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Assessment of Phytoplankton Community as a Bio Indicator of Organic Pollution in the Drainage System of the Edku Lagoon, Egypt.

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ABSTRACT: The phytoplankton community structure, as well as its seasonal variation, was analyzed and discussed in the four drains inflow to the Edku Lagoon over 7 years, from summer 2009 to winter 2016. Palmer's and Shannon-Weaver biotic indices were used in the assessment of the water quality of the different drains. The recognized phytoplankton species were 238 comprising 86 genera and 5 groups: 97 Bacillariophyceae, which formed 40.8% by number of the total phytoplankton standing crop, 74 Chlorophyceae (44.92%), 34 Cyanophyceae (4.77%), 23 Euglenophyceae (9.38%) and 10 Dinophyceae (0.13%). The dominant recorded phytoplankton genera were Cyclotella, Melosira, Navicula, Ankistrodesmus, Chlorella, Scenedesmus and Euglena. The standing crop attained the highest counts at El-Khairy Drain (472 unit /ml), while the lowest was at El--Bousily Drain (80 unit /ml). The Shannon-Weaver diversity (H′) reflects an inverse relationship to the degree of dominance of the main species. It ranged from a minimal of 0.57 at Edku Drain and the highest one (3.65) at El-Khairy Drain. Species evenness fluctuated between 0.248 (Edku Drain) and 0.924 (El-Khairy Drain). The result showed that El-Khairy Drain has between moderate pollution and probable high organic pollution, but the other sites have lack organic pollution. The present research is attempting to examine the potential use of the phytoplankton species as a bio indicator of organic pollution.

Keywords: Phytoplankton; Drainage system of Edku Lagoon; Diversity Index; Palmer Index.

INTRODUCTION: The Edku Lagoon is the third largest lagoon in the system of the Nile Delta coastal lagoons, it lies west of Rosetta Nile Branch. This is a shallow brackish coastal basin situated approximately 30 km east of Alexandria on latitude 30°N and longitude 31°E. The width of the Lake is about 19 km, with a surface area of about 85 km^2 and an average depth of about 1 m., The Lake communicates with the Mediterranean Sea through a narrow 2m depth short channel: Boughaz El-Maadia.

Two main drains namely: El-Khairy and Barsik discharge huge quantities of drainage waters to the Lake. Three sources of drainage waters come from, El-Bousily, Edku and Damanhour sub-Drains, discharge to El-Khairy Drain. Additionally, wastewater comes to El-Khairy Drain from 300 fish farms. Agricultural drainage water is discharged to the Lake from Barsik Drain (Figure 1). The drainage water discharged into the eastern part of the Lake is amounted to be about 83-280 x 10^3 m^3/ day (Shriadah and Tayel)[1], in addition to wastewater from fish farms. The drainage water from Barsik Drain affected the southern part of the Lake, which is characterized by an excessive growth of hydrophytes, such as *Phragmites calmness'* and *Typha australis* (Shaltout and Khalil)[2]. While the western part is directly connected, through Boughaz El-Maadiya to Abo Qir Bay, which is a semicircular shallow basin, it receives wastewater through El-Tabia pumping station with an average of 1850 x10^3m^3/ day[1]. Moreover, drainage water is discarded into the Lake through a group of pumping stations (see the schematic diagram in Figure 2. The Lake also receives seawater through Boughaz El-Maadia from Abu Qir Bay, which is contaminated with raw industrial wastes from many factories through El-Tabia Pumping Station with an average of 2 × 10^6 m^3/day.

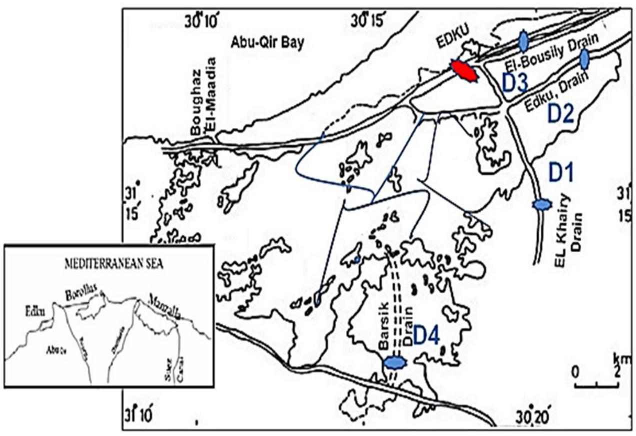

Figure 1: A map showing sampling stations from Edku Drains (After Ali and Khairy, 2016).

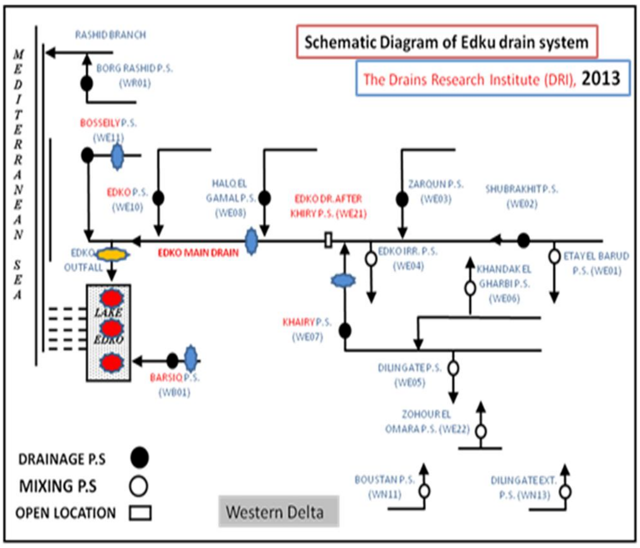

Figure 2: Schematic Diagram of Edku drains system. (Source the Drainage Research Institute; After DRI, 2013).

