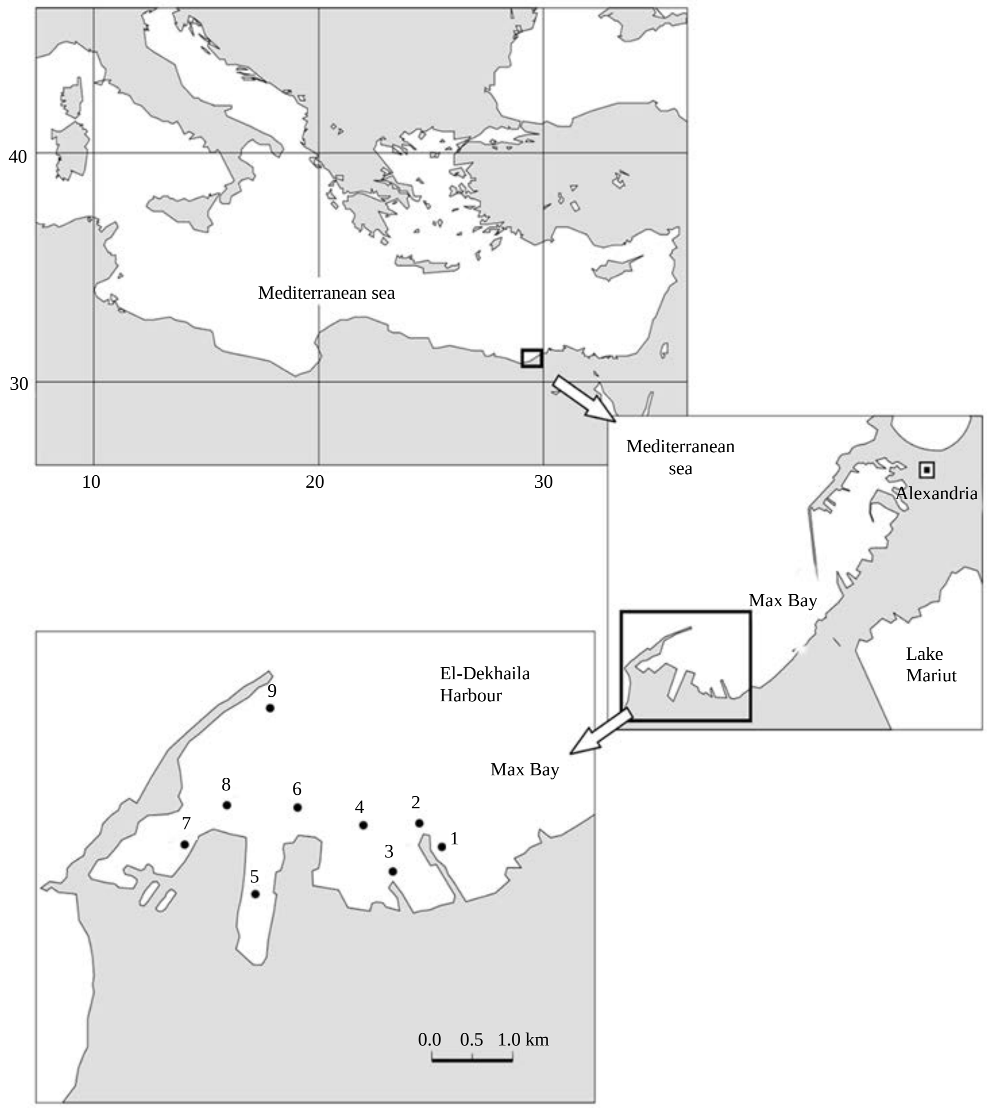

Fig. 1: Area of study and sampling sites

RESULTS

Hydrographic conditions: The assessed chemical parameters were already published by Shaltout and Abd-El-Khalek[13]. Surface water temperature in El Dekhaila Harbor changed from a minimum of 16.2°C in winter to a maximum of 28.7°C in summer. The surface salinity varied between 28.9 and 35.6 PSU with an average annual of 33.9±SD 1.8 PSU. The lowest values were recorded at station 6 (32.5±2.4) and the highest at station 3 (34.9±1.3). The seasonally average salinity demonstrated significantly lower values than those generally recorded in Egyptian coastal waters (>38 PSU).

Phytoplankton community structure and composition: From the analyzed data, an obvious change in phytoplankton community as to numerical abundance and species composition among stations and in the seasonal cycle. A total of 141 phytoplankton species were quantified through the examination of the 36 samples collected from nine stations in four seasons. Bacillariophyceae made up the highest number (34 genera, 72 species), yet there was a strikingly low number of Dinophyceae (14 genera, 43 species). Freshwater Chlorophyceae, Cyanophyceae and Euglenophyceae were represented by 14, 9 and 3 species, respectively. The most illustrative genera were *Navicula* (13 species) and *Nitzschia* (10 species). Bacillariophyceae and Dinophyceae were more

Table 1: Taxonomic composition and proportional representation of the phytoplankton groups in El Dekheila Harbor during 2012

Groups	Genus	Species	%	Cells (mL^{-1})	%
Bacillariophyceae	34	72	51.06	7885	84.58
Dinophyceae	14	43	30.50	567	6.08
Chlorophyceae	10	14	9.93	429	4.60
Cyanophyceae	6	9	6.38	236	2.54
Euglenophyceae	3	3	2.13	206	2.21
Total	67	141	100.00	9323	100.00

Table 2: Taxonomic composition of phytoplankton sampled during 2012 in El Dekhaila Harbor

	Diatoms		Dinophyceae		Chlorophyceae		Cyanophyceae		Euglenophyceae		Total		Mean relative abundance
Seasons	G	S	G	S	G	S	G	S	G	S	G	S	(cells mL^{-1})
Winter	33	61	12	31	7	10	6	8	3	3	61	113	6888
Spring	35	67	11	41	9	14	6	9	1	3	62	134	11549
Summer	35	70	10	39	8	10	5	6	1	3	59	128	14014
Autumn	34	65	12	40	9	12	4	6	1	3	60	126	4841
Total	34	72	14	43	10	14	6	9	3	3	67	141	9323

G: No. of genera, S: No. of species

abundant both qualitatively (81.56%) and quantitatively (90.66%) than the other taxonomic groups. They were obvious as the two most diverse groups with 51.06 and 30.50% of the total species number, respectively (Table 1).

