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Comparative Study of Phytoplankton Community Structure in Lake Edku, Southern Mediterranean Coast, Egypt

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ABSTRACT: Lake Edku is the third largest in the system of the northern coastal wetlands in Egypt. It is situated on the west part of Nile Delta and is considered as an important fishing area in Egypt. The Lake is a shallow basin of brackish water, nutrient replete system (particularly phosphorus and nitrogen), suffers from high levels of aquatic vegetation and from the expansion in fish farming and agricultural discharges. Ecological and biological status of Lake Edku was evaluated depending on seven years of seasonal monitoring from summer 2009 to winter 2016, at 9 stations representing the different regions within the Lake. Water transparency averaged 25.47 ± 7.56 cm. The water temperature was 23.54 ±5. 84 °C and water salinity was 2.24 ± 2.12 PSU. The dissolved oxygen was 9.37 ± 1.85 mg O_2/L, the biological oxygen demand was 17.56 ±15.19 mg O_2/L and the Chlorophyll-a was 90.23± 52.85 mg Chl- a /m^3. The recognized phytoplankton species were 309 taxa from 93 genera and six classes were recorded: 118 Bacillariophyceae, which formed 47.31% by number of the total phytoplankton standing crop, 93 Chlorophyceae (44.6%), 58 Cyanophyceae (5.51%), 27 Euglenophyceae (2.02%), 12 Dinophyceae (0.56%) and one species for Silicoflagellate. The present study revealed that the phytoplankton abundance and community are controlled by the environmental conditions, which fluctuate from one year to another, so while the phytoplankton seasonal succession. Generally speaking, a decrease was noted in the phytoplankton densities between 2009 and 2016. Phytoplankton diversity, varied broadly from 0.25 to 3.38, low values were accompanied by stable community, while higher diversities corresponded to non-steady state periods. Similarity was estimated for each and every single separate year and discussed.

Keywords: Lake Edku; Phytoplankton structure; Shannon diversity Index; Palmer Index and Similarity indices.

INTRODUCTION: Lake Edku is the third largest coastal water body in the system of the Northern Nile Delta Lakes. It is a shallow brackish seaside basin lies at approximately 30 km east of Alexandria (west of the Rosetta Branch), with an area of about 85 km^2. It is connected to the Mediterranean Sea through a narrow channel (Boughaz El-Maadia). The widest part is about 11 km, while the narrowest is merely 5 km as shown in Figure 1.

The area of the Lake Edku was approximately 20000 hectares before 1950 and has been reduced to approximately 10000 (of which 3000 hectares are overgrown) in 1985 primarily through land reclamation for farming and drying of the littoral lands. The eastern part of the Lake is subject to the discharge of huge amounts of drainage water; about 83-280 x 10^3 m^3/day[1], besides to wastewater from fish farms. The southern part is affected by drainage water from Barsik Drain, characterized by an excessive growth of hydrophytes[2]. While the western part is directly connected to Abo Qir Bay, which is a semicircular shallow basin, it receives waste water of about 1850 x $10^3 m^3$/day[1]. Drainage Research Institute[3] recorded the amount of industrial water received by Lake Edku to an average of 1.75 × 10^6 m^3/year. In spite of this, tourist beach, 7 Km east had been constructed before the 2000s. Water in the Lake Edku is not homogeneous.

