Annual phytoplankton variability in the Eastern Harbour, Alexandria (Egypt)

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ABSTRACT

To realize the specific-time importance of phytoplankton variability in the semi-enclosed marine basin (Eastern Harbour of Alexandria), the present study based on a short-time scale was conducted during a year cycle. The harbour is characterized by abrupt temporal variations of multitudes of different environmental variables, and experiences a high degree of pressure from natural and anthropogenic activity. The instability of the system and rapid phytoplankton variations hinder the full understanding the mechanism that underlying the differences in the community composition and production. The community structure responded quickly to modifications, consequently, displacement of different species occur in a couple of days. The study stresses the crucial role of temperature as a steering factor in determining the timing, magnitude, and composition of the spring bloom. Water mixing conditions and organic matter concentrations influence deeply the phytoplankton variability. The study examines the ecology of the massive blooms of potentially harmful/toxic species of different classes.

INTRODUCTION

Marine ecosystems are experiencing many different changes in response to natural processes, growing human pressures and climate change (**Boldt *et al.,* 2014; Häder *et al.,* 2020**). These changes alter the chemical, physical, and biological characteristics of seawater, which in turn affect the growth and distribution of marine microorganisms and ecosystem health (**Hutchins and Fu, 2017**). Marine phytoplankton dominate primary production, propagate up the food chain, and the potential productivity of ecosystems (**Beaugrand *et al.,* 2014**). The dynamics of coastal phytoplankton species are poorly understood (**Pannard *et al.,* 2008**). Thus, it is important to find a link between changes in physical and chemical ambient parameters and their influence on the growth, temporal, and regional distribution of different species on a short-time scale, which represent a critical step in better understanding coastal systems. The studies on short-term variations of phytoplankton in conjunction with environmental stressors received very rather limited attention in Alexandria waters (**Labib, 2000, 2002; Mikhail, 2001**). The present contribution was designed to put into perspective some features of the patterns of the

phytoplankton variability relevant to some prevailing physical and chemical variables on a short-time scale, in order to identify the potential key environmental factor/s and possible ecological links. Assuming the expected increase in human population, urbanization and accelerated developmental activities in Alexandria, the information gained can serve as a tool in sustainable utilization and help decision makers seeking for development of appropriate conservation strategies.

MATERIALS AND METHODS

Sampling site

The Eastern Harbour, at the central part of Alexandria City (longitudes $29°53'$ - $29°54'$-E and latitudes $31°12'$ - $31°13'$ -N, Figure 1), is a relatively shallow, sheltered marine basin (area 2.53 Km^2, water volume 15.2×10^6 m^3, average depth 6.5m). The harbour, through water exchange with adjacent Mediterranean waters receives discharged wastewater supply, but, mainly from Qaitbay sewer outlet located at its western vicinity. Meanwhile, its western part represents an additional source of pollution being used for anchoring fishing vessels, yachts sports, and boat building.
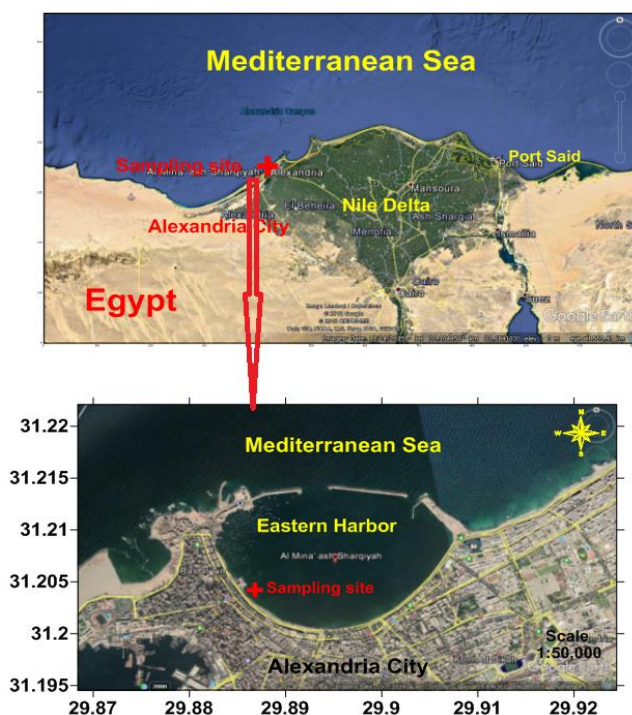
Figure 1. Location of the sampling station.

Physicochemical parameters of the seawater

The fixed sampling station (4m depth) was occupied for 49 times at almost weekly intervals from September 2018 to August 2019. Moreover, intensive daily sampling collection was operated during the bloom periods in autumn and summer. Water temperature and salinity were measured below the surface and over the bottom using the water checked physical parameter device HANA, Model HI 9828. The dissolved

inorganic nutrients (NO_3, NO_2, NH_4, PO_4, and SiO_4) were analyzed following the methods of **Parsons *et al*., (1984)**, the oxidizable organic matter (OOM) was estimated following **FAO (1976)**, and chlorophyll *a*, (Chl. *a*) the method of **Jeffrey and Humphrey (1975)**. The water transparency was measured using a white Secchi disc (30 cm diameter), and each reading was converted into extinction coefficient (**Holmes, 1970**), and the euphotic zone (Z_{eu}) is calculated as 2.7 times the Secchi depth (**Cole, 1983**).