While Bacillariophyceae was quantitatively the overwhelming division (84.58%), the total number of species on the analyzed stations showed more pronounced varieties at the spatial scale than the temporal one. A high diversity (132 and 131 species) was recorded at stations 1 and 9, while stations 3 and 4 sustained 125 and 126 species, respectively. Approximately comparable numbers of species (120-123 species) were recorded at stations 2, 5, 6 and 7. An obviously smaller number (119 species) was found at station 8. The numbers of phytoplankton species recorded in winter, spring, summer and autumn were 113, 134, 128 and 126, respectively (Table 2) and the maximum number of species in a single sample was 105, at station 1 during summer. Among the recorded species, 103 were perennial; 58 diatoms, 28 Dinophyceae, 5 Cyanophyceae, 9 Chlorophyceae and 3 Euglenophyceae.

Mean phytoplankton density was highest at station 3 (11852 cells mL^{-1}) and least at station 7 (7359 cells mL^{-1}), with an average annual density amounted 9323 cells mL^{-1}. Bacillariophyceae overwhelmed over dinoflagellates at all the harbor examining stations. The bottom-dwelling forms (Pennales) made up 38 species, while the truly planktonic forms (centrales) made up 34 species. The most abundant pennate diatoms recorded were *Pseudo-nitzschia seriata* (Cleve) H. Peragallo, 1899 (16.17*%), Asterionellopsis glacialis* (Castracane) Round, 1990 (7.04%) and *Pseudo-nitzschia delicatissima* (Cleve) Heiden, 1928 (3.25%). The true planktonic diatoms recorded *Skeletonema costatum* (Greville) Cleve, 1873 (21.07%), *Chaetoceros curvisetus* Cleve, 1889 Cleve (7.21%), *Leptocylindrus danicus* Cleve, 1889 (6.67%), *Thalassiosira rotula* Meunier, 1910 (6.57%) and *Cyclotella meneghiniana* Kützing (6.36%) as their overwhelming representative during the study time. *Prorocentrum micans* Ehrenberg, 1834 (16.13%), *Prorocentrum triestinum* J. Schiller, 1918 (14.66%), *Prorocentrum cordatum* (Ostenfeld) J.D. Dodge, 1975 (11.90%), *Prorocentrum minimum* (Pavillard) J. Schiller, 1933 (10.94%) and *Protoperidenium minutum* (Kofoid) Jørgensen, 1912 (9.08%) were the most abundant heterotrophic dinoflagellate recorded. Chlorophyceans were represented chiefly by *Scenedesmus communis* E. Hegewald, 1977, *Ankistrodesmus falcatus* (Corda) Ralfs, 1848 and *Chlorella marina* Butcher R. W., 1952. *Merismopedia* Meyen, 1839 and *Oscillatoria* Vaucher ex Gomont, 1892 dominating the cyanobacterial population and euglenoids typically represent a minor extent of the community and was represented by the genus *Euglena* Ehrenberg, 1830.

In Shannon-Wiener status, the maximum diversity recorded (H' = 3.387) was found in autumn at station 9, while the minimum (H' = 2.631) was recorded in summer at station 6. The general mean were 2.989±0.108 (winter), 3.064±0.141 (spring), 2.690±0.042 (summer), 3.174±0.107 (autumn). On the other hand, diversity and richness took after a similar pattern at most stations. High diversity was connected with high richness. Evenness demonstrated significant relation with diversity ($r = 0.925$, $p<0.001$) and insignificant with richness ($r = 0.095$, $p = 0.582$). The increase in richness was connected with increasing salinity ($r = 0.526$, $p<0.05$).

The correlation between phytoplankton density and diversity was strongly negative ($r = -0.650$, $p<0.001$) and it is evident that low diversity implies that a stress increases with poor water quality, while the inverse is valid for high diversity results with favorable condition. Species evenness (J) ranged between 0.591 in summer (station 6) and 0.753 in autumn