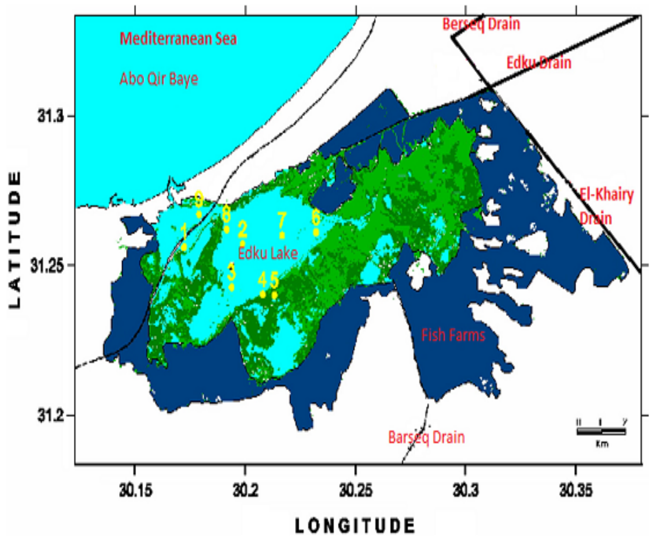

Figure 1: Map showing the sampling locations in Lake Edku and Drains.
(After the site of Environmental Monitoring Program for the Northern Lakes; E.M.P.N.L.)

The increasing inputs of nutrients indicate a threat to the environmental processes[4], which accelerate the rate of eutrophication[5&6]. The agricultural draining water containing fertilizers, pesticides and runoff supply both the water and the sediment in the Lake Edku with huge quantities of pollutant[2]. These conditions raise the biological productivity of the Lake. Moreover, the introduced sewage water may bring high numbers of microorganisms such as pathogenic Coliforms that might threaten aquatic plants and animals and present also a great hazard to public health[7].

Many studies have been previously conducted on the chemical and biological characteristics of Lake Edku, most of which was for only one year study period [6,8&9]. Siam and Ghobrial[7] studied the distinct water masses of Lake Edku regarding some of their biological and chemical characteristics. The interrelationship between bacteria (total bacterial counts, saprophytes and Faecal coliform), chlorophyll-a and some nutrients were investigated. Zaghloul and Hussein[6], studied the impact of pollution on phytoplankton community structure in the Lake, since it attained to a high level of eutrophication; as a result of a high concentration of nutrients, particularly phosphorus, which is the Primary-limiting for phytoplankton community. This impacts on lowering the diversity, values of phytoplankton population, species composition, relative abundance and dominance of the major components of the phytoplankton community. This reflects on the dominance of some species which considered as indicators of water pollution such as *Euglena* spp., and *Phacus* spp. besides altering the community composition from Bacillariophyceae to Chlorophyceae. Ossman and Bader[10], studied the relationship between Chlorophyll-a, total phosphorus and Secchi depth during 2006; in order to detect the concentration reduction from the drains to Lake Edku.

The present study mainly aimed to evaluate the Lake as an ecosystem regarding to phytoplankton community structure, phytoplankton species diversity, similarity depending on species composition for each station during seven subsequent years; in order to assess the recent case of the Lake ecosystem.

MATERIALS AND METHODS:

This work is supported by the National Institute of Oceanography and Fisheries with the Environmental Monitoring Program of the Northern Lakes.

Sampling sites: Phytoplankton samples were collected from nine selected locations distributed over the surface area of Lake Edku to fulfill the scope of work. Sampling was carried out seasonally for seven years during the period from summer, 2009 to winter, 2016 by using Ruttiner Sampler. Estimation of the phytoplankton standing was carried out by the sedimentation method[11]. Water samples were preserved immediately with 4% neutralized formaldehyde solution. The phytoplankton species were identified, counted and the results expressed as unit /ml.

Statistical analysis: Water quality was estimated according to Palmer[12]. Species diversity index[13], Correlation coefficients (r) at a confidence limit 95% were evaluated using a Minitab program. Moreover similarity index was estimated between the nine stations for each year, according to the type of species and its counts. The statistical design used for studying the species similarity is Multivariate Methods; species analysis (species clustering) using Primary Program, which is used to define species assemblages (species co-occur at the sites) using the Bray-Curtis similarity matrix with the aim to find" Natural grouping" of the samples more similar[14]. Attention appears to have turned to similarity[15], as they are good for detecting suitable changes in community structure.

