Asian J. Adv. Basic Sci.: **2015,** ***3(2),*** 91-98
ISSN (Print): 2454 – 7492
ISSN (Online): 2347 – 4114
www.ajabs.org

Short-term Eutrophication in the Eastern Harbor of Alexandria, Egypt

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(Received 01 June, 2015; Accepted 06 June, 2015; Published 11June, 2015)

ABSTRACT: The phytoplankton community was studied in historically and ecologically important area of the Egyptian Mediterranean coast at Alexandria. Once a week sample was collected from a semi-closed basin ;Eastern Harbor,(EH) from June 2011 to May 2012 and twice a week over other one year started from March 2013 till February 2014 at fixed station. The results indicated that a total of 116 phytoplankton species were identified during the first year and 156 species during the second one, with the predominance of diatoms in both two periods (64&100 species respectively) with a percentage frequency 84.23 % and 76.10 % in two periods respectively, followed with dinoflagellates (15.34 % & 23.67 % respectively) . The phytoplankton standing crop amounted to an annual average of 1.84 x 10^6cell / l during 2011-2012 and 2.48x10^6at 2013 – 2014. C lean differences were observed between the roles of diatoms and dinoflagellates as well as the abundance cycle of total phytoplankton in the two periods. Generally, during the second period high counts of dinoflagellates particularly in 12 of August 2013 cause fish mortality. Eutrophication in the study area was accompanied by more frequent algal blooms, which were sometimes dominated by toxic species. Correlation coefficient of biological factors with some physicochemical parameters are provided and discussed.

Keywords: Phytoplankton; Diatoms; Dinoflagellates; Eutrophication; Fish mortality; Eastern Harbor.

INTRODUCTION: The phytoplankton community have essential role in the biodiversity and productivity of marine life as well as in monitoring the environmental changes. This is due to their rapid response to perturbations of water condition which are beyond the tolerance of many other biota used for monitoring[1].

The Eastern Harbor (EH) was among the most important area over the world from historical point of view, whereas, thousands of ancient Egyptian artifacts is found on the bottom of the EH. In addition, the EH served as reservoir of sewage of Alexandria city for about 5 decades, fishing activities, yachts sports, boat building and recreations .The long-term observations indicated chronic eutrophication in the EH with pronounced changes in the acuteness from time to time relative to the modification of the sewer system in the harbor during the past 2 decades .The chronic eutrophication conditions and the drastic changes in the dynamics of phytoplankton community in the study area were the main items of numerous earlier studies[2,3,4,5,6,7,8,9,10&11].

On the other hand the hydrographic characteristics of the harbor were studied by several investigators[6, 11, 12, 13, 14, 15, 16&17]. Although the ecosystem of the Eastern Harbor has been intensively studied throughout the 5 decades, none of these studies concerned with the short-term variations of the ecosystem. The present study highlights to follow up the dynamics of phytoplankton community in the EH after closing the sewage outlets at weekly interval and the fundamental short-term changes occurred in the study area during two years.

MATERIAL AND METHODS:

1. Study Area: The Eastern Harbor (EH) is a shallow semicircular and semi-closed bay, with an area of about 2.8 Km^2. It is located along the central part of Alexandria, at longitudes 29°53^1- 29°54^1 E and latitudes 31°12^1- 31° 13^1 N (Figure 1). The harbor is isolated from the open sea by an artificial break water of concrete blocks, except two openings at the middle and eastern side of the break water, which allow active water exchange between the harbor and the open sea.