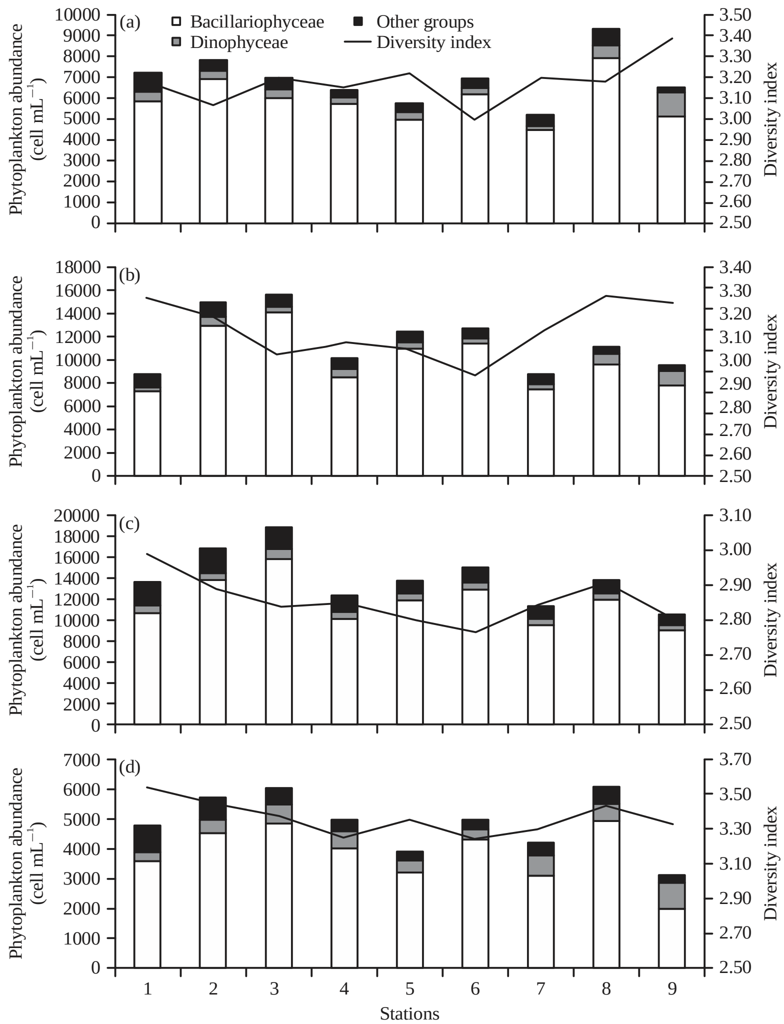

Fig. 2(a-d): Seasonal variations of phytoplankton abundance subdivided by algal groups and species diversity index of El Dekhaila Harbor from winter to autumn 2012 (a) Winter, (b) Spring, (c) Summer and (d) Autumn

(station 9), with moderately higher values generally recorded during autumn. On the other hand, diversity and evenness took after a similar pattern at most stations. Testing the diversity-equitability, diversity-species number and diversity richness relationship demonstrated that diversity was extensively uninfluenced by species number ($r = 0.197$, $p = 0.249$) and showed a strong significant relation with equitability ($r = 0.925$, $p<0.001$). As expected, diversity had a positive relationship with Margalef's index ($r = 0.447$, $p<0.05$).

Seasonal variation of phytoplankton: The average phytoplankton density was 9323±1591 cells mL^{-1} and the most elevated values were registered in summer and the least values were in autumn. There was a high vacillation in cell density when the temporal distribution of phytoplankton groups was examined. The phytoplankton community comprised mainly of Bacillariophyceae (84.58%) and too much lower extent Dinophyceae (6.08%) (Fig. 2), which exhibited a pronounced increase in autumn (11.02%), while Chlorophyceae, Cyanophyceae and euglenoids collectively fluctuated between 9.9 and 11.3% of the total density.

During winter, the seasonal mean total phytoplankton cell abundance was 6888±1194 cells mL^{-1}, with most significant cell density recorded in station 8, while the least density recorded in station 7. Bacillariophyceae (79.01-90.32%) was the overwhelming division at all the stations. The diatom *Skeletonema costatum* was a major component (15.33% of the total phytoplankton) followed by *Thalassiosira rotula* (9.35%), *Leptocylindrus danicus* (7.85%), *Pseudo-nitzschia delicatissima* (7.17%) and *Chaetoceros curvisetus* (6.95%) (Table 3). Dinophyceae exhibited a pronounced percentage at station 9 (17.63%), stations 5 and 8 (6.39%), while

Table 3: Top 15 dominant phytoplankton species sampled during 2012 and their percentage to the total phytoplankton in El Dekhaila Harbor

Winter	%	Spring	%	Summer	%	Autumn	%
Skeletonema costatum	15.33	*Skeletonema costatum*	15.25	*Skeletonema costatum*	23.99	*Chaetoceros curvisetus*	11.68
Thalassiosira rotula	9.35	*Pseudo-nitzschia seriata*	10.30	*Pseudo-nitzschia seriata*	22.26	*Skeletonema costatum*	9.62
Leptocylindrus danicus	7.85	*Leptocylindrus danicus*	6.89	*Asterionellopsis glacialis*	5.42	*Pseudo-nitzschia seriata*	9.55
Pseudo-nitzschia delicatissima	7.17	*Asterionellopsis glacialis*	6.62	*Dactyliosolen fragilissimus*	5.31	*Dactyliosolen fragilissimus*	9.08
Chaetoceros curvisetus	6.95	*Thalassiosira rotula*	6.01	*Thalassiosira rotula*	5.02	*Cyclotella meneghiniana*	8.88
Nitzschia microcephala	6.70	*Cyclotella meneghiniana*	5.68	*Aulacoseira granulata*	4.86	*Chaetoceros affinis*	6.28
Melosira varians	6.25	*Chaetoceros curvisetus*	5.42	*Chaetoceros curvisetus*	4.31	*Asterionellopsis glacialis*	5.88
Asterionellopsis glacialis	5.98	*Melosira varians*	4.07	*Leptocylindrus danicus*	4.13	*Leptocylindrus danicus*	3.94
Cyclotella meneghiniana	5.12	*Cylindrotheca closterium*	3.82	*Cyclotella meneghiniana*	4.06	*Navicula cryptocephala*	2.64
Pseudo-nitzschia seriata	4.78	*Nitzschia microcephala*	3.72	*Scenedesmus communis*	1.89	*Ankistrodesmus falcatus*	2.08
Nitzschia sigma	2.80	*Nitzschia sigma*	3.64	*Merismopedia punctata*	1.85	*Prorocentrum triestinum*	1.82
Dactyliosolen fragilissimus	2.50	*Pseudo-nitzschia delicatissima*	3.41	*Lepocinclis acus*	1.64	*Prorocentrum micans*	1.59
Proboscia alata	2.02	*Scenedesmus communis*	2.69	*Ankistrodesmus falcatus*	1.45	*Pseudo-nitzschia delicatissima*	1.56
Scenedesmus communis	1.63	*Dactyliosolen fragilissimus*	2.44	*Euglena granulata*	1.23	*Scenedesmus communis*	1.52
Prorocentrum micans	1.40	*Proboscia alata*	1.77	*Prorocentrum triestinum*	0.96	*Lepocinclis acus*	1.40

Chlorophyceae (2.57-7.63%) was the second group at stations 1, 2, 3, 6 and 7. The most significant contributor to the dinflagellates community structure was the genus *Prorocentrum* with three species. *Scenedesmus communis* and *Ankistrodesmus falcatus* were the most green algae observed. Cyanophyceae was rarely recorded, with more persistence of *Merismopedia punctata* Meyen, 1839 at station 1, while euglenoids achieved least numbers at most stations.