Phytoplankton collection and identification

Surface water samples for phytoplankton counting and identification were collected using a fine net (20µ) and then the samples were preserved by adding neutralized formalin (4%), and a few drops of Lugol's acid solution. After sedimentation (**Utermöhl, 1958**), subsamples were examined with Optika 100 inverted microscope at 400x magnification for identification following the taxonomic guideline of **Tomas (1997)**, and counted (**Hasle, 1978**). The abundance was expressed as unit/ liter.

Statistical analyses

The multiple linear regressions were done by applying the regression model of **Hintze (1993)** that computed to determine the relative importance of independent variables, and the combined corresponded dependent phytoplankton variables. Pearson's correlation analysis was performed to determine the relation of biotic components with water physical and chemical variables, and the inter correlation link. The results were tested at significant levels 0.01 and 0.05, *P* test for each pair of variables.

RESULTS

The means of physicochemical parameters of the collected water are illustrated in Table 1. Temperature went through a clear seasonality with a minimum in January and a maximum in July. The over-bottom temperature was slightly wormer than the surface in winter within 0.2-0.5°C. The spring warming in March raised temperature by 1.3-5°C compared with late February, continued to reach $> 21.5°C$ in late May. A weak thermal vertical gradient was developed in early spring, became well established in summer. Salinity exhibited an irregular temporal trend, with the highest in winter, and lowest in summer. Levels <37 psu contributed 14.29% of the total measurements, signaling fresh water impact. Except for the homogenous condition in winter, the surface water was always diluted than the over-bottom, and the well developed halocline within 0.8-1.6 psu was performed in summer. Salinity promoted substantial differences in temporal changes of the chemical properties of the harbour water as evidenced from a significant inverse correlation with the measured nutrients. The Secchi depth values never reach the bottom. The values between 2-3m contributed 44.9% of all, 1-2m (34.69%), and 3-3.5 m (16.32 %). Only two incidents of < 1m were restricted to winter turbid mixed water column under rough sea condition. Generally, the measurements were relatively lower in autumn and summer. The light extinction coefficient ranged between 0.49 and 3.4, and the calculated euphotic zone 1.35 and 9.45m (mean 5.68±0.25 m). Temperature seems to be closely correlated with the Secchi reading in spring, while it was deeply influenced by salinity in winter and summer. The same relation was found between nutrients and transparency in winter, particularly for NH_4, as well as in summer ($r=0.78$ and 0.81, respectively, $p< 0.01$). The pH values lie within the alkaline side, the higher observed

during algal over growth periods. The values skewed with uniform distribution towards lower concentrations in winter, as well as in May.

Table 1. Descriptive analyses of the measured physical and chemical variables

Autumn										
	Tem.	Salinity	Transp.	pH	NO_3	NO_2	NH_4	SiO_4	PO_4	OOM
Mean	23.23	37.18	1.91	8.35	2.11	0.40	2.13	2.61	1.20	2.81
Standard Deviation	3.51	1.78	0.63	0.26	1.59	0.17	0.94	2.71	0.83	0.84
Minimum	18.20	33.00	0.60	8.04	0.75	0.23	0.82	0.60	0.12	2.01
Maximum	28.50	39.00	2.70	8.85	6.30	0.80	4.20	8.50	2.50	4.70
Confidence Level (95.0%)	2.12	1.07	0.38	0.16	0.96	0.10	0.57	1.64	0.50	0.51
Winter										
Mean	13.53	39.49	2.31	8.28	1.53	0.41	2.53	1.79	2.56	2.35
Standard Deviation	1.14	0.35	0.85	0.11	0.84	0.07	1.21	0.79	1.01	0.36
Minimum	12.40	39.00	0.50	8.18	0.45	0.32	1.25	0.60	0.85	1.88
Maximum	16.00	39.90	3.20	8.60	3.20	0.52	4.51	2.60	4.20	3.05
Confidence Level(95.0%)	0.72	0.22	0.54	0.07	0.54	0.05	0.77	0.50	0.64	0.23
Spring										
Mean	17.34	37.93	2.28	8.43	2.15	0.32	2.15	1.64	2.11	4.51
Standard Deviation	2.73	0.73	0.62	0.28	1.11	0.11	0.78	0.64	0.83	1.49
Minimum	14.70	37.00	1.50	7.96	0.50	0.20	1.18	0.80	0.80	2.39
Maximum	21.50	39.40	3.50	8.80	4.50	0.56	3.71	2.60	3.80	6.50
Confidence Level (95.0%)	1.73	0.46	0.40	0.18	0.71	0.07	0.50	0.40	0.53	0.94
Summer										
Mean	25.63	36.66	1.98	8.59	0.92	0.33	2.31	1.56	1.48	7.24
Standard Deviation	2.05	1.22	0.47	0.16	0.31	0.13	1.10	1.37	0.69	3.88
Minimum	22.80	34.20	1.50	8.30	0.50	0.14	0.58	0.40	0.58	2.92
Maximum	28.80	38.00	2.90	8.80	1.50	0.51	4.21	5.20	3.20	16.92
Confidence Level (95.0%)	1.30	0.78	0.30	0.10	0.20	0.08	0.70	0.87	0.44	2.46

The nutrient concentrations varied significantly through the study period, and no any particular trend could be detected (Figure 2). The total nitrogen (TN) here means the Sum of NO_3, NO_2, NH_4 concentrations. Nitrate contributed 12.45-69.9% of TN, mostly in the range 1-2 μM (40.81% of the all), followed by 30.61% for < 1 μM, and the levels >3 μM were infrequently observed (10.2%). Seasonally, the highest NO_3 appeared in late October, while, the almost undetectable values in summer and mid winter.