Lake Edku is subjected to large nutrient inputs of allochthonous origin (especially phosphorus and nitrogen) from drainage, agriculture, and sewage discharges. These cause a general increase in both algal growth and biological productivity in the Lake. Comparison with earlier observations points to a progressive decrease in the phytoplankton density during the last decades. Zaghloul and Hussein[3] mentioned that Lake suffered a high level of eutrophication because of a high concentration of nutrients, especially phosphorus, which is considered as the primary-limiting nutrient. Also, the study published by DRI[4] estimated that Lake Edku receives an average flow of 1.75×10^6 m^3/year from the industrial point source discharge. Abdel-Shafy and Ali,[5] explained that the agricultural network, irrigation and river systems do heavily suffer from abnormal water wastes along their passage up to the northern lakes and seacoast. This problem impacts on the health of the rural people beside its vigorous influences on the national overall economy. This agrees with the finding of Gaber[6].

Phytoplankton is considered as an indicator of ecosystem conditions; because it changes quickly, both species composition and densities; according to changes in the environmental conditions[7]. Zębek,[8] confirmed this fact, because of the short life span of phytoplankton. Consequently, phytoplankton is considered a good indicator to determine the water quality[9,10,11&12]. Thus, the density and the diversity of phytoplankton were undertaken as a biological indicator of evaluating water quality and the degree of eutrophication[13,14,15&16].

Now, the Edku Lagoon is under continuous stress as a result of the increasing urban and industrial activities that affect the water quality of the drain discharges into it. Presently there are several studies on the physicochemical and biological characterization of the Edku Lagoon by different authors, but studies on the water quality of the drains, which feed this lagoon, are missed dramatically.

Accordingly, the principle objective of this investigation is to follow up the changes occurring in the population density, seasonal variation, community structure, species diversity, species richness, and species evenness of phytoplankton in the four drains flowing into the Edku Lagoon; to assess the Palmer index in order to determine the level of organic pollution in the different drains and to examine the potential use of phytoplankton species as bio indicators of pollution in the sampling stations.

MATERIAL AND METHODS: Surface water samples were collected seasonally for quantitative and qualitative phytoplankton analysis (24 cruises within four drains) using Ruttiner bottle, during the period from summer 2009 to winter 2016. Water samples were preserved by Lugol's solution. Phytoplankton samples were counted and identified using 2-ml settling chambers with a Nikon TS 100 inverted microscope at ×400 magnification using the Utermöhl method[17] and the population density was expressed as unit/ml. Qualitative and quantitative phytoplankton analyses were made up to the genus, and planktonic organisms were numerically counted, identified, according to the following handbooks and Publications [18,19,20,21,22&23]. The phytoplankton density was expressed as unit /ml.

Statistical analysis: Three indices were used to estimate the community structure: diversity (*H'*)[24] evenness or equitability (J), Pielou,[25] using the SPSS 8.0 Statistical Package Program and the analysis of water quality, different qualitative (Palmer)[26].

RESULTS AND DISCUSSION:

Phytoplankton community structure and composition: Over the 7 years of the study period, 238 phytoplankton species were identified from summer 2009 to winter 2016. Bacillariophyceae recorded the highest number (33 genera, 97 species) while Chlorophyceae ranked the second (26 genera, 74 species). There were a remarkably low number of Cyanophyceae (20 genera, 34 species) and Euglenophyceae (3 genera, 23 species). Dinophyceae was represented by 4 genera and ten species. The dominant species of genera were; Nitzschia (19 species), Navicula (13 species), Scenedesmus (11 species), Euglena (6 species), and Oscillatoria (6 species). Chlorophyceae was the most dominant group (44.92% by number of the total phytoplankton density) followed by Bacillariophyceae (40.8%). Euglenophyta shared by 9.38%, Cyanophyceae contributed to 4.77% and Dinophyceae was rarely recorded (0.13%).

Generally speaking, phytoplankton standing crop attained an average of 857 units/ml for the seven studied years. This count is higher than that previously recorded (322 unit/ml) at the same region during 1995[27].

The mean phytoplankton density for the seven years was as high as 472 units/ml in El-Khairy Drain, 173 units/ml in Barsik Drain and 132 units/l in Edku Drain. Lower mean values, on the other hand, were recorded in El-Bousily Drain (80 units/ml). Bacillariophytes were of high percentage frequency in Edku Drain (45.98 %) and at El-Bousily Drain (43.53 %). Chlorophyceae dominated the community in Barsik Drain (49.62 %) and El-Khairy Drain (45.78%). Cyanophyceae appeared in obvious numbers in El-Bousily (5.72 %). Euglenophyta was frequently recorded in El-Bousiely Drain (12.98 %) and ranged between 8.38% and 9.29% in the other drains. Dinophyceae was minor groups. The ten dominant phytoplankton species, recorded in the period from summer 2009 to winter 2016, and their percentage to the average phytoplankton count in the differential drains are shown in Table 1.

Approximately similar numbers of species (187 and 157 species) were recorded at El-Khairy Drain and Barsik Drain, respectively, while a conspicuously smaller number (146 and 140 species) were found at El-Bousily Drain and Edku Drain, respectively. The total numbers of phytoplankton species recorded during the successive investigated years were 147, 89, 79, 97, 116, 94 and 74. The annual average of the different phytoplankton groups, their percentage frequencies and number of species changed from one year to another as shown in Table 2. The maximum species number in a single sample was 66 at El-Khairy Drain during summer, 2014. The numbers of taxa found at the different sites over 7 years within individual phytoplankton classes were dissimilar. Cyclotella, Navicula and Melosira genera from Bacillariophyceae were particularly vastly represented as well as Scenedesmus and Chlorella genera from Chlorophyceae. Cyanophyceae was dominated by Oscillatoria spp. Merismopedia punctata and Euglenophyceae by Euglena. Many species of the community were rare, having a negligible frequency of occurrence, but they were very important because they controlled the levels of species diversity.