Spatial change of phytoplankton occurred in spring and fluctuated widely as to abundance and predominant species, with a mean achieved 11549±2547 cells mL^{-1}. The total density fluctuated between 8689 cells/ml (station 7) and 15585 cells mL^{-1} (station 3). Diatoms achieved the most remarkable percentage (81.72-90.19%), while Dinophyceae dropped to 5.43%. The most abundant and frequent species to the total phytoplankton were *Skeletonema costatum* (15.25%), *Pseudo-nitzschia seriata* (10.30%), *Leptocylindrus danicus* (6.89%), *Asterionellopsis glacialis* (6.62%), *Thalassiosira rotula* (6.01%), *Cyclotella meneghiniana* Kützing, 1844 (5.68%) and *Chaetoceros curvisetus* (5.42%) (Table 3). Dinophyceae was second in importance (3.09-13.97%) at stations 4, 5, 6, 8 and 9, while Chlorophyceae (3.54-7.06%) at stations 1, 2, 3 and 7. The genera *Protoperidenium* and *Prorocentrum* from Dinophyceae and *Scenedesmus* from green algae were frequently noticed.

Phytoplankton flourishes during summer to achieve an average of 14014±2611 cells mL^{-1}. The density ranged between 10518 cells mL^{-1} (station 9) and 18851 cells mL^{-1} (station 3). Bacillariophyceae (78.60-86.88%) dominated the harbor at all stations. *Skeletonema costatum* and *Pseudo-nitzschia seriata* were the leaders forming 23.99 and 22.26% of the total abundance (Table 3). Running with this summer, a lesser density of dinoflagellates (3.87-5.62%) showed up obviously at stations 3 and 8. Chlorophytes showed up (3.10-7.04%) at stations 1, 2 and 9. The genus *Prorocentrum* (4 species) and *Scenedesmus communis* were frequently observed. Cyanophyceans and euglenophyceans constituted all 6.89 % of the total phytoplankton.

The most minimal phytoplankton abundance was seen in autumn (4841±1002 cells mL^{-1}). The percentage of diatoms decreased (79.07%), while the percentage of the dinoflagellates increased (11.02%). *Chaetoceros curvisetus* (11.68%), *Skeletonema costatum* (9.62%), *Pseudo-nitzschia seriata* (9.55%) and *Rhizosolenia fragilissima* Bergon, 1903 (9.08%) co-dominating the phytoplankton community (Table 3). With the exception of station 1, dinoflagellates were the second most abundant group making up 7.14-27.83% of the total phytoplankton. The genera *Prorocentrum* was the overwhelming. Chlorophyceae formed 8.66% of the total phytoplankton at station 1, in which *Ankistrodesmus falcatus* and *Scenedesmus communis* were frequently recorded. The development of euglenoids achieved the greatest at stations 1 and 2 (7.71 and 6.22%, respectively). Cyanophyceae significantly observed at station 8 (2.21% of the total phytoplankton). The percentage composition of Chlorophyceae at station 1 was extensively higher than different stations and generally second in important during the year round.

Phytoplankton community in relation to physico-chemical characteristics: Spearman rank correlation analyses were performed on environmental parameters and phytoplankton groups in order to research significant relationships. Salinity variations in El Dekhaila Harbor (28.89-36.46 PSU) impact on behavior characters of the other bio-physicochemical variations because of the terrestrial releases originating from Umoum Drain loaded by domestic, farming and mechanical waste water and furthermore by global passing exercises by vessels. For example, correlations between salinity variations and other physicochemical parameters demonstrated significant correlations, as dissolved oxygen ($r = -0.356$, $p<0.05$), dissolved phosphate (-0.445, $p<0.05$) and pH ($r = 0.343$, $p<0.05$).

Temperature was correlated with phytoplankton abundance ($r = 0.491$, $p<0.05$) and comparably with diatoms ($r = 0.447$, $p<0.05$), Cyanophyceae ($r = 0.598$, $p<0.001$), Chlorophyceae ($r = 0.450$, $p<0.05$) and Euglenophyceae ($r = 0.763$, $p<0.001$), yet no significant correlations were found between the biological variables and water salinity. Positive correlations were found between pH and phytoplankton abundance ($r = 0.500$, $p<0.05$) and similarly with diatoms ($r = 0.458$, $p<0.05$), Cyanophyceae ($r = 0.712$, $p<0.001$), Chlorophyceae ($r = 0.429$, $p<0.05$) and Euglenophyceae ($r = 0.671$, $p<0.001$). Negative correlations were found between phytoplankton abundance and nitrate ($r = -0.783$, $p<0.001$), nitrite ($r = -0.701$, $p<0.001$) and ammonia ($r = -0.391$, $p<0.05$). Phytoplankton biomass (Chlorophyll-a) was strongly correlated with phosphate ($r = 0.777$, $p<0.001$) and silicate ($r = 0.519$, $p<0.05$) and negatively correlated with ammonia ($r = -0.412$, $p<0.05$). Nitrate and nitrite were correlated with diatoms ($r = -0.782$ and $r = -0.701$ at $p<0.001$, respectively), Cyanophyceae ($r = -0.656$ and $r = -0.568$ at $p<0.001$, respectively), Chlorophyceae ($r = -0.538$ and $r = -0.400$ at $p<0.05$, respectively) and Euglenophyceae ($r = -0.635$, $p<0.001$) and ($r = -0.487$, $p<0.05$), respectively. None of the other correlations between dinophyceae and environmental variables were statistically significant ($p> 0.05$).