2. Samples Collection: Water samples were collected once a week from June, 2011 to May, 2012 this work is a part of research plan " Study on steal corrosion rates in seawater by weight loss technique and the effect of environmental parameters ",the results of this plan(corrosion rates) is published[18]and twice a week from March,2013 to February, 2014 included in the research plan " Statistical study on some physical, chemical and biological factors affect steel corrosion in seawater and its protection using some marine natural extracts", the results of this plan (steel corrosion) is published[19]from one site in EH in front of NIOF (Figure 1)

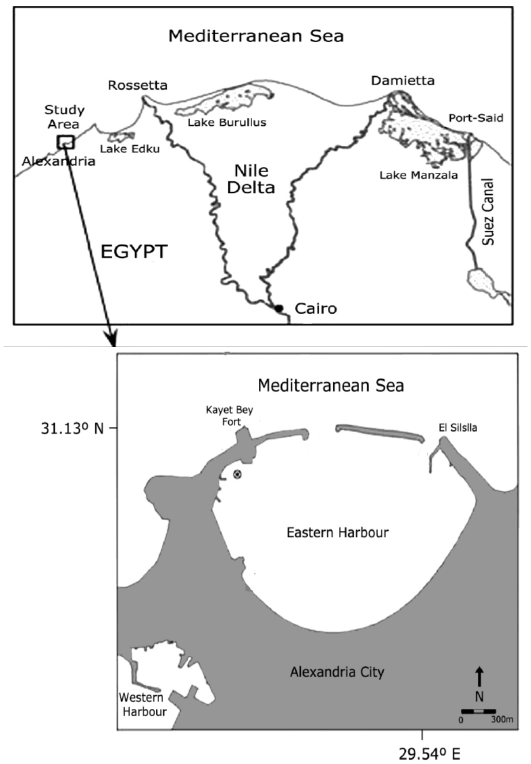

Figure 1: The map of the Eastern Harbour of Alexandria, Egypt showing the sampling station. (Khairy et al.[11])

For phytoplankton count one liter of collected seawater sample was preserved in 4 % of neutralized formaldehyde solution left 4 days for setting and the cells were counted and identified using 2-ml setting chambers with a Nikon TS 100 inverted microscope at 400x magnification using Utermohl[20] (1958)method. Phytoplankton species was counted and the results expressed as cells per litter. Various key books and papers were consulted for the identification of phytoplankton species.

3. Statistical analysis: Correlation coefficient by using Excel, 2010 program at a confidence limit 95 % ($p \leq 0.05$), were estimated for the first period ($n = 48$) and for second period ($n = 84$) to determine the phytoplankton standing crop in relation to the most relative physicochemical parameters .In addition to Principle component analysis (PCA) for weekly data of each period were done by using SPSS program and discussed.

RESULTS AND DISCUSSION:

1. Phytoplankton community structure: The phytoplankton community in the study area was more diversified 116spp; during June, 2011 – May, 2012 and 156spp. during March 2013 – February 2014, but the species composition was completely similar in both periods of investigation. Diatoms comprised the highest number of species (64&100 spp. in two periods respectively). This is followed by dinoflagellates (46&50 spp. respectively). In both periods, freshwater forms were less diversified including Euglenophyta (6 species in each period). The number of species showed monthly variations ranging between 48 and 72 species. The numbers of species during the present study were similar to that recorded during 2002[10]at the same area of investigation since the phytoplankton samples were weekly collected. While it is higher than that recorded by lsmael & Halim[7]and Tawfik[8], 75 &76species respectively. Considering that the number of species in the present study was taken only at one station, which certainly does not represented the community of the whole harbor, this number indicates that the harbor's phytoplankton started to restore its high diversity which was earlier recorded by Ismael[12].On the other hand, the higher number of dinoflagellates species in the present study(46&50),in the two periods of investigation which was higher than those of Ismael[12] and Tawfik[8](54&31species respectively) .This supporting the increase of their role in the Eastern Harbor, and their greater contribution to the total phytoplankton count.

The phytoplankton count was generally high in both periods, but abnormal spatial differences were observed, $1.84 \times 10^6$and 2.48×10^6 cells $.l^{-1}$ respectively, of these counts, diatoms constituted 84.23 % and 76.10 % in two periods respectively against 15.34 % and 23.67 % for dinoflagellates. The freshwater taxa showed almost low count, constituting collectively 0.43 % & 0.23 % respectively.