El- Khairy Drain, a total of 187 species of phytoplankton were recorded, of which 73 species belonged to Bacillariophyceae and 61 species for Chlorophyceae, 26 species to Cyanophyceae, 19 to Euglenophyceae, and 8 species belonged to Dinophyceae. The phytoplankton density attained an average of 473 units /ml. This value is higher than the other drains. In regard to the phytoplankton distribution during the 7 years (Table 2), it attained high counts most of the investigated period, except at 2012/2013 (176 unit/ml). Bacillariophyceae dominated the phytoplankton community composition during 2011/2012 (59.6%), 2013/2014 (33.4%) and 2015/2016 (62.9%). While Chlorophyceae shared with high density during the other periods (Table 2). Cyanophyceae was frequently recorded all the years round with higher percentage, frequency in 2012/2013 (18%). As well as, Euglenophyta appeared with high counts during three years (2013-2015) as shown in Table 2, with the highest percentage 31.9% in 2013/2014. Regarding the number of recorded species, it varied from one year to another; it ranged from 57 (2015/2016) to 104 (2009/2010) as shown in Table 2. The species diversity values ranged from 2.19 (2014/2015) to 3.54 (2013/2014). Species evenness (j) varied between 0.501 (2014/2015) and 0.78 (2013/2014).

Edku Drain, a total of 140 species of phytoplankton were recorded, of which 61 species belonged to Bacillariophyceae and 45 species for Chlorophyceae, 16 species to Cyanophyceae, 15 to Euglenophyceae, and 3 species belonged to Dinophyceae. The phytoplankton standing crop ranged from 21 units/ml (2010/2011) to 188 units/ml (2009/2010), with an average of 132 units/ml. This is corresponding to the lowest number of recorded species (140 spp.). Bacillariophyceae formed the main community composition during 2009/2010 (60.4%), 2012/2013 (54%), 2014/2015 (47.9%) and 2015/2016 (47.9%). Chlorophyceae constituted the main bulk of the phytoplankton structure during other periods (Table 2). Euglenophyta was frequently recorded during most of the investigated period (from 2010-2016), with the highest occurrence at 2014/2015 (16.4%). Regarding the number of recorded species, it fluctuated between 43 (2010/2011) and 74 (2009/2010). Diversity values attained higher values, it ranged from 2.33 (2009/2010) to 3.5 (2013/2014) as shown in Table (2). Species evenness (j) varied between 0.542 (2009/2010) and 0.864 (2015/2016).

Barsik Drain, a total of 157 species of phytoplankton were recorded, of which 66 species belonged to Bacillariophyceae and 48 species for Chlorophyceae, 22 species to Cyanophyceae, 18 to Euglenophyceae, and 3 species belonged to Dinophyceae. The density of phytoplankton ranged between 27 units/ml (2010/2011) and 352 units/ml (2014/2015) with an average of 173 units/ml and number of species 157 during the all investigated periods. Bacillariophyceae dominated during four years; 2009/2010 (50.3%), 2010/2011 (62.8%), 2013/2014 (40.6%) and 2015/2016 (63.2%). While Chlorophyceae ranked the dominated phytoplankton groups at the other periods (Table 2). Cyanophyceae was frequently recorded during most of the studied period, with a higher percentage during 2009/2010 (12.8%) and 2015/2016 (8.6%). As well as, Euglenophyta was present during all the investigated periods, particularly; in 2009/2010 (12.7%), 2012/2013 (9.3%), 2013/2014 (16.1%) and 2014/2015 (10.1%). Regarding the number of recorded species, it fluctuated between 48 (2015/2016) and 103 (2009/2010). Diversity values ranged from 2.22 (2011/2012) and 3.86 (2013/2014) as shown in Table 2. Species evenness (j) varied between 0.521 (2011/2012) and 0.839 (2013/2014).

El-Bousily Drain, a total of 146 species of phytoplankton were recorded, of which 64 species belonged to Bacillariophyceae and 43 species for Chlorophyceae, 19 species to Cyanophyceae, 16 to Euglenophyceae, and 4 species belonged to Dinophyceae. The phytoplankton density fluctuated between 31 units/ml (2011/2012) and 173 units/ml (2014/2015) with an average of 80 units/ml and number of species of 146 for the seven years. Bacillariophyceae dominated during five years; 2009/2010 (55.2%), 2011/2012 (47.7%) and from 2013 till 2016: 36.4%, 42.9% and 68%, respectively. Chlorophyceae ranked as a dominant group during the other periods. It is obviously clear that Cyanophyceae appeared as a frequent group during the 2012 /2013 (11.4%) as shown in Table 2. Euglenophyta is recorded during the period 2011-2016 with a maximum occurrence at 2013/2014 (26.2%). Regarding the number of recorded species, it fluctuated between 39 (2015/2016) and 92 (2009/2010). Diversity values ranged from 2.4 (2015/2016) to 3.65 (2013/2014). Species evenness (j) varied between 0.64 (2009/2010) and 0.852 (2014/2015).

Table 1: Top ten dominant phytoplankton species sampled from summer 2009 to winter 2016 and their percentage frequency to the average phytoplankton in different Edku Drains.

El-Khairy Drain	**Percentage**	**Edku Drain**	**Percentage**
Chlorella vulgaris	15.45	*Chlorella vulgaris*	25.65
Melosira variens	12.18	*Cyclotella meneghiniana*	9
Cyclotella meneghiniana	10.68	*Melosira variens*	7.59
Cyclotella meneghiniana glomerata	4.61	*Nitzschia acicularis*	5.37
Kirchneriella obesa	4.45	*Scenedesmus bijua*	4.19
A.falcutus v. mirabile	3.91	*Navicula radiosa*	5.2
Ankistrodesmus falcatus	3.89	***A.falcutus v. mirabile***	3.96
Navicula cryptocephala	3.06	*Scenedesmus quadricauda*	3.21
Scenedesmus bijua	1.93	*Kirchneriella obesa*	1.58
Scenedesmus quadricauda	1.8	*Euglena caudata*	1.16
Barsik Drain	**Percentage**	**El-Bousily Drain**	**Percentage**
Chlorella vulgaris	16.42	*Melosira variens*	22.72
A.falcutus v. mirabile	14.57	*Cyclotella meneghiniana*	16
Navicula radiosa	10.97	*Scenedesmus quadricauda*	10.03
Cyclotella meneghiniana	10.08	*Chlorella vulgaris*	7.1
Melosira variens	9.55	***A.falcutus v. mirabile***	4.08
Ankistrodesmus falcatus	4	*Ankistrodesmus falcatus*	4
Oscillatoria limnetica	1.58	*Euglena caudata*	0.85