Among the predominant phytoplankton species, *Skeletonema costatum* and *Pseudo-nitzschia seriata* demonstrated significant positive correlations with temperature ($r = 0.604$; $r = 0.771$, respectively) and pH values ($r = 0.667$, $r = 0.793$, respectively) at $p<0.001$.

DISCUSSION

El Dekhaila Harbor is characterized by high nitrogen and phosphorus concentrations[8,29,12]. The results of chemical parameters after Shaltout and Abd-El-Khalek[13], demonstrated that the annual averages nitrate and ammonia concentrations were 6.67 and 13.22 μM, respectively, these values are higher than the levels of eutrophication (4 and 2 μM) proposed by Franco[30]. Reactive phosphate averaged 5.93 μM, this value is pronouncedly more noteworthy than the eutrophication limit (0.3 μM) that appointed by Marchetti[31] and Stirn[32]. The concentration of reactive silicate increased from 14 μM[12] during 1998-99 to achieve 34.72 μM[13]. Then again, Chlorophyll-a demonstrated a pronounced diminish from an average of 107.5 μg L^{-1}[12] to a mean of 60.83 μg L^{-1}[13].

The phytoplankton community in El Dekhaila Harbor was mainly made out of diatoms throughout the year. The pioneer of diatoms could be due to their ability to adjust quickly to the changing in the environmental conditions[33]. The prevalence of diatoms over different groups is similar to observations in many other eutrophic environments in Egypt, for example, Eastern Harbor and Kayet Bey[34-36] and in Rosetta and Abu-Qir[37].

Bacillariophyceae consisted of centric (34 species) and pennate (38 species) forms. The dominance of pennate over the centric seems, by all accounts, to be a typical component in various estuaries[38]. Pennate forms of diatoms observed in this work were mostly represented by *Navicula* and *Nitzschia*. The centric forms of Bacillariophyta in El Dekhaila Harbor were generally represented by *Skeletonema costatum* and too much lesser degree *Leptocylindrus danicus*. The last species has not been archived before from El Dekhaila Harbor[15,11].

Species of dinoflagellates were often recognized, specifically; *Prorocentrum micans*, *Prorocentrum triestenium, Prorocentrum cordata, Prorocentrum minimum* and *Protoperidenium minutum*. These species are known globally as harmful algal bloom-forming genera and are known to produce toxins[39].

Phytoplankton community structure in El Dekhaila Harbor was seen to be controlled by 7 diatoms which constituted collectively >60% of the total phytoplankton density; *Skeletonema costatum* (17.82%), *Pseudo-nitzschia seriata* (13.68%), *Chaetoceros curvisetus* (6.10%), *Asterionellopsis* *glacialis* (5.95%), *Leptocylindrus danicus* (5.64%), *Thalassiosira rotula* (5.55%) and *Cyclotella meneghiniana* (5.38%). These species as was showed up in eutrophicated environments, for example, in Eastern Mediterranean[40,41]. Of these, the two first species are neritic, cosmopolitan and consider as an indicator of eutrophication[42] and known as toxin production[43].

Positive correlation was seen between phytoplankton density and both of water temperature ($r = 0.497$, $p<0.05$) and pH values ($r = 0.506$, $p<0.05$). Furthermore, cell densities of Bacillariophyceae, Chlorophyceae, Euglenophyceae and Cyanophyceae were correlated with pH and water temperature. Ismael and Dorgham[11] demonstrated that salinity is the most important factor controlling the phytoplankton succession in El Dekhaila Harbor.

A negative correlation was seen amongst diatoms and each of NO_3 ($r = -0.783$, $p<0.05$), NO_2 ($r = -0.701$, $p<0.001$) and ammonia ($r = -0.391$, $p<0.05$), which means that diatoms can assimilate nitrogen in the form of nitrate, nitrite and to less extent ammonium.

Among the nutrients, silicate did not impact on phytoplankton multiplication as it exhibited no significant relation between silicate and phytoplankton abundance ($r = 0.007$, $p = 0.969$) and Chl-a ($r = 0.519$, $p<0.001$). This correlation implies an excess of silicate present in the system. A comparative observation was clear with PO_4, in which it exhibited no correlation with phytoplankton abundance ($r = 0.129$, $p = 0.452$), but showed strong correlation with Chl-a ($r = 0.777$, $p<0.001$). This indicated that PO_4 concentrations play a critical part in governing the instantaneous rates of chlorophyll *a* and not of phytoplankton density.

Phytoplankton abundance weakly correlated with chlorophyll *a* ($r = 0.452$, $p<0.05$), this might be because of the presence of large numbers of picoplankton or nanoplankton cells which unfortunately were not checked during the present study. The essential portion of the phytoplankton was connected to the presence of diatoms, which were positively correlated with chlorophyll a ($r = 0.491$, $p<0.05$) and with dinoflagellates was not significant ($r = 0.059$, $p = 0.733$) or other taxonomic groups, so chlorophyll *a* was just controlled by diatoms.

Chiaudiani and Vighi[44] showed when N:P lies in the 4.5-6 range, the assimilation of the two elements by marine algae is about ideal, however at a ratio of >6, phosphorus transforms into the limiting element and when N:P <4.5, nitrogen is the limiting variable. El Dekhaila Harbor was characterized by low N:P ratio during winter and spring and high ratio in summer and autumn. The average values of N:P in winter, spring, summer and autumn were 1.94, 1.08, 44.60 and 208.94, respectively. Diatoms can easily become dominant when developing in non-limiting conditions[5], though when nutrients are limited, diatoms are more easily influenced than dinoflagellates, particularly under phosphorus limitation[45]. However, there is no evidence of nitrogen or phosphorus limitation in El Dekhaila Harbor; indeed, phytoplankton density reflected high phytoplankton abundance all the year round. Moreover, the minimal phytoplankton density in autumn (average 4841 ± 1002 cells mL^{-1}) coincided with the maximum N:P ratios (22-364). It subsequently appears that a variable N:P ratio is not a sign of nitrogen or phosphorus limitation or the species composition of the phytoplankton community. Extreme fluctuation of N:P is common along the Mediterranean coast of Egypt, especially in zones presented to land-based runoff[46,47,15,10].