RESULTS AND DISCUSSION:

Hydrographic condition: The estimation of Chlorophyll-a and the physico-chemical characteristics of Lake Edku were simultaneously studied parallel to the present phytoplankton study at the sampled stations as reported at the site of the Environmental Monitoring Program for the Northern Lakes (E.M.P.N.L.). These, together with previous data in sequential years, are summarized in Table (1).

Salinity and temperature: Salinities exhibited a wide variety; they varied between 0.77 PSU during spring, 2013 to 7.8 PSU during winter, 2016 with the exception to higher reading at El-Boughaz station (St.9) during November, 2011 (34.47 PSU). Water temperature in Lake Edku did not deviate from the normal seasonal fluctuations on the southeastern coast of the Mediterranean Sea (23.5 ± 5.8 °C).

Water transparency: Transparency fluctuated between 5 cm to 80 cm (an average of 25.47 ± 7.56 cm) over the lake sampling stations with a decrease during the spring season according to phytoplankton blooms. Higher values of transparency were recorded at El-Boughaz station (St. 9).

Dissolved Oxygen (DO) and the Biological Oxygen Demand (BOD): As for dissolved oxygen, the Lake water was well oxygenated (9.37 ± 1.85 mg O_2/L). DO range from 0.93 to 22.3 mg O_2/L with a minimum value at station 6 and maximum values at station 9. The present results showed an increase in BOD values for most stations during the winter season; particularly 2015 (72.66 mlO_2 /l). This may be attributed to the increase in DO content and the continuous mixing of water with sediment by wind action that increases the bacterial count.

Nutrient salts: Nitrite concentration attained a wide range from 0.85 (autumn, 2014) to 472.2 µg /l (winter, 2013) with an average of 95.72 ± 63.34 µg /l. Maximum nitrite concentrations were recorded in most parts of the lake during winter season 2013. This was met with an increase of nitrite concentration of the water discharges from drains. In contrast, nitrate concentrations weren't exceeding 0.77 µg /L (0.32 ± 0.37 µg /l). Ammonia concentration ranged from 0.01 (autumn, 2013) to 5.27 µg /L (winter, 2015), with an average of 0.73 ± 0.63 µg /l. Contrasting nitrates; phosphate level ranged from 9.3 (autumn, 2010) to 1078.2 µg /L (winter, 2013) with an average of 278.01 ± 167.2 µg /l. It attained to its minimum value during summer. Silicates concentration ranged from 0.03 µg /l (winter, 2016) to 47.0 µg /L (winter, 2011), with an average of 3.17 ± 2.22 µg /L, among sites (Table 1).

Chlorophyll-a dynamics: Values of Chlorophyll- a concentration has been always higher than the eutrophication level (10 mg Cl a /m^3). According to the trophic classification of inland waters based on chlorophyll-a concentration by OECD[18], Lake Edku may be considered among eutrophic lakes, since chlorophyll-a is higher than 30 mg /l. Over the study period, it ranged from 3.7 mg Chl- a/m^3 (autumn, 2013) to 391.8 mg Chl- a/m^3 (spring, 2014) as shown in Table (1).

Phytoplankton Standing Crop:

Community composition: The magnitudes of phytoplankton abundance in the present study are much different than the range of previous works rather than the range of numbers of species as shown in Table (2). Also, the species composition showed different patterns of dominance. The average of phytoplankton standing crop, main groups and their percentage frequency during different years are given in Table (2) as compared with the previous records in Lake Edku.

Table 1: Evaluation of physicochemical parameters (range & mean) in Edku Lagoon between 2000 and 2016.