Ammonia was the richest N source. Monthly, values below 2 μM represent 41% of the all measured, and the overall minimum was measured in late August, while, the highest levels appeared scattered, but mainly in January in mixed water condition. Phosphate showed also enhanced concentrations in January, and it was almost traced in September. Most of the concentrations ranged between 1-2 μM (36.7%), while, the intermediate levels around 2.2 μM were registered to the transient period from late February to late March, and the values exceeding 3μM were relatively scarce (16.32%). Regarding the total nitrogen/phosphate ratio (N/P), more than 93% of the total samples suggest N limitation, and the rest is considered phosphorous limited, which accompanied a mutispecific bloom periods of different classes. The negative significant correlation

found between N/P and salinity indicates the effects of discharged water (r=-0.32, *p* at 0.05); relatively higher with NH_4. The SiO_4 concentrations showed almost the same trend of NO_3, peaked in early and late October, homogeneous intermediate levels in mid-January-mid-April, and were relatively lower in late August. Levels <1 µM were frequently determined (28.57% of the total), particularly in summer. The results revealed limited fluctuations in the silicate/nitrogen ratios (Si/N) during the same season. Almost equal relatively higher Si/N values were registered in autumn and summer. The strong positive correlation between TN/P and Si/TN (*r*= 0.37, *p* at 0.05) might indicate a single impacting source of variation on absolute concentrations. Meanwhile, temperature, salinity, and OOM seem contributing factors for both ratios, explaining in combination about 31% and 26% of the TN/P and Si/TN variations, respectively. The OOM sustained a very wide range of variation; an abrupt increase by 1.7 fold was measured by late April compared with March, the highest concentration was measured in July, relatively lower in the second week of August. A weak inverse relation was found between OOM and NO_3 and SiO_4, but both temperature and salinity seem affecting the OOM temporal distribution (r=0.45 and -0.52, p<0.01).
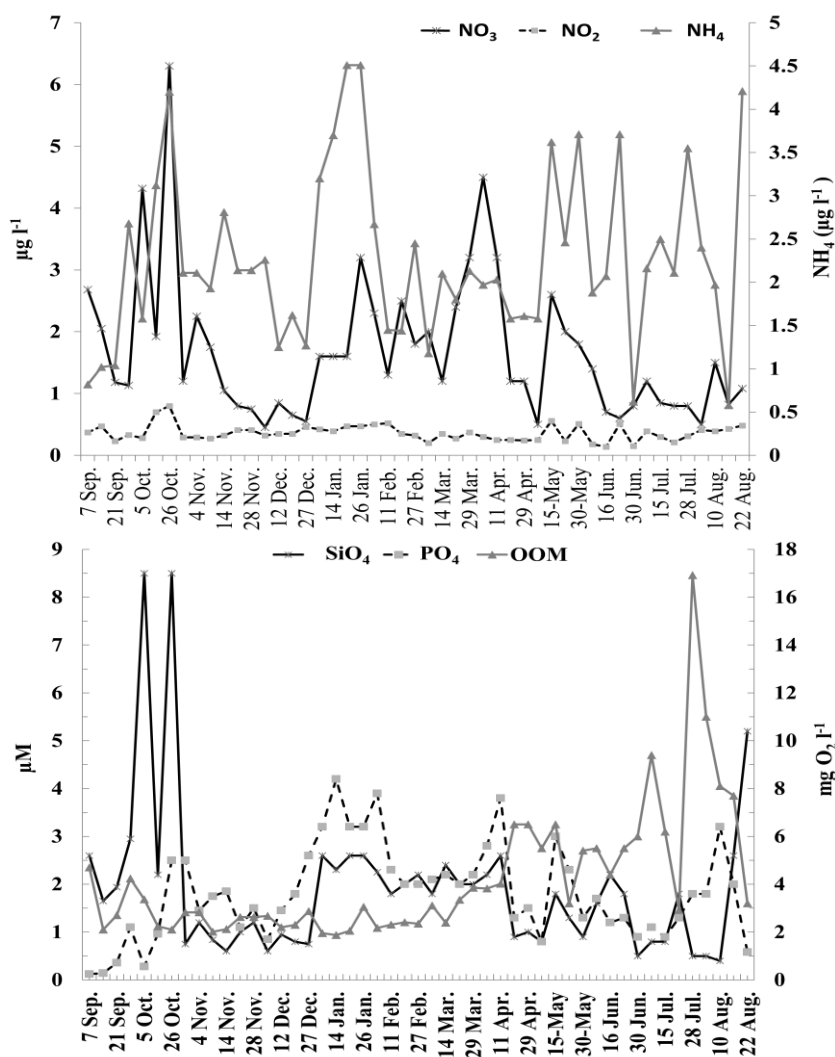
**Figure 2.** Nutrient and oxidizable organic matter concentrations.

Phytoplankton community and abundance

Distinct heterogeneity in phytoplankton community was recorded (169 spp.), classified into 6 different families, and including 28 potentially harmful/toxic species. Diatoms were the species-richest group (108 taxa, 63.9% of the total species number), followed to a much lesser extent by dinoflagellates (37 taxa, 21.89%), chlorophytes (10 taxa, 5.92%), cyanophytes (8 species, 4.73%), euglenophytes (4 species, 2.37%), and raphidophytes (2 species, 1.18%).