Egge[45] considered that when silicate concentration in the system was >2 µmol L^{-1}, diatoms could overwhelm the phytoplankton community if other different nutrients were sufficient. In the 4 cruises, the average silicate concentrations were clearly higher than this value and fluctuating between 10 and 78 µM, this implies that silicate was sufficient and couldn't be limiting factor in El Dekhaila Harbor, thus phytoplankton abundance versus Si:P ratios demonstrated no prominent relationship ($r = -0.320$, $p = 0.057$). Roberts *et al.*[48] suggested that diatom development can be restricted by dissolved silica when the N:Si ratio is over 1:1, while Guo *et al.*[49] recommended that N:P ratio, however evidently not Si:N, is argued to be a significant factor in controlling phytoplankton community structure. The mean N:Si ratios were 0.64 in winter; 0.29 in spring; 0.65 in summer, however, the ratio increased to achieve 1.76 in autumn. The ratios in the first three seasons promoted diatom development (6×10^6-12×10^6 cells L^{-1}) but during autumn, the DIN:DSi ratios were over 1 (1.76) which makes this period less favorable for diatom development, thus lowest diatom density was recorded during autumn (4×10^6 cells L^{-1}).

Other than the factors that controlling phytoplankton abundance discussed above, grazing can be of great importance in species succession if there is specific grazing on one particular phytoplankton group. To discuss this relation in El Dekhaila Harbor, multiple regressions between the total zooplankton groups, that studied by Heneash[17] and the predominant phytoplankton species and furthermore between selected zooplankton species and the dominant species of phytoplankton were performed using SPSS Programme.

Copepods as the predominant group in El Dekhaila Harbor were significantly and negatively correlated with diatoms as a phytoplankton group ($r = -0.502$, $p<0.05$) and with the prevailing species; *Skeletonema costatum* (r = -0.583, p<0.001); *Pseudo-nitzschia seriata* (r = -0.509, p<0.05); *Thalassiosira rotula* (r = -0.466, p<0.05). Additionally, protozoa as a group was negatively correlated with diatoms (r = -0.437, p<0.05) and some of the predominant species; *Skeletonema costatum* (r = -0.423, p<0.05), *Asterionellopsis glacialis* (r = -0.464, p<0.05), yet no relation with *Leptocylindrus danicus* and *Thalassiosira rotula*. It shows up from the correlations that dinoflagellate as a group or dinoflagellate as a species are unsuitable as a prey for zooplankton; a similar observation was recorded by Ismael and Abdel-Aziz[16], thus no relationship was found amongst dinoflagellates and zooplankton or any group and zooplankton species. The results showed a significant negative correlation between copepod *Oithona nana* and diatoms as a group (r = -0.576 , p<0.001) and with the diatom species as *Skeletonema costatum* (r = -0.600, p<0.001) and other diatom species at p<0.05 *as Pseudo-nitzschia seriata* (r = -0.564); *Asterionellopsis glacialis* (r = -0.488); *Leptocylindrus danicus* (r = -0.416); *Thalassiosira rotula* (r = -0.432). Guergues[50], examined the gut content of *Acanthocyclops americanus* and found that it contain mainly the chlorophyte species and concluded also that feeding in *A. americanus* is not aimless but rather selective.

In spite of the fact that tintinnids represent the second important component among zooplankton, they showed a negative correlation with diatoms (r = -0.487) and other diatom species as *Asterionellopsis glacialis* (r = -0.501); *Skeletonema costatum* (r = -0.484) at p<0.05 and stay away from other diatoms species. Smetacek[51] presumed that in the pelagic environment the ciliate diet is restricted to nanoplankton and bacterioplankton.

This study confirms the importance of studying the relationship between phytoplankton and zooplankton in any aquatic system, rather than studying the physical and chemical parameters.

CONCLUSION

The results demonstrated that, in El Dekhaila Harbor, the grazing by zooplankton play a leading role in controlling phytoplankton community structure. Copepods as the predominant group prefer diatoms, but dinoflagellates are unsuitable as a prey. The nutrient salts concentrations have a weak impact on phytoplankton and so, the latter being limited rather by zooplankton grazing than by nutrient availability.

SIGNIFICANCE STATEMENTS

This study discovers the possible effect of zooplankton grazing activity on phytoplankton composition and distribution in a harbor suffered with high nutrient salts concentrations. Other combinations that may be also effect on phytoplankton density as water temperature and pH values, yet no significant correlations were found between phytoplankton variables and the concentrations of nutrient salts or their ratios. This study will help the researcher to discuss the role of zooplankton grazing activity on the phytoplankton abundance and community structure in any aquatic system as well as the other abiotic factors.

ACKNOWLEDGMENTS

The authors are thankful to National Institute of Oceanography and Fisheries, Marine Environment Division, Egypt for providing necessary facilities.