The present average phytoplankton counts in the study area (1.84×10^6& 2.48×10^6cells $.l^{-1}$) was markedly low as compared with the earlier studies in that (4.1×10^6cells $.l^{-1}$) recorded during 1990 -1991 (Hussein[13]) and that (4.3×10^6cells$.l^{-1}$) during 2004 -2005 (Abdel-Halim & Khairy)[9] . The drop of phytoplankton count could be related to change in nutrient concentrations during the past two decades.

The permanent and abundant occurrences of several toxic species were one of the characteristic features in the study area, which were almost associated with the eutrophication condition and frequent algal blooming. All these species were previously recorded in the study area, some at remarkably high counts. For example, *Alexandrium minutum* was identified for first time in the EH by Halim[21], and remained as dominant species for a long time[6, 13, 22 & 23]. After short time of disappearance the species reappeared during the present study.

1.1 Weekly variations of phytoplankton community composition: The abundance cycle of phytoplankton exhibited clearly different patterns in two monitored periods.

1.2 First period: During June, 2011 till May, 2012, the phytoplankton density ranged from minimum counts of $3.6x10^3$cells.l^{-1} at 16/1/2012 to maximum of $4.6x10^6$cells.l^{-1} at 17/10/2011 with an annual average $1.84x10^6$cells.l^{-1}. This value is slightly high than that recorded during 2009 at the same area of investigation[11]. Diatoms flourished during 19/9, 17/10, 23/11, 21/12 /2011and 15/5/2012 (Figure 2), while dinoflagellates showed slight increase during 14/6and 23/8/2012. Lowest phytoplankton counts were recorded during January till March 2012 (Fig. 2). This may be due to low water temperature (ranged from 16.5^{o}C to18.9^{o}C.)

The environmental condition in the study area plays fundamental role in the dynamic of phytoplankton community. The water temperature showed effect on the distribution of phytoplankton abundance. The highest phytoplankton peak was observed in 17October, 2011($4.58x10^6$cells/l) at water temperature 26.2°C and dissolved oxygen (6.84ml/l) due to the dominance of diatom species (*Skeletonema costatum,* 98.9%).On the other hand, high temperature enhanced the growth of dinoflagellates, in 14/6 at27.1^{o}c and in23/8; at32.1^{o}C. This confirmed with a positive correlation between dinoflagellates and water temperature ($r = 0.48$; $p \geq 0.05$). These results are in agreement with Ismael [24] who observed heavy bloom of dinoflagellates in summer in the same area of study.

The high phytoplankton count in 17/10 was associated with high nitrite and nitrate (4.6&7.6μmol/l respectively). Such relationship may be attributed to a positive correlation between phytoplankton and both nitrite concentration ($r = 0.26$; $p \geq 0.05$) and nitrate content ($r = 0.22$; $p \geq 0.05$). It seems that nitrite has a pronounced role in the growth of phytoplankton in the study area. The occurrence of nitrite as intermediate compound between ammonia and nitrate may contribute to its uptake by phytoplankton easier than the other two nitrogenous compounds[11]. Also, high phytoplankton counts on17 October 2011 are met with high values of pH (8.71) and dissolved oxygen (6.84ml.l^{-1}). This confirmed with a positive correlation with pH($r = 0.52$; $p \geq 0.05$) and dissolved oxygen ($r = 0.24$; $p \geq 0.05$). The same result sustains by diatoms since it is positive correlated with pH($r = 0.51$; $p \geq 0.05$), dissolved oxygen ($r = 0.26$; $p \geq 0.05$), nitrite ($r = 0.25$; $p \geq 0.05$) and nitrate ($r = 0.24$; $p \geq 0.05$).While dinoflagellates showed positive correlation with water temperature ($r = 0.48$; $p \geq 0.05$) as mentioned previously and negative one with water salinity ($r = 0.38$; $p \geq 0.05$).