Year	Temp. (°C)	Transp. (cm)	pH	Salinity ‰	DO	BOD	Chl.a (mg /m3)	PO_4	SiO_2	NO_2	NO_3	NH_4	References
					ml/l			µmol/l					
2000	-	-	-	-	1.58-6.98	0.12-6.23	-	6.8-18.3	19.4-206	1.2-9.7	11.0-62.3	3.2-31.0	Okbah & El-Gohary[16]
	-	-	-	-	3.7 5 ± 1.16	1.35± 1.11	-	10.0± 1.5	91.1± 19.2	4.95± 1.2	29.22± 8.6	12.8± 4.7	
2004	17.0-27	20-60	7.5-8.71	-	5.44-14.07	-	`-	0.92-15.97	3.68-210.08	0.38-16.11	0.08-70.23	0.26-45.12	Shakweer[17]
	22.38± 3.39	30.63± 9.49	8.04± 0.3	-	8.34± 1.72	-	-	7.19± 4.51	88.4± 48.24	5.91± 4.75	17.54± 14.85	13.65± 14.24	
2010/11	14.75-31.2	5.0-80	7.17-9.04	0.9-29.03	1.05-17.75	1.72-27.08	3.72-143.72	9.27-484.27	0.24-470	1.95-299.7	0.04-1.14	0.03-3.25	Environmental Monitoring Program for the North Lakes. (http://www.eeaa.gov.eg/ar-eg)
	23.6±6.0	35.5±7.5	8.09±0.42	2.35±1.7	8.62±0.84	11.78±6.96	61.09±15.53	254.6±40.7	2.87±1.1	108.9±59	0.45±0.11	0.82±0.56	
2011/12	11.2-35.5	10.0-40	7.78-9.13	0.85-34.47	1.96-18.43	2.13-41.44	9.59-416.95	19.25-803.14	0.47-10.52	1.41-355.4	.01-0.39	0.05-2.8	
	22.47±7.85	22.21±6.61	8.23±0.46	4.07±4.26	10.36±1.11	11.78±0.84	110±93.65	352.3±273.7	4.02±3.05	97.4±56.4	0.67±0.33	0.61±0.35	
2012/13	14.0-30.8	15-75	7.61-9.11	0.86-3.25	0.93-11.92	5.94-58.3	6.73-228.38	25.39-1078.2	0.28-10.73	2.47-472.2	0.01-0.77	0.02-3.09	
	22.67±6.22	26.65±9.0	8.5±0.24	1.52±0.37	7.26±2.3	10.36±1.11	85.87±38.4	323.2±20.7	4.7±2.9	136.9±72.4	0.15±0.06	0.69±0.25	
2013/14	14.7-30.0	10.0-75	7.7-9.1	0.75-15.07	1.91-18.76	4.19-53.89	3.7-391.8	11.0-441.7	0.08-4.49	0.85-162.9	0.003-0.318	0.01-4.23	
	22.71±5.85	28.9±8.3	8.51±0.23	2.35±1.28	10.43±1.42	7.26± 2.3	126.59±53.6	229.6±149.8	1.57±0.8	66.4±22.9	0.162±0.04	0.54±0.33	
2014/15	15.0-30.1	12.9-50	7.95-9.51	0.81-3.61	0.32-17.7	0.42-288	18.34-137.1	31.1-632.7	0.06-6.56	4.07-145.9	0.03-0.28	0.03-5.27	
	28.84±0.07	21.96±11.4	8.51±0.23	1.74±0.35	9.57±0.73	10.43±1.42	67.16±15.15	275±160	3.36±1.96	46.9±22.6	0.095±.008	1.15±0.31	
2015/16	16.0-31.0	20-60	7.71-9.0	0.78-7.8	0.95-22.26	1.83-58.3	18.34-137.1	9.92-488.5	0.03-5.19	0.11-232.7	0.03-0.62	0.02-3.98	
	23.63±8.34	30.28±5.11	8.56±0.16	1.92±1.15	10.81±1.94	9.57± 0.73	67.14±15.13	186.0±118.4	2.03±1.08	91.2±50.9	0.23±0.12	0.84±0.32	

Table 2: The annual average numbers of the different phytoplankton groups, their percentage frequencies and number of species in Lake Edku during 1995 (Gharib[19]); 2000 (Zaghloul &Hussin[6]) and during the period from summer 2009 to winter 2016.