Phytoplankton abundance and Chl. *a* (Figure 3) displayed distinct annual variations, where the lowest was observed in winter and the highest in summer, with relatively high levels in autumn compared with spring. Three distinct peaks were recorded. The first bloom occurred in the first and the last week of September; mainly consist of diatoms (66.51% and 83.56%). The second bloom in summer started in early June, reaching its peak on late July, and extends in August with relatively lower densities (545×10^3-675.63×10^3 unit l^{-1}). This multispecific bloom was dominated mainly by chlorophyte (43.25%), and raphidophyte species (42.53%), in association with diatoms (14.06%). The third minor bloom of diatoms predominance took place in spring, with the highest density in mid-April (Chl. $a = 5.5$ µgl^{-1}). No bloom was recorded in winter; the abundance was a minimum in late February. Except for the bloom periods, the seasonal variations of Chl. *a* experienced a wide range of variability between minimum in the mixed winter waters (0.23-0.63 µg l^{-1}, December-late January), and 4.21-5.57 µg l^{-1} in March-April.

Temperature-abundance relationship shows different regimes; very close, significant in spring ($r=0.71$, $p <0.01$), and the reverse in summer ($r=0.26$, $p <0.05$). Salinity exhibits indisputable strong relation with abundance in autumn, summer, and spring ($r= 0.51$, $p <0.05$ in autumn). The nitrogen concentrations apparently show a limited influence and might promote unclear substantial differences in temporal abundance changes, except that of NO_2 in winter and spring, and NH_4 in the latter season ($r=0.47$, $p <0.05$). Significant and negative relations were found between PO_4 and abundance in autumn and spring, similar to that observed for OOM. The prominent link of SiO_4 with abundance was detected in autumn ($r=0.54$ $p <0.05$) and winter. The regression analyses showed temperature and pH variations, in combination explain about 38% of the abundance variability. Chlorophyll *a* variation seems to be linked with the same variables mentioned for the phytoplankton abundance, suggesting its proper use as an indicator of phytoplankton abundance. This result is full supported by the indisputable strong relationship ($r= 0.89$-98, $p<0.01$).

Regarding the temporal distribution, diatoms contributed the main fraction of the standing crop (average 227.8×10^3 unit l^{-1}, 64.21%). Its seasonal average density arranged as summer > autumn > spring > winter. However, the abundance of diatoms failed to reflect the degree of dominance, particularly in summer and winter. The species succession developed as *Cyclotella nana* dominates in September, *Chaetoceros socialis* in November, *Asterionellopsis glacialis* in the whole winter, *Rhizosolenia delicatula* and *Skeletonema costatum* in spring, and the latter two species in association with *Peudonitzschia longissima* in summer. The recorded species, in general are eurythermal, euryhaline temperate water forms.
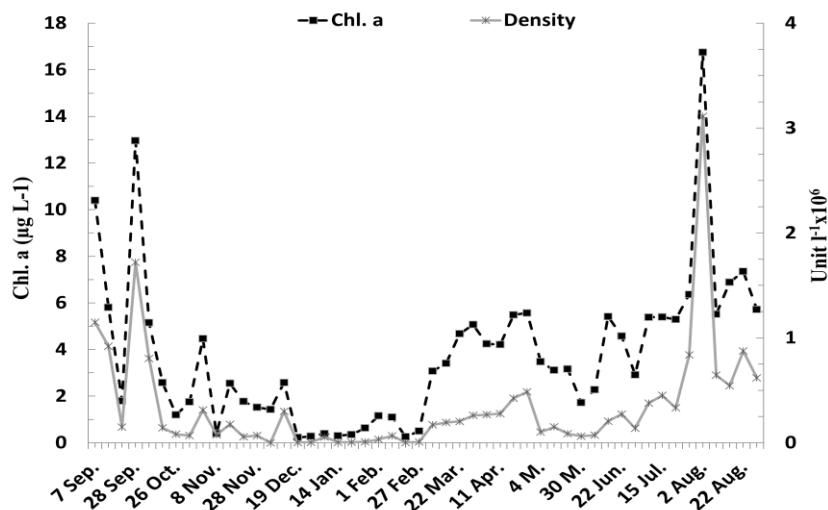
Figure 3. Variations of the abundance of phytoplankton and chlorophyll *a* concentrations

Diatoms for its distinct varied composition seem to be adaptive to a wide range of environmental variables, but relay on no specific variable, which simultaneously interacts in combination to explain such variability. Temperature, salinity and pH variations seem to be leading factors correlating with the abundance. Except for spring, salinity may have a prominent effect on diatoms in autumn, as well as for transparency in spring (negative association). Nutrient concentrations are irregularly connected with changes in diatom abundances, and the nitrogen sources seem to have in an apparent effect, particularly for NH_4 in spring ($r=-0.49$, $p < 0.05$). It is also hard to define a specific role for the other nutrients, yet availability in SiO_4 seems of significant contribution on the variation of diatom abundances during winter, spring and summer ($r=0.41$, $p < 0.05$ in the latter season), and PO_4 and OOM as determinants in winter and spring. The latter two parameters correlated differently with the diatoms abundance. The dominant species prevailed under different environmental conditions. *Skeletonema costatum* achieved its maximum abundance in late April and July (305.1×10^3 and 501.1×10^3 cell l^{-1}) at a wide temperature range ($16.2\,^{\circ}C$ and $25.8\,^{\circ}C$), mediate salinity (36-38.5psu), relatively reduced NH_4 (1.6-2.1μM), and low NO_3, SiO_4, and PO_4. The occurrence of *A. glacialis* was restricted to the period from early November till late April under relatively low temperature (18.5-$22.9°C$) and salinity (31.3- 32.9 psu), and it was followed by a complete disappearance during the rest of the year. *Cyclotella pseudonana* formed frequent minor blooms sustaining different environmental conditions, its massive peak occurred at $24.5\,^{\circ}C$, 37.2 psu, a weak stratified water column, at relatively low NO_3, PO_4, and intermediate SiO_4, and this peak was preceded by pronounced increased nitrogen and SiO_4 concentrations. The pennate species *Pseudo-nitzschia longissima* contributed significantly to the summer massive bloom under high temperature, relatively low salinity and changeable nutrient concentrations.