With regards to high phytoplankton counts during 15/5/2012(3×10^6cells.l^{-1}) is met with lowest water salinity (35.5), high pH value (8.65) and water alkalinity (3.8meq/l) as well as high phosphate content (3.7μmol/l). The high percentage frequency of dinoflagllates; *Prorocentrum* (99%) during June (14/6/2011) might be attributed to consumed of phosphate content (from 3.2μmol/l to 0.15μmol/l) as well as during 23/8/2011; *Protoperidinium minutum* was(83.4%) it is also met with consumed of phosphate (from 9.556μmol/l to 0.85 6μmol/l). The high counts of phytoplankton during 20/9, 17/10 and 23/11 are accompanied with high concentration of dissolved oxygen (5.98, 6.84& 5.2 ml.l^{-1} respectively).

Diatoms were more flourished during autumn were mainly due to *Skeletonema costatum*. In addition to *Cyclotella meneghiniana*, *Chaetoceros affinis*, *Bellorochia* sp. and *Nitzschia paradox* and *N.closterium*. The increase counts of dinoflagellates were attributed mainly to *Protoperidinium minutum*, *Dinophysis cauda* beside *Scrippsiellace trochoidea*, *Prorocentrum cordate*, *P. compressa*, *Alexandrium minutum* and *Gonyalax catenceta*. However, *Protoperidinium* spp. were previously recorded in the Eastern Harbor as cysts from the harbor sediment which forming 43 % (Ismael *et al.*) [25]. Indicating that, increasing in diatoms and nutrient concentrations are the causes of increasing heterotrophic dinoflagellate in the Eastern Harbor. On the other hand, *Euglena* species was less frequent and showed flash appearance, with pronouncedly high counts in EH at 14/12/2011 (6.2 %) and 22/3/2012(41.2%).

1.2.1. Principal Component Analysis (PCA): Principal component analysis is applied to multivariate data derived from the water quality analysis of the water samples of all weeks during the year 2011-2012 in the Eastern Harbor of Alexandria. The output data reveals four factors (PC1-PC4) affect the water quality, association and sources, with cumulative covariance of 69.96%.Varimax rotated components matrix is presented in Table (1) to give an overview of the nature of loading among the parameters. PC1, PC2, PC3 and PC4 have covariance of 26.31%, 21.30%, 13.32% and 9.04% respectively. PC1represented loading of temperature (0.72) and nitrite (0.71) associated with negative loading of total alkalinity (-0.78), nitrate (-0.78) and silicate content (-0.81) which can be demonstrate autochthonous sources of both nitrate and silicate. PC2 had loading for pH (0.66), phytoplankton counts (0.97) and diatoms (0.97) which demonstrated the positive relation between phytoplankton and its main component and pH value. PC3 had loading effect of water salinity (0.76) associated with negative relation of dinoflagellates (-0.84). PC4 represented loading of dissolved oxygen (0.77) with negative loading of phosphate (-0.68) where phosphorus is limiting factor in phytoplankton growth.

1.3. Second period: During March 2013 – February 2014, phytoplankton community changed numerically and species composition was minimum counts during 19/5/2013 ($1.02x10^3$cells/l) and maximum at 22/12/2013 ($4.25x10^6$cells/l) with an annual average of2.48 x 10^6 cells/l. This value is higher than that recorded during 2009 at the same area of investigation[11]and during 2011/2012[18].The highest counts (22/12/2013) were met with lowest values of water transparency (87cm) and water temperature (17°C) as well as higher values of pH (8.77) and dissolved oxygen (7.06 ml/l).

Regarding the weekly distribution (Figure 3), high phytoplankton count was observed most of the year round except in September, particularly in 4/9 and 22/9, this accompanied by lowest dissolved oxygen content (4.33 ml/l for both) and water alkalinity (2.8&2.3meq/l) as well as moderate temperature (26.0 & 27.5°C respectively). The abundance cycle of phytoplankton showed many distinctive peaks; 26/6, 24/7, 12/8, 6/11, 22/12 &16/2.All increases are due to diatom blooms except in 12/8 due to the increase count of dinoflagellates. This accompanied with increase in concentration of dissolved oxygen (5.7, 5.01, 6.61, 5.34, 7.07&5.7ml/l respectively) and this confirmed with significant correlation with them($r=0.30$; $p \geq 0.05$).