Table 2 : The annual average numbers of the different phytoplankton groups, their percentage frequencies, number of species and diversity values during 2009-2016 in Edku Drains

El-Kahairy Drain	2009/2010	No.	%	2010/2011	No.	%	2011/2012	No.	%	2012/2013	No.	%	2013/2014	No.	%	2014/2015	No.	%	2015/2016	No.	%
Bacillariophyceae	274514	41	41.7	315686	25	59.6	76183	21	24.8	55605	32	31.7	192725	34	33	76500	25	13	342200	16	62.9
Chlorophyceae	318302	39	48.4	189367	24	35.6	211539	26	69	73764	25	42	140653	31	27	414500	25	72	165500	18	30.4
Cyanophyceae	35379	10	5.4	16817	10	3.1	11836	8	3.9	31575	9	18	17523	11	3.3	26500	15	4.6	12850	10	2.3
Euglenophyceae	28693.5	12	4.3	8464	9	1.6	7116	10	2.3	14620	12	8.3	165228	15	32	56050	12	9.8	22700	11	4.2
Dinophyceae	1350.5	2	0.2	225	4	0.1	0	0	0	0	0	0	1240	3	0.2	250	2	0.1	1000	2	0.2
Diversity	3.38			2.63			2.67			3.33			3.54			2.19			2.52		
Total phytoplankton	658239	104	100	530559	72	100	306674	65	100	175564	78	100	517369	94	100	573800	79	100	544250	57	100

Edku Drain	2009/2010	No.	%	2010/2011	No.	%	2011/2012	No.	%	2012/2013	No.	%	2013/2014	No.	%	2014/2015	No.	%	2015/2016	No.	%
Bacillariophyceae	113766	37	60.4	6900	19	32.7	25723	20	37.1	100895	31	54	43030	37	24	54600	19	48	79950	22	47.9
Chlorophyceae	61883	21	32.8	11260	11	53.4	31258	18	45	67443	18	36.1	105123	25	59	36050	13	32	59150	16	35.4
Cyanophyceae	8699	6	4.6	1038	6	4.9	4950	7	7.1	3046	6	1.6	8453	11	4.8	4650	7	4.1	9150	6	5.5
Euglenophyceae	3201	8	1.7	1905	7	9	7520	7	10.8	15624	10	8.3	20075	14	11	18800	9	16	18750	9	11.2
Dinophyceae	825	2	0.5	0	0	0	0	0	0	0	0	0	325	2	0.2	0	0	0	0	0	0
Diversity	2.33			3.06			3.08			3.06			3.5			2.53			3.43		
Total phytoplankton	188374	74	100	21103	43	100	69451	52	100	187008	65	100	177006	89	100	114100	48	100	167000	53	100

Barsik Drain	2009/2010	No.	%	2010/2011	No.	%	2011/2012	No.	%	2012/2013	No.	%	2013/2014	No.	%	2014/2015	No.	%	2015/2016	No.	%
Bacillariophyceae	94585	45	50.3	16815	23	62.8	96772	28	33.6	48990	32	33.4	45648	43	41	81900	25	23	60865	24	63.2
Chlorophyceae	44058	34	23.4	7658	14	28.6	180342	22	62.5	77790	23	53.1	43338	29	39	224000	14	64	22770	9	23.6
Cyanophyceae	23984	13	12.8	1510	7	5.6	6193	10	2.1	6210	10	4.2	5085	12	4.5	10600	9	3	8280	8	8.6
Euglenophyceae	23925	9	12.7	790	4	3	5051	11	1.8/	13623	11	9.3	18090	13	16	35450	10	10	4410	8	4.6
Dinophyceae	1418	2	0.8	0	0	0	0	0	0	0	0	0	283	2	0.3	0	0	0	0	0	0
Diversity	2.95			3.04			2.22			2.9			3.86			2.77			3.09		
Total phytoplankton	187970	103	100	26773	48	100	288358	71	100	146613	76	100	112444	99	100	351950	58	100	96325	49	100

El-Bousily Drain	2009/2010	No.	%	2010/2011	No.	%	2011/2012	No.	%	2012/2013	No.	%	2013/2014	No.	%	2014/2015	No.	%	2015/2016	No.	%
Bacillariophyceae	35401	46	55.2	8373	22	30.6	14833	19	47.7	43788	31	34.1	29805	32	36	74185	19	43	37950	18	68
Chlorophyceae	22433	28	35	15935	11	58.3	11290	10	36.3	47668	21	37.1	28190	21	###	70370	20	41	13550	7	24.3
Cyanophyceae	5627	10	8.8	1665	6	6.1	2538	7	8.1	14577	3	11.4	2120	6	2.6	4280	7	2.5	1300	5	2.3
Euglenophyceae	435	5	0.7	1378	5	5	2455	8	7.9	22333	11	17.4	21450	14	26	22130	11	13	2700	6	4.8
Dinophyceae	196	3	0.3	0	0	0	0	0	0	0	0	0	215	2	0.3	1800	2	1.1	300	3	0.6
Diversity	2.89			2.74			3.05			3.39			3.65			3.48			2.41		
Total phytoplankton	64092	92	100	27351	44	100	31116	44	100	128366	66	100	81780	75	100	172765	59	100	55800	39	100

Seasonal variations of phytoplankton: Over the 7-year study period, the phytoplankton communities consisted mainly of Chlorophyceae and Bacillariophyceae, even if their contribution to the composition of the community in terms of abundances was different at the different drains, being 44.92% and 40.8%, respectively, of the total abundance. Phytoplankton abundance decreased in the drains discharging into the Edku Lake during the sequence years to reach the lowest counts during the 2010–2011 (151 unit/ml). The highest count was during the 2014–2015 (303 units /ml).