Dinoflagellates constitute an insignificant part of the phytoplankton (average 9.8×10^3 unit l^{-1}, 2.77%), among them; six species were reported toxic. Dinoflagellates species exhibited a real seasonal variability in population abundance, with a minimum in cold winter and highest in hot July-August. The perennial major forms of different

temporal variation with different frequencies include *Prorocentrum triestinum*, *P. minimum*, *Scrippsiella trochoidea*, and *Alexandrium minutum*. In general, *P. minimum* was scarcely observed in early March; *S. trochoidea* and *P. triestinum* reached up at 20×10^3–33×10^3 cells l^{-1} in May when the spring diatom bloom dominated by *S. costatum* was developed; and *P. triestinum* was of common distribution. These species besides *Gymnodinium catenatum* continued prevalence in summer under increased temperature, steep stratification condition of the water column, and relatively high nutrients. Statistically, temperature and pH are significantly connected with the abundance, but mostly in autumn and winter. Nutrients correlated with abundance in different regimes, NH_4 and PO_4 in autumn (-), all except NH_4 in winter (-), NH_4 and OOM in spring (+), and both SiO_4 (+), and OOM (-) in summer. Dinoflagellates temporal occurrence exhibits positive linkage with diatoms ($r = 0.31$, p<0.5).

The raphidophytes include the two species *Chattonella antiqua* and *Heterosigma akashiwo*. These species exhibited no seasonal distribution trend, and their massive occurrence exclusively observed in September-October, and from early July to mid-August. Yet, they collectively, formed about 13.81% of the total abundance (mean 46.7×10^3 cell l^{-1}). These two periods maintained a high temperature (23-28.8°C) and wide variations in salinity and nutrients. Temperature, salinity (-), pH, and OOM might affect the occurrence of *C. antiqua*, the latter was of significant linkage (r=0.67, p<05), while temperature, PO_4 and OOM significantly correlated with the variations in abundance of *H. akashiwo*.

The chlorophytes (average 44.5×10^3) was the third important contributory of the annual production (12.7%), mainly consisted of *Scenedesmus* spp. However, numerically, the prasinophycean picoeukaryotic species *Micromonas pusilla* was the major constituent (71%). This species displayed sporadic occurrences, reaching its maximum (1.01×10^6 unit l^{-1}) in late July under temperature at 25.8°C, salinity 35.8 psu, relatively high NH_4 (3.55 μM), and themo-haline stratification of the water column within 1°C, and 2.2 psu. Very strong association was observed between raphidophytes and chlorophytes ($r=0.98$, $p < 0.01$).

Euglenophytes (average 10.02×10^3 unit l^{-1}, 2.83%) was dominated by the genus *Euglena*, mainly observed under the chlorophytes bloom conditions. Salinity imposes significant correlation with the temporal distribution ($r=-52$, $p<0.05$).

Cyanophytes represented the poorest constituent of the abundance (average 1024 units l^{-1}, 0.29%), appeared as scattered units in no particular season. Among them; *Microcystis aeruginosa*, *Oscillatoria limosa*, and *Chroococcus* spp. were of noticeable occurrence, with abundance up to at 9×10^3-17.5×10^3 unit l^{-1} in July and August under high temperature (27.2-28.8°C), relatively low salinity (35 and 37psu), and relatively high NH_4 and OOM. A relatively strong relation was found between variability of cyanophytes and temperature, salinity, pH and OOM.

DISCUSSION

The results describe the harbour ecosystem as harsh and dynamic, characterized by abrupt temporal changes of multitudes of different environmental and biotic variables. It experiences a high degree of pressure from anthropogenic activity, signaling eutrophication symptoms. Phytoplankton submitted to rapid short-time variations

displays complex seasonal patterns of the community groups and production, with different enigmatic aspects. The community structure responded quickly to modifications in the physical and chemical conditions, consequently, displacement of different species occur in a couple of days, that able us to characterize the system dynamic and eutrophic status. However, no clear seasonality was detected. The instability of the system and rapid phytoplankton variations hinder full understanding the mechanism that underlying the observed differences in the community composition and production. However, the study stresses the crucial role of temperature as evidenced by its positive correlation with increased species number (species diversity), in accordance with **Schabhüttl et al. (2012)**. Yet, the increasing species, generally did not match well with the corresponding abundance, in contrary with **Polat et al. (2000)**. The temperature role as a steering factor was clear in determining the timing, magnitude and composition of the spring bloom, which represents a part of the classical paradigm cycle in temperate waters (**Lewandowska and Sommer, 2010**). Yet, the effect of increased temperature in the present study seems to be contradicted and suspected as indicated from the negative correlation found with abundance and biomass, similar to **Boyce et al. (2010)**. The silicate depletion with the progress of the spring peak may stay behind the distinct observed species succession, which generally promotes a shift from diatom dominated communities to flagellate-dominance, in consistent with **Chang et al. (2003)**.