It is obvious that phytoplankton abundance in the Eastern Harbor has passed distinctive changes throughout the past decade, in both the maximum values and the frequency of peaks. The present study recorded several peaks over the year, while Ismael[12] reported unimodal peak in January and Tawfik[8] observed tri-modal peak in February, June and October.Madkour[10];which samples were weekly collected in the EH; illustrated seven peaks**,** besides the highest one (1209 $x10^3$unit/l) was observed at the end of April. This indicates that the actual number of peaks could not recognize within macro time scale like season or months.

The environmental condition in the study area plays also fundamental role in the dynamic of the phytoplankton community, high temperature enhanced the growth of dinoflagellates .This confirmed with significant correlation between temperature and dinoflagellates ($r=0.35$; $p \geq 0.05$). The August peak (12/8) is mainly due to dinoflagellates; *Alexandrium minutum* was met with lowest water transparency (78cm), water alkalinity (2.4meq/l), water salinity (34.62) and phosphate content (0.16μmol/l) as well as highest water temperature (33.0 °C) and dissolved oxygen (6.6 ml/l). This is accompanied with fish mortality in the EH at 12/8/2013. During August, eight collected samples; (1/8, 4/8, 6/8, 12/8, 18/8, 21/8, 25/8 & 28/8). The first three samples showed that diatoms, *Cyclotella*, and dinoflagellates; *Alexandrinum minutum* formed about 50% for each (Fig. 3). While at 12/8, dinoflagellates contributed 93 % by number to the total counts there. So the same dominant dinoflagellate species formed over 99 % till the end of this month. Although neither the diatom blooms nor the dominant dinoflagellate species *Alexandrium minatum* red tide are toxic, occasional fish mortality occur due to antoxicity and/or gill clogging. The same phenomenon was previously recorded at the same area of study during May 1987[6] for the same reason. So, the increase in diatoms production is the main cause of increasing heterotrophic dinoflagellates, this agrees with finding of Matsuoka[26].

The highest phytoplankton count during 22December 2013 was mainly due to dominance of diatom, *Skeletonema costatum* (97.5% by number to the total phytoplankton counts). This is met with low values of water temperature (16.9°C), and water salinity (35.48) as well as high values of pH (8.7), dissolved oxygen (7.06 ml/l) and high silicate content (8.98μmol/l), this could be attributed to low uptake by diatom due to the effect of low winter temperature. Meanwhile, high diatom counts in 26/6/2013 (Figure 3) and clearly high silicate were recorded (4.34 6μmol/) at high temperature (30°C) may be explained by other factors rather than silicate concentration, such as comparatively high ammonia content (55.026μmol/l).

The phytoplankton flourishing in spring and early summer was due to *Sk. costatum*, reaching its maximum during December 2013. While *Chaetoceroros* spp. were recorded during January and February 2014 which contributed over 85 % by number to the total phytoplankton counts at these two months respectively. In addition to *Cyclotella* in 24 July (95.8%).Some of less frequent *Euglena* species showed flash appearance, with pronouncedly high counts in EH at 22/12/2013 ($44x10^3$ cell/l).

However, the dominant species during this study were *Skeletonema costatum, Chaetoceroros* spp, *Cyclotella meneghiana* and *Alexandrium minutum*. The effect of these species is different, as water coloration and foam or mucilage production[27], clogging the fish gills[6 & 28] and this similar to that the result of Ismael[29]. Moreover, there were dominant potentially harmful algae and they appeared *A.minutum*. The latter species was previously recorded in the Eastern Harbor as cysts from the harbor sediment forming 21% (Ismael *et al.*)[25]. The continuous coastal alternations in the area lead to an increase in the potentially harmful algal species along the Egyptian Mediterranean coast from 29 species to 38 species (Ismael & Halim)[30].