The annual variation of phytoplankton abundance and the dominating phytoplankton groups differ over the four drainage basins (Figure 3).

The phytoplankton density in El-Khairy Drain showed high values in the spring season (Figure 3), particularly during the year of 2010 (2034 units/ml), 2011 (1770 units/ml) and 2014 (1420 units/ml). This is attributed to nutrient rich effluent, which reflects changes in the community composition and dominant species. Chlorophyceae, reached its maximum counts in spring season of 2010. The most dominant chlorophycean species were Ankistrodesmus spp. (17.8% by number of the total phytoplankton standing crop during spring season), Scenedesmus spp. (11.5%) and Chlorella (11.5%). In addition to the presence of bacillariophycean species; Nitzschia spp. (21.5%) and Cyclotella spp. (10%). This bloom reflects high diversity, value (2.92) and presence of 49 species. The outstanding peak was recorded in spring of 2011. It consisted mainly of Bacillariophyceae; Melosira spp. (38.1%) and Cyclotella spp. (13.6%). The presence of recorded species is 40 and diversity value 2.26. Beside to chlorophycean species; Pediastrum spp. (13.8%) and Ankistrodesmus spp. (11.9%). The third phytoplankton bloom was recorded in the spring season of 2014 as shown in Figure 3. It mainly comprised Bacillariophyceae species; Cyclotella spp. (29.7%), Nitzschia spp. (4.2%) and Euglena spp. (27.6%). Although the phytoplankton density in winter, 2014 is low (67 units/ml), yet the highest diversity values was recorded (3.65) as shown in Table 3. Such high values are attributed to the dominance of several species; Euglens spp. (18.7%), Scenedesmus spp. (14.8%), Navicula spp. (11.8%), Nitzschia spp. (10.1%), Ankistrodesmus spp. (7.9%) and Oscillatoria (5.4%). On the other hand, the lowest phytoplankton counts were recorded during the autumn season of 2009 and spring of 2013. This corresponds to the lowest diversity values (Figure 3). During autumn 2009, the phytoplankton density was 37 units/ml, this accompanied with lower diversity, value (1.58) and presence of only 14 species. This is met with the dominant of a few species; Microcystis (54.8%), Pediastrum spp. (20%). However, the bloom of spring, of 2013 was due to Ankistrodesmus spp. (76%) and Chlorella (5.8%). This reflects the lower value of diversity (1.32). Generally speaking, the number of species in El-Khairy Drain fluctuated between 14 (autumn, 2009) and 66 (summer, 2014). The diversity index ranged from 1.32 to 3.65 during spring, 2013 and winter; 2014, respectively with an average of 2.71. Species evenness (j) varied between 0.427 (summer, 2014) and 0.924 (winter, 2014).

Table 3: Diversity indices of phytoplankton in the different Edku Drains

Diversity index	Years	El-Khairy Drain	Edku Drain	Barsik Drain	El-Bousily Drain
Shannon-Weiner index		*H′*	*H′*	*H′*	*H′*
	2009-2010	3.38	2.33	2.95	2.89
	2010-2011	2.63	3.06	3.04	2.74
	2011-2012	2.67	3.08	2.22	3.05
	2012-2013	3.33	3.06	2.9	3.39
	2013-2014	3.54	3.5	3.86	3.65
	2014-2015	2.19	2.53	2.77	3.48
	2015-2016	2.52	3.43	3.09	2.41
Species evenness		*j*	*j*	*j*	*j*
	2009-2010	0.727	0.542	0.637	0.64
	2010-2011	0.614	0.814	0.785	0.723
	2011-2012	0.64	0.78	0.521	0.805
	2012-2013	0.764	0.734	0.67	0.808
	2013-2014	0.78	0.779	0.839	0.845
	2014-2015	0.501	0.654	0.683	0.852
	2015-2016	0.623	0.864	0.794	0.657
Species richness		*D*	*D*	*D*	*D*
	2009-2010	7.688	6.01	8.399	8.222
	2010-2011	5.387	4.227	4.611	4.214
	2011-2012	5.065	4.575	5.568	4.156
	2012-2013	6.376	5.272	6.172	5.526
	2013-2014	7.069	7.464	8.426	6.652
	2014-2015	5.882	4.036	4.463	4.809
	2015-2016	4.24	4.324	4.183	3.504
Number of species		*N*	*N*	*N*	*N*
	2009-2010	104	74	103	92
	2010-2011	72	43	49	44
	2011-2012	65	52	71	44
	2012-2013	78	65	76	66
	2013-2014	94	89	99	75
	2014-2015	79	48	58	59
	2015-2016	57	53	49	39