REFERENCES

1. Lewitus, A.J., E.T. Koepfler and J.T. Morris, 1998. Seasonal variation in the regulation of phytoplankton by nitrogen and grazing in a salt-smarsh estuary. Limnol. Oceanogr., 43: 636-646.
2. Riegman, R., I.A. Flameling and A.A.M. Noordeloos, 1998. Size-fractionated uptake of ammonium, nitrate and urea and phytoplankton growth in the North Sea during spring 1994. Mar. Ecol. Progr. Ser., 173: 85-94.
3. Rabouille, C., F.T. Mackenzie and L.M. Ver, 2001. Influence of the human perturbation on carbon, nitrogen and oxygen biogeochemical cycles in the global coastal ocean. Geochimica Cosmochimica Acta, 65: 3615-3641.
4. Fernandes, L.F. and F.P. Brandini, 2004. Diatom associations in shelf waters off Parana State, Southern Brazil: Annual variation in relation to environmental factors. Braz. J. Oceanogr., 52: 19-34.
5. Smayda, T.J., 1997. Harmful blooms: Their ecophysiology and general relevance to phytoplankton blooms in the sea. Limnol. Oceanogr., 42: 1137-1153.
6. Mafra, Jr. L.L., L.F. Fernandes and L.A.O. Proenca, 2006. Harmful algae and toxis in Paranagua Bay, Brazil: Bases for monitoring. Braz. J. Oceanogr., 54: 107-121.
7. Halim, Y., S.A. Morcos, S. Rizkalla and M.K. El-Sayed, 1995. The impact of the Nile and the Suez Canal on the living marine resources of the Egyptian Mediterranean waters (1958-1986). In: Effects of Riverine Inputs on Coastal Ecosystems and Fisheries Resources, FAO Fisheries Technical Paper No. 349, Rome, Italy, pp: 19-57.

8. Abdalla, R.R., F.A. Zaghloul, Y.A. Hassan and H.M. Moustafa, 1995. Some water quality characteristics of El-Dekhila Harbour of Alexandria, Egypt. Bull. Nat. Inst. Oceanogr. Fish., 21: 85-102.
9. Fahmy, M.A., F.T. Tayel and M.M. Sheriadah, 1997. Spatial and seasonal variations of dissolved trace metals in two contaminated basins of the coastal Mediterranean Sea, Alexandria, Egypt. Bull. Fac. Sci. Alexandria Univ., 37: 187-198.
10. Abdel-Aziz, N.E., 2001. Zooplankton in beach waters of the Southeastern Abu Qir Bay. J. Egypt. Acad. Soc. Environ. Dev., 2: 31-53.
11. Ismael, A.A. and M.M. Dorgham, 2003. Ecological indices as a tool for assessing pollution in El-Dekhaila Harbour (Alexandria, Egypt). Oceanologia, 45: 121-131.
12. Fahmy, M.A., N.E. Abdel-Aziz and M.M. Dorgham, 2004. Water quality observations in the Dekhaila Harbour, Alexandria, Egypt. Arab Gulf J. Scient. Res., 22: 206-216.
13. Shaltout, N.A. and D.E. Abd-El-Khalek, 2014. Assessment of seawater quality of El-Dekhaila Harbor, Alexandria, Egypt. Asian J. Adv. Basic Sci., 3: 206-216.
14. Gharib, S.M., 1998. Phytoplankton community structure in Mex Bay, Alexandria, Egypt. Egypt. J. Aquat. Biol. Fish., 2: 81-104.
15. Zaghloul, F., R.. Abdalla, H.M. Mustafa and A. Badr, 1995. Phytoplankton community structure in El-Dekhaila harbor of Alexandria, Egypt. Bull. Nat. Inst. Oceangr. Fish, 21: 103-123.
16. Ismael, A.A. and N.E. Abdel-Aziz, 2003. Selective grazing on phytoplankton in El-Dekhaila Harbour (Alexandria). Mar. Life, 13: 21-30.
17. Heneash, A.M.M., 2015. Zooplankton composition and distribution in a stressed environment (El Dekhaila Harbour), South-Eastern Mediterranean Sea, Egypt. Int. J. Adv. Res. Biol. Sci., 2: 39-51.
18. Utermohl, H., 1958. Zur vervollkommnung der quantitativen phytoplankton-methodik. [On improvements in quantitative phytoplankton methods]. Mitteilungen: Internationale Vereinigung Theoretische Angewandte Limnologie, 9: 1-38.
19. Cupp, E.E., 1943. Marine plankton diatoms of the West coast of North America. Bull. Scripps Inst. Oceanogr., 5: 1-238.
20. Hendey, N.I., 1964. An introductory account of the smaller algae of British coastal waters. Part V: Bacillariophyceae (diatoms). Minist. Agric. Fish. Food, Fish Invest., London, UK., pp: 1-317.
21. Prescott, G.W., 1975. Algae of the Western Great Lakes Area. Michigan State University Press, Michigan, USA., ISBN-13: 9780697045522, Pages: 998.
22. Dodge, J.D., 1982. Marine Dinoflagellates of the British Isles. Her Majesty's Stationery Office, London, UK., ISBN-13: 9780112411963, Pages: 303.
23. Al-Kandari, M., F. Al-Yamani and K. Al-Rifaie, 2009. Marine Phytoplankton Atlas of Kuwait's Waters. Kuwait Institute for Scientific Research, Kuwait, ISBN-13: 9789990641240, Pages: 354.
24. Opute, F.I., 2000. Contribution to the knowledge of algae of Nigeria. I. Desmids from the Warri/Forcados estuaries. Part II. The elongate baculiform desmids. J. Limnol., 59: 131-155.
25. Opute, F.I., 2003. Contribution to the knowledge of algae of Nigeria Chlorophyceae from the Warri/Forcados estuaries. Part 1. The orders Volvocales and Chloroccocales. Benin Sci. Dig., 1: 31-52.
26. Shannon, C.E. and W. Wiener, 1963. The Mathematical Theory of Communications. University of Illinois Press, Urbana, ISBN 0-252-72548-4, Pages: 117.
27. Margalef, R., 1978. Life-forms of phytoplankton as survival alternatives in an unstable environment. Oceanologica Acta, 1: 493-509.
28. Pielou, E.C., 1975. Ecological Diversity. John Wiley Sons, New York, USA., ISBN-13: 9780471689256, Pages: 165.
29. Tayel, F.T.R., M.A. Fahmy and M.M.A. Sheriadah, 1996. Studies on the physico-chemical characteristics of Mex Bay and New Dekhaila Harbour waters of Alexandria, Egypt. Bull. Natl. Inst. Oceanogr. Fish., 22: 1-19.
30. Franco, P., 1983. Fattori influent sulla productivita primaria della adriatico settentrionale. Proceedings of the International Conference on Problems of the Adriatic Sea, September 26-27, 1983, Trieste, Italy.
31. Marchetti, R., 1984. Quadro analitico complessivo del risultati delle indagini condotte negli anni 1977-1980. II. Problema dell'eutrofizzazione delle acque costiere dell'Emilia Romagna: Situazione ipotesi di intervento, Regione Emilia Romagna, Bologna. Assessorato Ambiente e Difesa del Suolo-Servizio Tutela e Risanamento Ambientale, Emilia-Romagna, Italy, pp: 1-308.
32. Stirn, J., 1988. Eutrophication in the Mediterranean Sea. Proceeding of the Scientific Workshop on Eutrophication in the Mediterranean Sea: Receiving Capacity and Monitoring of Long-Term Effects, March 2-8, 1987, Bologna, Italy, pp: 161-187.
33. Gowda, G., T.R.C. Gupta, K.M. Rajesh, H. Gowda, C. Lingadhal and A.M. Ramesh, 2001. Seasonal distribution of phytoplankton in *Nethravathi estuary*, Mangalore. J. Mar. Biol. Ass. India, 43: 31-40.
34. Labib, W., 2002. Phytoplankton variability in the Eastern Harbour (Alexandria, Egypt). Egypt. J. Aquat. Biol. Fish., 6: 75-102.
35. Abdel-Halim, A.M. and H.M. Khairy, 2007. Potential impact of some abiotic parameters on a phytoplankton community in a confined bay of the Eastern Mediterranean sea: Eastern harbour of Alexandria, Egypt. Mediterr. Mar. Sci., 8: 49-64.
36. Khairy, H.M., N.R. Hussein, H.M. Faragallah and M.M. Dorgham, 2014. The phytoplankton communities in two eutrophic areas of the Egyptian mediterranean coast. Rev. Biol. Marinay Oceanografia Agosto, 49: 267-277.
37. Shams El Din, N.G., E.M. Abo El Khair and M.M. Dorgham, 2014. Phytoplankton community in the Egyptian Mediterranean coastal waters. Indian J. Geo-Mar. Sci., 43: 1-9.