1.3.1 Principal Component Analysis (PCA): Principal component analysis is applied to multivariate data derived from the water quality analysis of the water samples of all weeks during the year 2013-2014 in Eastern Harbor of Alexandria. The output data reveals four factors (PC1-PC4) affect harbor water quality, association and sources, with cumulative covariance of 63.10%.Varimax rotated components matrix is presented in Table (2) to give an overview of the nature of loading among the parameters.PC1, PC2, PC3 and PC4 have covariance of 21.73%, 16.89%, 14.14% and 10.34% respectively. PC1 represented positive loading of water temperature (0.84) and ammonia content (0.84) associated with negative loading of pH (-0.75) which can be demonstrated autochthonous sources of ammonia. PC2 had high negative loading of diatoms (-0.84). PC3 had loading of dinoflagellates (0.65) associated with negative loading of water salinity (-0.78) which can be demonstrate the suitable favorite condition for dinoflagellate cysts maturation from the harbor sediment. PC4 represented loading of silicate content (0.63) and nitrate (0.62), which demonstrated the positive relation between silicate and nitrate confirming their allochthonous origin.

From Table (3) and Fig (3), the hot dates of phytoplankton blooms are clearly affected with principle component assessment during 8July with PC1.While PC3 affect the sample dated 1, 4,12,18,21 and 25 August. In addition to the effect of PC2 during 12 August and PC4 at 25 August. As well as PC4 affect during 28 August and 8September. The effects of PC2 are clearly appeared during the highest phytoplankton blooms at 22, 25 December and 16 February, which previously confirmed with the environmental condition.

Table 1: Varimax rotated component matrix for physicochemical and biological parameters in Eastern Harbor of Alexandria during 2011-2012.

Parameters	Component			
	1	2	3	4
Temperature	0.722	0.115	-0.438	-0.219
pH	-0.005	0.658	-0.086	-0.329
Alkalinity	-0.784	-0.021	-0.054	-0.006
Dissolved oxygen	0.047	0.260	0.190	0.772
Phosphate	0.128	0.136	0.091	-0.68
Nitrite	0.712	0.282	0.015	0.038
Nitrate	-0.782	0.255	0.044	-0.169
Silicate	-0.809	0.023	0.012	0.098
Salinity	0.059	-0.008	0.764	0.177
Total Phytoplankton	0.018	0.967	-0.136	0.075
Diatom	-0.004	0.970	-0.003	0.072
Dinoflagellate	0.147	0.184	-0.839	0.044
Variance	26.311	21.303	13.321	9.037
CV %	26.311	47.615	60.936	69.973

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization.[a]
a. Rotation converged in 7 iterations

Table 2: Varimax rotated component matrix for physicochemical and biological parameters in Eastern Harbor of Alexandria during 2013-2014.

Parameters	Component			
	1	2	3	4
Temperature	0.794	0.127	0.443	0.055
pH	-0.749	-0.274	0.137	-0.057
Alkalinity	0.597	-0.241	-0.392	0.165
Dissolved oxygen	0.050	-0.596	-0.375	0.164
Phosphate	0.378	0.099	-0.451	0.472
Silicate	-0.091	0.099	0.198	0.626
Nitrite	0.297	-0.197	0.0368	0.595
Nitrate	-0.194	0.251	0.114	0.623
Ammonia	0.839	0.009	-0.117	-0.102
Salinity	0.095	0.0422	-0.778	-0.116
Diatom	-0.155	-0.844	-0.057	-0.097
Dinoflagellate	0.225	-0.285	0.648	0.129
Total Phyto-plankton	21.735	16.892	14.139	10.339
CV %	21.735	38.627	52.765	63.104

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization.[a]
a. Rotation converged in 7 iterations

Table 3: Principal component factor scores of water samples at the different dates of the Eastern Harbor of Alexandria during 2013 – 2014.