The monthly distributions of Chl. *a* resemble in a typical way the phytoplankton abundance, supporting other data (**Satpathy et al., 2010; Panda et al., 2012**), whereas the very limited deviations in their linear relationship explain interference of freshwater species. Its annual values are comparatively lower than that recently recorded in 2012-2013 (**Tadros et al., 2016**). A positive linear significant correlation was found between species number and Chl. *a* content, and the observed deviations as expected were due to the dominance of large-sized freshwater forms.

The role of nutrient availability in the harbour was unclear, and it is hard to define specific regulating element since nutrient availability is regularly disturbed by escalating external and internal input related to anthropogenic activities, episodic storm events in winter that can export nutrient-rich sediments of the shallow water depth, and from algal decaying after the termination of massive blooms. The strong correlation found frequently between the different nutrient variables might explain the same source of variation. However, the excess of nutrients does not necessarily mean enhanced Chl. *a* concentration. The Secchi depth proved to be a weak predictor of biomass most of the time since their relationship rely on interference of multiple factors as the biotic phytoplankton amounts, structure and humic substances.

The dominance and persistent occurrence of diatoms agree with other results in the harbour (**Mikhail et al., 2007**). Even the community was well diversified, a few species were responsible for the major fraction of the production, declaring clear signs of eutrophication. The recorded major species are endemic in Alexandria waters, known to form massive blooms at intermittent periods (**Mikhail and Halim, 2009**). Statistically, most of the measured abiotic parameters simultaneously interact in combination to explain diatoms variability. However, no specific variable is determined so far. Despite the high significant correlation found between diatoms and pH, other studies deny such exclusive relation and show no clear patterns (**Langer et al., 2009**), and insignificant effect of solo pH variation on species composition and production (**Kim et al., 2006;**

Feng *et al.,* 2009). Mixing in winter and the transient periods allowed, for different reasons (**Lionard *et al.,* 2005**) the predominance of the small, fast species of high intrinsic growth rates that suppress the growth of other species, in accordance with . On the other hand, the observed dinoflagellates dominance in well thermo-haline stratified water column is well accepted (**van Haren *et al.,* 1998**). Mixing condition for its influence on light, nutrients, phytoplankton production, and concentration of dominant species should be included among the driving factors. Salinity variations as the fingerprint of the arrival of water masses significantly contribute to the chemical characteristic and stoichiometric nutrient ratios of the water. While, most of the recorded species are considered euryhaline forms, the preference of certain species to a certain range of salinity was seen temporarily. Salinity individually seems not able to restrict the diatoms occurrence to a certain salinity limit but seems able to link to shifts in phytoplankton diversity. The dominance of certain diatom species and other fresh water forms under low salinity confirms the conclusion of **Pannard *et al.,* (2008)** for the important impact of discharged water input. The study declares diatoms capability to generate blooms in which biomass can increase several orders of magnitude in just a few days as reported by **Platt *et al.,* (2009)**. The co-dominant species *S. costatum*, *A. glacialis*, and *C. affinis* could be described opportunistic, which benefit sudden excess of nutrients to grow rapidly and dominate. **Litchman *et al.,* (2006)** stated that small species as *S. costatum* are better competitors for nutrients and light than larger ones by their high surface/volume ratio and high uptake rates of nutrients.

While, most diatoms are considered benign, the present blooms influence the water quality and thereby the existing flora. Among the causative summer massive bloom species; *C. antiqua* and *H. akashiwo* were previously registered aliens of recent introduction to Alexandria coastal waters (**Mikhail, 2001**), succeeded to form harmful blooms (fish mortality, **Mikhail, 2007; Mikhail and Labib, 2014**). The observed inverse relation, between *H. akashiow* and *C. antiqua* indicates strong species interaction, which has been a focus of interest of numerous research works. This interaction possibly affects their growth in nature, allowing bloom formation of separate species. As *C. antiqua* and *H. akashiwo* sustain the same short period of duration, it is hard to identify specific environmental factor/s governing the occurrence. However, the data prior to July-August bloom cannot deny the important role of nutrients; man-made disturbance of the environment may be possible reasons for worldwide distribution of the blooms occurrences (**Tas and Hilmaz, 2015**). The significant relation with OOM might support the results of **Imai and Yamaguchi (2012)** that a suitable concentration of humic acid enhances the growth of *C. antiqua*. The results, thus, explain OOM probably another important ecological factor influencing phytoplankton variability.

The strong link of the co-occurrence of chlorophytes and raphidophytes with salinity and nutrients variations indicates the effect of freshwater input, and the significant positive correlations with PO_4 declare high demand for phosphate (**Rybak and Gąbka, 2018**). The high NH_4 concentration with a major abundance of *M. pusilla supports the conclusion of **Collos and Harrison (2014); Glibert et al. (2016)** for its high adaptation to use of* NH_4.