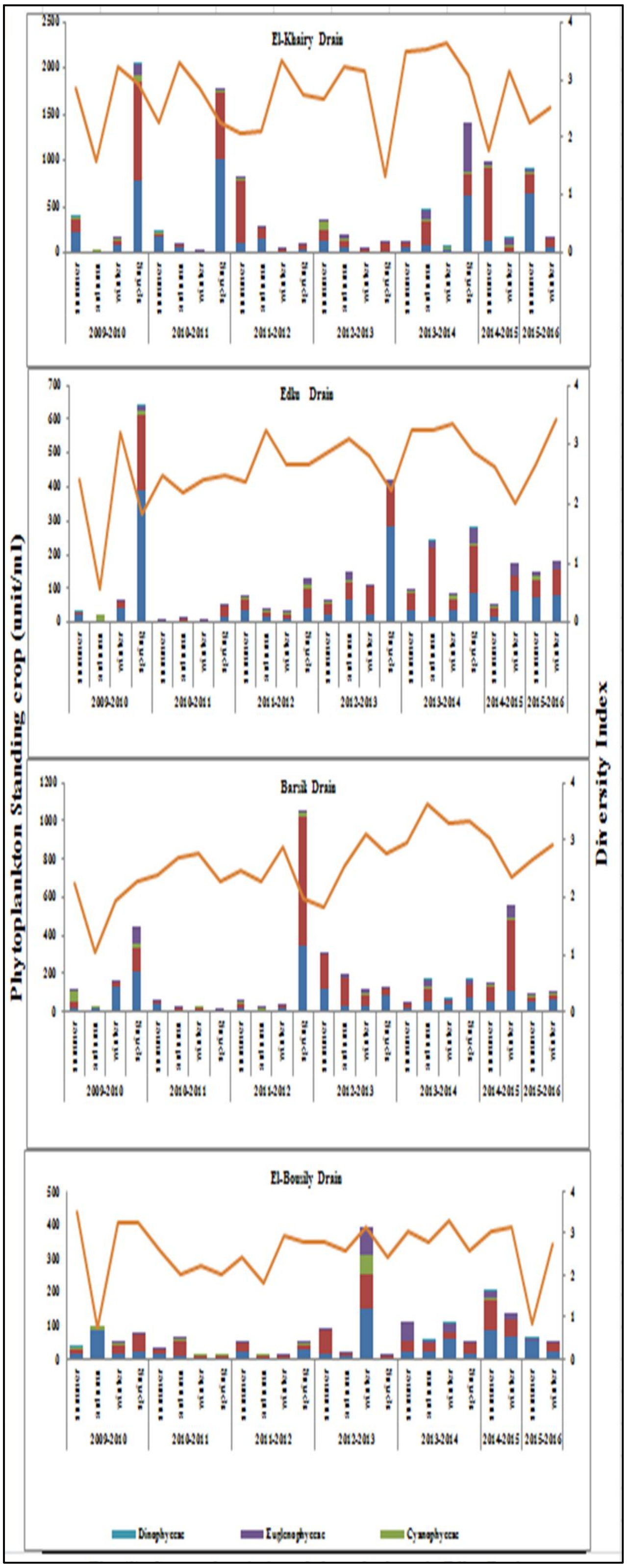

Figure 3: Seasonal variations of phytoplankton groups and diversity values in Edku Drains from summer 2009 to winter 2016.

The standing crop of phytoplankton of Edku Drain showed the highest density during spring; 2011 (640 units/ml) and lowest density at the spring; 2013 (423 units/ml) and 2014 (277 units/ml). The lowest count reached was during the winter, 2011; (6 unit/ml). The first phytoplankton peak was mainly to Bacillariophyceae (60% by number of the total phytoplankton standing crop during the spring season); Cyclottella (27.5%), Melosira varians (24.8%) and Navicula radiosa (7.8%), and Chlorophyceae (35%); Chlorella (28.5%). This reflects low value of both diversity (1.8) and number of species (29 spp.). The second phytoplankton bloom of spring 2013; showed the same dominant groups; Bacillariophyceae (67.3%) as the increased number of Navicula spp. (62%), particularly N. acicularis (44.1%). While Chlorophyceae shared by 25.6%; mainly to Chlorella (17.5%) and Ankistrodesmus spp. (4.9%). However, Euglena spp. formed 3.5%. The recorded species attained to a high number (43 spp.). This met with diversity, value of 2.24 (Figure 3). The last outstanding phytoplankton peak; spring 2014; showed that Chlorophyceae was the dominant group (50.1%), mainly due to Chlorella (23.4%), Scenedesmus spp. (9.8%) and Ankistrodesmus spp. (6.2%), and less so of Euglenophyta; mainly to Euglena spp. (12.3%), Phacus spp. (3.2%) and Bacillariophyceae, due to increased percentage frequency of Melosira varians (11.8%), Navicula spp. (7.8%) and Nitzschia spp. (6.4%). This accompanied by the presence of 48 species and high value of diversity (3.5, Table 3). On the other hand, the lowest diversity (0.57) was recorded in autumn, 2009, which coincided with the bloom of only one species: Microcystis (89.2%).). Species number fluctuated between 10 (autumn, 2009) and 53 (winter, 2014). The species diversity values ranged from 0.57 (autumn, 2009) to 3.37 during winter; 2014 with an average of 2.61. Species evenness (j) varied between 0.248 (autumn, 2009) and 0.918 (winter, 2012).

The phytoplankton standing crop in Barsik Drain fluctuated between 12 units/ml (spring, 2011) and 1053 units/ml (spring, 2012). The highest phytoplankton density was recorded during spring; 2012, winter; 2015 and spring; 2010 (Figure 3). The first outstanding peak (spring, 2010) was mainly due to the increase counts of Bacillariophyceae (45.9%); it is mainly due to Cyclotella (29.8%), Navicula radiosa (11.2%), and Melosira spp. (3.6%). Besides to presence of Chlorophyceae (27.5%); Carteria (14.9%), Scenedesmus spp. (5.6%) and Ankistrodesmus spp (4.5%). Euglenophyta (20.6%) was represented by Euglena spp. (7.1%) and Phacus spp. (3.4%). This is attributed to the presence of 49 species, which reflects the diversity of a, value of 2.26. The highest outstanding phytoplankton peak was recorded during spring; 2012; it is mainly due to increase percentage frequency of Chlorophyceae (64.4%). The dominant species were, Chlorella (35%), Scenedesmus spp. (15.5%) and Ankistrodesmus spp. (11.8%). Bacillariophyceae shared by 32.7%, it was represented with Melosira varians (26%) and Cyclotella (3.8%). Although; the species number is high (63), yet, the diversity; value was low (1.99) as the dominant of fewer numbers of species. The third phytoplankton peak recorded in winter; 2015 (Figure 3). This is mainly due to increase count of Chlorophyceae (66.9%). It represented with Ankistrodesmus spp. (49%) and Chlorella (11.6%). Bacillariophyceae constituted 19.7%; it represented by Navicula spp. (7.7%), Amphiprora (3.9), Nitzschia spp. (2.4%) and Melosira spp. (2.2). This bloom is attributed to the presence of many species (41 species) and diversity values of 2.36. Species number fluctuated between 9 (autumn, 2009) and 56 (autumn, 2014). The species diversity values ranged from 1.05 (autumn, 2009) to 3.62 during autumn; 2014 (Table 3) with an average of 2.58. Species evenness (j) varied between 0.513 (winter, 2010) and 0.90 (autumn, 2013).