Hot dates	PC1	PC2	PC3	PC4
08-Jul	1.875	-0.82874	0.85416	-0.12988
01-Aug	0.51579	0.50755	1.64526	-0.75546
04-Aug	0.32303	0.66943	1.60412	-0.69899
12-Aug	0.97752	-2.38396	4.53783	0.07535
18-Aug	0.25729	0.76066	1.66878	0.726
21-Aug	-0.11019	0.04791	1.8543	0.31145
25-Aug	0.10098	-0.64889	1.60972	2.1356
28-Aug	0.60669	-0.52056	0.81593	2.69313
08-Sep	-0.0522	0.97674	0.28703	1.88149
22-Dec	-1.12427	-5.68009	-0.24914	-0.01051
25-Dec	-1.00913	-2.86618	-0.85446	-0.16521
16-Feb	-1.40609	-1.98183	-0.14702	-1.21646

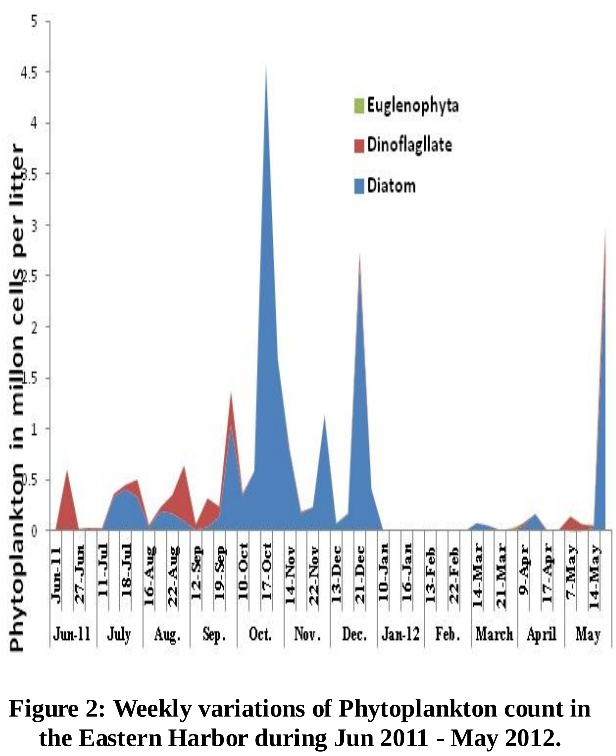

Figure 2: Weekly variations of Phytoplankton count in the Eastern Harbor during Jun 2011 - May 2012.

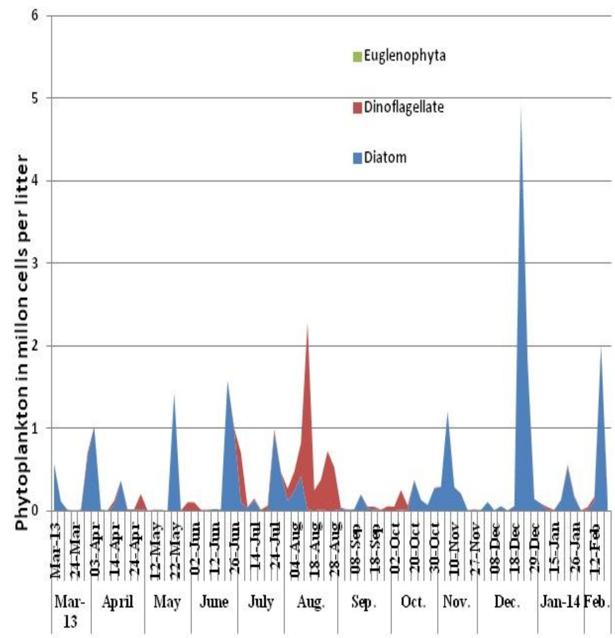

Figure 3: Weekly variations of phytoplankton count in the Eastern Harbor during March 2013 - February 2014.

CONCLUSION:

On the short term scale, the phytoplankton community is differed from one week to another and from one month to the other according to the prevalent environmental condition .The present study indicated that the Eastern Harbor is still suffering from eutrophication although great part of discharged wastes have been stopped, since two decades. This phenomenon was indicated from high nutrient concentrations and intensive phytoplankton growth. In the meantime, the phytoplankton community experienced drastic changes in the species composition, abundance and dominance on the short term scale, beside the permanent existence of several toxic species.

Monitoring continuously of this area is imperative flow the appearance of potentially harmful algal species, make this region susceptible to drastic effect at flourishing of these species during favourable conditions.

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