While the study fails to define specific factor/s that drive variability in dinoflagellates assemblages, temperature, and pH seem highly significant rather than nutrients, similar to **Kamykowski and Zentara (2003)**. Dinoflagellates via diel vertical migration through

density stratified water column can flourish well, even in low-nutrient surface waters (**Wong *et al.,* 2007**). The elevated high pH affinity measured with a high abundance of dinoflagellates could help explain the present successional sequences of diatom predominance followed by the significant contribution of dinoflagellates, where ample input nutrients as pulses shared responsibility.

The increased occurrence of cyanophytes in summer conditions of high temperature, stratified water column, low transparency, and relatively high NH$_4$, and OOM confirms others (**Paerl *et al*., 2014; Berg and Sutula, 2015**). The dominance of *M. aeruginosa* declares the rapid changes and replacement in community structure. The extremely observed high OOM with its increased density and the afterward-rapid reduction as well may indicate release and utilization of OM, declaring its significant role. The strong correlation between variability of cyanophytes and OOM might prove such results. The significant relation found with pH indicates its preference to alkaline conditions (**Muthukumar *et al.,* 2007**).The present study declares the dominance of *Euglena* in summer and early autumn influenced by temperature and pH, which confirm the results of **Krajčovič *et al.* (2015)**.

CONCLUSION

Our approach to management of harmful algae blooms and eutrophication must consider the complexity in nutrient proportions and forms, and the reduction of a single limited variable is challenged. It is useful to have flow charts or action plans outlining the steps to be taken in different circumstances, such as a human poisoning or fish mortality episode.

REFERENCES

Beaugrand, G.; Harlay, X. and Edwards, E. (2014). Detecting plankton shifts in the North Sea: a new abrupt ecosystem shift between 1996 and 2003. Inter-Research Science Publishe*r*, 502:85-104.

Berg, M. and Sutula, M. (2015) Factors affecting the growth of cyanobacteria with special emphasis on the Sacramento-San Joaquin Delta. *Southern California Coastal Water Research Project Technical Report* 869 August 2015.

Boldt, J.L.; Martone, R. and Samhouri, J. (2014). Developing ecosystem indicators for responses to multiple stressors. Oceanogr **27**: 116-133.

Boyce D.G.; Lewis, M.R.; Worm B. (2010). Global phytoplankton decline over the past century. Nature 466:591-596.

Chang, H.F.; Zeldis, J.; Gall, M. and Hall, J. (2003). Seasonal and spatial variation of phytoplankton assemblages, biomass and cell size from spring to summer across the north-eastern New Zealand continental shelf. J plankton Res 25(7):737-758.

Collos, Y. and Harrison, P.J. (2014). Acclimation and toxicity of high ammonium concentrations to unicellular algae. Mar Pollut Bull 80: 8-23.

Cole, G. (1983). Textbook of Limnology, 3rd edn. London: The C.V. Mosby Co.

FAO (1976). Manual of methods in aquatic environmental research part I: permanganate value (oxidability) of organic matter in natural waters. FAO Fisheries Technical Paper 137:169.

Feng, Y.Y.; Hare, C.E.; Leblanc, K. and Rose, J.M. (2009). Effects of increased CO_2 and temperature on the North Atlantic spring bloom. I. The phytoplankton community and biogeochemical response. Mar Ecol Prog Ser 388: 13-25.

Glibert, P.M.; Wilkerson, F.P.; Dugdale, R.C., *et al* (2016). Pluses and minuses of ammonium and nitrate uptake and assimilation by phytoplankton and implications for productivity and community composition, with emphasis on nitrogen-enriched conditions. Limnol Oceanogr 61:165-197.

Häder, D.; Banaszak, A.T. and Villafañe, V.E., *et al* (2020). Anthropogenic pollution of aquatic ecosystems: Emerging problems with global implications. Sci Total Environ 713:136586-136586.

Hasle, G.R. (1978). The Inverted-Microscope Methods. *In*: Sournia, A, Ed, Phytoplankton Manual, *United Nations Educational, Scientific, and Cultural Organization, Paris*, 88-96.

Tadros, H.R.; Galila, H.I.; El-Zokom, G.M. and Okbah, M.A. (2016). Multivariate analysis to investigate the organization of physicochemical parameters in the Eastern Harbour Alexandria, Egypt. Int J Cont Appl Sci **3**(3):33-58.

Holmes, R.W. (1970). The Secchi disk in turbid coastal waters. Limnol Oceanogr 15, 688-694

Hintze, J. L. (1993). Number Cruncher Statistical System (NCSS). Version 5:035-93.

Hutchins D.A. and Fu, F. (2017). Microorganisms and ocean global change. Nat Microbiol **2**: 17058.

Imai, I. and Yamaguchi, M. (2012) Life cycle, physiology, ecology and red tide occurrences of the fish-killing raphidophyte *Chattonella*. Harmful Algae 14: 46-70.

Jeffrey, S.W. and Humphrey, G.F. (1975) New spectrophotometric equations for determining chlorophylls *a*, *b*, cl and c2 in higher plants, algae and natural phytoplankton. Biochem Physiol Pflanz 167: 191-194.

Kamykowski, D. and Zentara, S.J. (2003) Can phytoplankton community structure be inferred from satellite-derived sea surface temperature anomalies calculated relative to nitrate depletion temperatures? Remote Sensing Environ 86: 444-457.

Kim, J.M.; Lee, K.; Shin, K. *et al.* (2006). The effect of seawater CO_2 concentration on growth of a natural phytoplankton assemblage in a controlled mesocosm experiment. Limnol Oceanogr 51:1629-1636.