The phytoplankton standing crop in El-Bousily Drain ranged from 7 units/ml (Autumn, 2011) to 392 units/ml (winter, 2013). The outstanding peaks were recorded during winter; 2013 and less so in summer; 2014 (Figure 3). The phytoplankton community composition during winter; 2013 was mainly due to Bacillariophyceae (37.5%), Chlorophyceae (27.6%), Euglenophyta (21.1%) and Cyanophyceae (13.7%). Nitzschia spp. (15%), Amphiprora (9.6%) and Navicula spp. (4.7%) from Bacillariophyceae. Ankistrodesmus spp. (10%), Scendesmus spp. (9.2%) and Chlorella (7.5%) from Chlorophyceae. Phacus spp. (12.4%) and Euglena spp. (8.8%) from Euglenophyta. Oscillatoria limntica (11.4%) from Cyanophyceae. This is corresponding to 41 recorded species and a high diversity; value (3.16). The second phytoplankton peak was recorded during the summer; 2014 is mainly attributed to Chlorophyceae (43.1%), Bacillariophyceae (40.8%) and Euglenophyta (10.4%). Scendesmus spp. (17.8%), Chlorella (13%) and Ankistrodesmus spp. (7.2%) from Chlorophyceae. Melosira spp. (21.5%) and Cyclotella spp. (10.1%) from Bacillariophyceae. Phacus spp. (6.8%) and Euglena spp. (3.4%) from Euglenophyta. This is met with 39 recorded species and a high value of the diversity index (3.03, Table 3). Species number fluctuated between 12 (winter, 2011) and 55 (summer, 2009). The species diversity values ranged from 0.76 (autumn, 2009) to 3.5 during summer; 2009 with an average of 2.55. Species evenness (j) varied between 0.281 (summer, 2015) and 0.91 (winter, 2012).

Palmer's index of pollution was calculated at the different drains; in order to rate water samples as high or low in organic pollution. While Edku Drain, Barsik Drain and El-Bousily Drain rated lack organic pollution, El-Khairy Drain rated moderate pollution score list of more than 15, indicating a high rate of organic pollution therein. Of the reported algal indicator genera, Ankistrodesmus, Cyclotella, Euglena, Chlorella vulgaris and Secnedesmus were dominantly observed at all study sites.

Generally speaking, the phytoplankton community structure is sensitive to the presence of pollutants in water, which causes an eutrophication in some times and also affect on the water quality[28]. Moreover, it helps in detecting the ecological pressure in the water. This agrees with the conclusions of Ingole et al.,[12]; Zębek[8], since the phytoplankton has a short life span. As well as, it is responsive to changes in the environment, which agrees with the finding of Shinde et al. [29].

The present study represents the first attempt to investigate the structure of the phytoplankton communities depending on samples accumulated seasonally during 7 years from the four drains surrounding the Edku Lagoon basin, and using this as a biomonitor of organic pollution. Results revealed that the phytoplankton community structure is influenced with the prevailing environmental factors over the investigated area. This agrees with the results of Shen et al.,[30] The present study showed that, the water discharged from the investigated drains into Lake Edku are the main sources of nutrients; particularly phosphorus and nitrogen, which impacts on the water quality, water circulation[31&32] and change the water chemistry. This is the case of most shallow lakes, e.g. Lake Burullus in Egypt[33] Lake Merja Zerga (Tunisia) and Ghar El Melh Lake (Morroco)[34].

According to the DRI[35] water discharged to Edku Lake from Edku drain (64-90 million m^3/month) are much lower than those of Barsik drain (166-497 million m^3/month). The latter was contaminated with harmful bacteria (e.g. Coli forms and fecal bacteria) as recorded by Ali and Khairy[36]. This is attributed, as in El-Khairy Drain to the released water from 300 surrounded fish farms[37]. The Lake's water attained high phosphorus concentrations as a direct, result of releasing fertilizers, detergents, house washing ups (urbanized wastes), deposition of animal feces and water mixing processes with sediment. This causes a decrease in the fish stock and causes skin diseases for fishermen[38]. This is the case for most North African coastal lakes[39,40&41] and other shallow water bodies worldwide; such as Lake Apopka in Florida [42] and Lake Lugano, between Italy and Switzerland[43] as well as most shallow freshwater lakes north and west of the Netherlands[44].

The recognized phytoplankton species in Edku Drains are 238 during the research period (7 years), showing a well-diversified taxonomy. Analyses showed that the dominating forms throughout the study period were; Cyclotella, Melosira, Nitzschia, Chlorella vulgaris and Scenedesmus, whereas Ankistrodesmus and Euglenoids where frequent appearance; the previous genera were recorded at all sites in all seasons during almost all times of the investigated years.

The phytoplankton density and the nutrient enrichment have been proportional[45&46]. As well as, both phytoplankton abundance and species diversity decreased as a result of the contamination of the investigated drains, all over the studied years. The same phenomena were recorded[47].

The present study showed that, the number of recorded taxa for the four studied drains were 147, 89, 79, 97, 116, 94 and 74. While the average phytoplankton densities were, 275, 151, 174, 170, 207, 303 and 214 units/ml, during the years 2009/2010, 2010/2011, 2011/2012, 2012/2013, 2013/2014, 2014/2015 and 2015/2016, respectively. There was a progressive decrease in both phytoplankton density and diversity. This resulted from the increasing pollution, which in turn causes the increase in the number of tolerant species to pollution and the decrease of some very sensitive one[48]. And also, the pollution reflects the occurrence of harmful algal bloom[49&50].