38. Pednekar, S.M., V. Kerkar and S.G.P. Matondkar, 2014. Spatiotemporal distribution in phytoplankton community with distinct salinity regimes along the Mandovi Estuary, Goa, India. Turk. J. Bot., 38: 800-818.
39. Hallegraeff, G.M., M.A. McCausland and R.K. Brown, 1995. Early warning of toxic dinoflagellate blooms of *Gymnodinium catenatum* in Southern Tasmanian waters. J. Plankton Res., 17: 1163-1176.
40. Dorgham, M.M., M.I. El-Samra and T.H. Moustafa, 1987. Phytoplankton in an area of multi-polluting factors West of Alexandria, Egypt. Qatar Univ. Sci. Bull., 7: 393-419.
41. Turkoglu, M., 2005. Succession of picoplankton (Coccoid Cyanobacteria) in the Southern black sea (Sinop Bay, Turkey). Pak. J. Biol. Sci., 8: 1318-1326.
42. Smayda, T.J., 1965. A quantitative analysis of the phytoplankton of the Gulf of Panama. II-on the relationship between C^{14} assimilation and the diatom standing crop. Inter-Am. Trop. Tuna Commn. Bull., 9: 467-531.
43. Bates, S.S., M.F. Hiltz and C. Leger, 1999. Domoic acid toxicity of large new cells of *Pseudo-nitzschia multiseries* resulting from sexual reproduction. Proceedings of the 6th Canadian Workshop on Harmful Marine Algae, February 1999, St. Andrews, NB., Canada, pp: 21-26.
44. Chiaudiani, G. and M. Vighi, 1978. Metodologia standard di saggio algale per lo studio della contaminazione delle acque marine. Quaderni IRSA No. 39, Consiglio Nazionale delle Ricerche, Italy.
45. Egge, J.K., 1998. Are diatoms poor competitors at low phosphate concentrations? J. Mar. Syst., 16: 191-198.
46. Nessim, R.B. and A.B. Tadros, 1986. Distribution of nutrient salts in the water and porewater of the Western Harbour of Alexandria, Egypt. Bull. Natl. Inst. Oceanogr. Fish., 12: 165-174.
47. Nessim, R.B. and F.A. Zaghloul, 1991. Nutrients and chlorophyll in the polluted Kait Bey region, Alexandria. Proceedings of the International Symposium on Marine Chemistry in the Arab Region, April 1991, Suez, Egypt, pp: 71-80.
48. Roberts, E.C., K. Davidson and L.C. Gilpin, 2003. Response of temperate microplankton communities to N:Si ratio perturbation. J. Plankton Res., 25: 1485-1495.
49. Guo, S., Y. Feng, L. Wang, M. Dai, Z. Liu, Y. Bai and J. Sun, 2014. Seasonal variation in the phytoplankton community of a continental-shelf sea: The East China Sea. Mar. Ecol. Progr. Ser., 516: 103-126.
50. Guergues, S.K., 1979. Ecological study of zooplankton and distribution of macro-fauna in Lake Manzalah. Ph.D. Thesis, Faculty of Science, Alexandria University, Egypt.
51. Smetacek, V., 1981. The annual cycle of Protozooplankton in the Kiel bight. Mur. Biol., 63: 1-11.