Krajčovič, J.; Vesteg, M. Schwartzbach S.D. (2015). Euglenoid flagellates: a multifaceted biotechnology platform. J Biotechnol 202:135-145.

Labib, W. (2000). Short-term scale phytoplankton variability and ambient conditions in a highly dynamic Egyptian marine basin. La mer, Société franco-japonaise d, océanographie, Tokyo. 1-9.

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

Langer, G.; Nehrke, G.; Probert, I., *et al.* (2009). Strain specific responses of *Emiliania huxleyi* to changing seawater carbonates chemistry. Biogeosci 6:2637-2646.

Lewandowska, A. and Sommer, U. (2010). Climate change and the spring bloom: a mesocosm study on the influence of light and temperature on phytoplankton and mesozooplankton. Mar Ecol Prog Ser 405:101-111.

Lionard, M.; Muylaert, K.; Gansbeke, D.V. and Vyverman, W. (2005). Influence of changes in salinity and light intensity on growth of phytoplankton communities from the Schelde River and estuary (Belgium/The Netherlands. Hydrobiol 540:105-115.

Litchman, E.; Klausmeier, C. A.; Miller, J.R.; *et al.* (2006). Multi-nutrient, multi-group model of present and future oceanic phytoplankton communities. Biogeosci 3: 585-606.

Mikhail, S.K. (2001). Phytoplankton variability in the Eastern Harbour of Alexandria during 2000. Bull Nat Oceanogr Fish A.R.E. **27**:32-52.

Mikhail, S.K. (2007. First monospecific bloom of the harmful raphidophyte *Chattonella antiqua* (Hada) Ono in Alexandria waters related to water quality and copepod grazing. Chem Ecol 23 (5): 393-407.

Mikhail, S.K. and Halim, Y. (2009). Phytoplankton diversity and limiting resources in a semi-enclosed marine ecosystem (Alexandria, Egypt). Egypt J Aquat Res **35** (1), 131-147.

Mikhail, S.K. and Labib, W. (2014). Red tide outbreaks in Alexandria waters: Invasive harmful species. The 15th Conference on Harmful Algal Blooms. Korea Republic. 29 October-2 November, 2013.

Muthukumar, C.; Muralitharan, G., Vijayakumar, R., *et al.* (2007). Cyanobacterial biodiversity from different freshwater ponds of thanjavur, Tamilnadu (india). Acta Bot Malac 32: 17-25.

Paerl, H.W., Xu, H., Hall, N.S., *et al.* (2014). Controlling cyanobacterial blooms in hypertrophic Lake Taihu, China: will nitrogen reductions cause replacement of non-N_2 fixing by N_2 fixing taxa? PLoS ONE 9(11): 113-123.

Panda, S.S.; Dhal, N.K. and Panda, C.R. (2012). Phytoplankton diversity in response to abiotic factors along Orissa coast, Bay of Bengal. Int J Environ. Sci **2**:1818-1832.

Pannard, A.; Claquin P.; Klein C., *et al.,* (2008). Short-term variability of the phytoplankton community in coastal ecosystem in response to physical and chemical conditions changes. Estuar Coast Shelf Sci 80: 212-224.

Parsons, T.R.; Maita, Y. and Lalli, C.M. (1984). A manual of chemical and biological methods for seawater analysis. Pergamon Press Toronto.

Platt, T.; George, N.W; Li, Z.; Shubha, S. and Shovonlal, R. (2009). The Phenology of Phytoplankton Blooms: Ecosystem Indicators from Remote Sensing. Ecol Modell 220:3057-3069.

Polat, S.; Sarihan, E. and Koray, T. (2000). Seasonal changes in the phytoplankton of the northeastern Mediterranean (Bay of Iskenderun). Turk J Bot 24:887-906.

Rybak, A.S. and Gąbka, M. (2018). The influence of abiotic factors on the bloom-forming alga *Ulva flexuosa* (Ulvaceae, Chlorophyta): possibilities for the control of the green tides in freshwater ecosystems. J Appl Phycol 30:1405-1416.

Satpathy, K.K.; Mohanty, A.K.; Natesan, U., *et al*. (2010). Seasonal variation in physico-chemical properties of coastal waters of Kalpakkam, East coast of India with special emphasis on nutrients. Environ Monit Assess 164:153-171.

Schabhüttl, S.; Hingsamer, P.; Weigelhofer, G., e*t al*. (2012). Temperature and species richness effects in phytoplankton communities. Oecologia 171(2): 527–536.

Schlüter, M.; Mcallister, R.R.J.; Arlinghaus, R., et al. (2012). New horizons for managing the environment: a review of coupled social-ecological systems modeling. Nat Resour Model 25(1):219-272.

Tas, S. and Yilmaz, I.N. (2015). Potentially harmful microalgae and algal blooms in a eutrophic estuary in the Sea of Marmara (Turkey). Mediterr Mar Sci 16: 432-443.

Tomas, C.R. (1997). Identifying marine phytoplankton. Academic Press, San Diego.

Utermöhl, H. (1958). Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. Int Ver Theor Angew Limnol Verh 9:1-40.

van Haren, H.; Mills, D.K. and Wetsteyn, L.P. (1998). Detailed observations of the phytoplankton spring bloom in the stratifying central north sea. J Mar Res 56:655-680.

Wong, K.T.M.; lee, J.H.W. and Hodgkiss, I.J. (2007). A simple model for forecast of coastal algal blooms. Estuar Coast Shelf Sci 74:175-196.