The phytoplankton community composition in the four studied drains; showed that Bacillariophyceae and Chlorophyceae were the main dominant classes in different relative abundances. In which, the percentage frequency of Bacillariophyceae varied between 13.3 % in El-Khairy Drain during 2015/2016 and 68 % at El-Bousily Drain during 2015/2016. This is factually based on the source of pollutant, environmental parameters and biological conditions [51&52]. There are some species, which are considered as indicators to specific pollutant such as, N. palea for metal-polluted sites[53&54]. C. meneghiniana regarded as pollution tolerant[55]. The genera of Euglena are classified as indicators of pollution from fifth class, Nitzschia from the third class[26]. Although, the habitat of genus Carteria (Chlorophyceae) is the pure water forms[56]. It has been found in sewage water and wastewater treatment ponds[47&57]. This is mainly because Chlorella vulgaris is able to remove the heavy metal from water and soil[58&59]. Han et al.,[60] found that C. vulgaris became a dominating species when it is added to the fish ponds.

Biodiversity indices in the present research were estimated by using Palmer's algal index and Shannon-Wiener diversity index; in order to find out the diversity of phytoplankton and the pollution status of the different drains. Three diversity indices were used to serve as indications that the ecosystem is under the influence of pollution, stress or eutrophication[61]. The results of the analyses 7 years revealed that the Shannon-Wiener diversity reflects an inverse relationship to the degree of dominance of the main species. This agrees with the result of Margalaf[62]. The absolute values of the diversity index in the different drains; showed that the lowest value (0.57) was recorded in Edku Drain (Autumn, 2009); due to the blooms of one species: Microcystis aeruginosa (89.2%). While the highest recorded one (3.65) at El-Khairy Drain (winter, 2014) is related to the dominance of several species:; Euglens spp. (18.7%), Scenedesmus spp. (14.8%), Navicula spp. (11.8%), Nitzschia spp. (10.1%), Ankistrodesmus spp. (7.9%) and Oscillatoria (5.4%). Rehabilitations resulted in a major ecosystem shift in an extremely polluted estuary and were followed by successive blooms of numerous species[63]. The normal characteristic of eutrophic ecosystems is known to be the occurrence of few dominant species with high density[64].

The majority of phytoplankton diversity indices fluctuated between 2 and 3 formed 58% of the recorded data. However, 29% was formed over diversity values 3, which demonstrates the low degree of pollution levels. In general, the diversity indices showed that the drains have a more or less well balanced phytoplankton community that liked an even representation of several species indicating the dynamic nature of the aquatic ecosystem.

The relationship revealed that diversity was significantly influenced by species evenness ($r = 0.838$, $p < 0.001$), species number ($r = 0.535$, $p < 0.001$), and species richness ($r = 0.637$, $p < 0.001$) and exhibited significant negative relation with phytoplankton density and evenness ($r = -0.294$, $p < 0.004$). Equitability had a significant positive relationship with species numbers ($r = 0.96$, $p < 0.001$). Species evenness index varied from 0.248 and 0.924. These variations reflecting the heterogeneity of the population that would be regularly analyzed by phytoplankton are out of balanced. Evenness had a negative correlation with phytoplankton abundance ($r = -0.294$, $p < 0.004$), which means that evenness decreased with increasing size of the phytoplankton population and many species are equally considerable. There exists a significant correlation between diversity index and evenness ($r = 0.838$, $p < 0.001$); this relationship is similar to that in the research by Reed[65], who found that diversity indices were closely related to evenness. The highest value of richness index (5.168) was noted in El-Bousily Drain during summer, 2009 and the lowest value (0.768) in Barsik Drain during autumn; 2009. While the highest value indicated healthy status, and the lowest value indicated unhealthy and contaminated status; due to the elimination of sensitive species and the flourishing of tolerant species.

A comparison of the average biodiversity indices in the four drains suggested that the diversity indices were slightly higher in El-Khairy Drains (2.71) and lower in El-Bousily Drain (2.55) and Barsik Drain (2.58). This may be related to the extreme restrictive environmental conditions associated with the eutrophication process[66].

Palmer[26], made the first major attempt to identify and prepare a collection of genera and species of algae tolerant to organic pollution also to set up the status of the aquatic body. Two Palmer algae pollution indices (one listed by genera, the other by species) were compiled and ranked the genera/species most often experienced in waters with high rates of organic pollution. According to Palmer, scores of 20 or more are indicators of high organic pollution. Pollution-tolerant genera and species as Oscillatoria, Euglena, Scenedesmus, Navicula, Nitzschia, and Ankistrodesmus are the species present in organically polluted waters as supported by Jafari and Gunale[67].

Similar findings have been recorded in the present investigation, where Scenedesmus, Euglena, Phacus, Nitzschia, Navicula, Oscillatoria, Cyclotella, Chlorella and Ankistrodesmus were the more common pollution-tolerant genera encountered in the studied drains. Cyclotella which was found to be the most active participant in every sampled station may be the best indicator of pollution tolerance; similar observation is recorded by Venkatachalapathy and Karthikeyan[68].

By utilizing Palmer's index of pollution, the rating of water samples to register the degree of organic pollution at the four drains. The present study revealed 15 pollution-tolerant genera found at all sampling stations, which Chlorophyceae comprised 5, Cyanophyceae 2, Bacillariophyceae 5, and Euglenophyceae 3 genera. Regarding to Palmer algal ranking, El-Khairy Drain has between moderate pollution and probable high organic pollution, however the other sites have lack organic pollution

CONCLUSION: Depending on the various indices used in the present investigation, the water quality of Lake Drains, Edku Drain, Barsik Drain and El-Bousily Drain are the best. Among the four investigated drains, El-Khairy is considered of moderate pollution. The increase in the anthropogenic activities and agricultural runoff is a major cause of eutrophication at these sites. These kinds of selected drains require immediate attention; in order to conserve their water quality. And therefore, management attempts should be focused consequently to check the deteriorating water quality of these drains. Based upon these observations, other researchers can develop concepts to monitor the water quality of different water bodies. To consider, phytoplankton has got the potential to act as bioindicators of pollution status. These should be preferred over others for early signals; because of their low cost, less time consuming, and ease of handling.

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