Years	1995-1996			2000			2009 - 2010			2010 - 2011			2011 - 2012		
Phytoplanktion groups	Average No	No. Spp.	%	Average No	No. Spp.	%	Average No	No. Spp.	%	Average No	No. Spp.	%	Average No	No. Spp.	%
Bacillariophyceae	5213000	40	69.3	1526681	25	33.69	829585	67	55.92	326160	52	38.46	524175	50	37.31
Chlorophyceae	863000	39	11.50	2506945	15	55.32	527946	63	35.59	388480	42	45.81	793605	42	56.48
Cyanobacteria	109000	21	1.50	86858	11	1.92	69546	31	4.69	105429	19	12.43	59043	22	4.26
Dinophyceae	786000	2	10.4	12858	2	.28	16174	7	1.09	1589	4	.19	1687	4	0.12
Eyglenophyceae	547000	17	7.3	398485	8	8.79	40078	24	2.70	26432	15	3.12	26544	15	1.83
Total	7517000	119	100	4531827	61	100	1483344	192	100	848090	132	100	1405054	133	100

Years	2012 - 2013			2013 - 2014			2014 - 2015			2015 - 2016		
Phytoplanktion groups	Average No	No. Spp.	%	Average No	No. Spp.	%	Average No	No. Spp.	%	Average No	No. Spp.	%
Bacillariophyceae	805636	44	46.42	1072806	50	58.92	400539	39	44.72	700401	38	41.87
Chlorophyceae	801994	41	46.21	690255	46	37.91	432193	39	48.26	642599	34	38.42
Cyanobacteria	94230	22	5.43	31243	22	1.72	17963	19	2.01	106550	20	6.37
Dinophyceae	746	4	.04	1216	3	0.7	3354	4	.04	117	4	.02
Eyglenophyceae	32755	19	1.89	25117	17	1.38	44564	17	4.98	222780	17	13.32
Total	1735361	130	100	1820638	138	100	895594	118	100	1672447	113	100

The annual average of the present phytoplankton standing crop in Lake Edku of the seven studied year's reached 1409 units /ml. This value is lower than that previously recorded at the same region during the 1995 /1996 (7517 unit /ml; Gharib[19] and during 2000 (4532 unit /ml; Zaghloul and Hussein[6]). Regarding the annual average during the seven examined years; Bacillariophyceae taxes were most abundant with 47.31% by number to the total phytoplankton community. Chlorohyceae ranked second (44.6%). Cyanophyceae and Eugenophyceae formed 5.51% and 2.02%, respectively. Dinophyceae was rarely recorded (0.56%). Silicoflagellate was scarcely recorded in 2009/2010. However, the number of species was higher and the picture was altered; Bacillariophyceae became predominant during 2009/2010 (55.9%) and 2013/2014 (58.9%). On the other hand, Chlorophyceae dominated during 2010/2011 (45.8%), 2011/2012 (56.5%) and 2014/2015 (48.3%) as shown in Table (2).

The phytoplankton of Lake Edku exhibited extensive variability, both in respect to the number of taxa and to phytoplankton density. Over the 7 years of study, a total of 309 taxa from 93 genera and 6 classes, namely; Bacillariophyceae (39 genera, 118 species), Chlorophyceae (27 genera, 93 species), Cyanobacteria (17 genera, 58 species), Euglenophyceae (5 genera, 27 species), Dinophyceae (4 genera, 12 species) and taxon for silicoflagellates were recorded. An increase in Bacillariophyceae and Chlorophyceae, the most common genera were *Cyclotella* (3 species), *Navicula* (14 species), *Nitzschia* (20 species), *Melosira* (3 species), *Chlorella*, *Scenedesmus* (19 species), and *Euglena* (12 species).

The number of identified phytoplankton species in Lake Edku during the period of this study ranged from 113 (2015/2016) to 192 (2009/2010) phytoplankton taxa. The highest count attained 1821, 1735, 1672 unit /ml during 2013/2014, 2012/2013 and 2015/2016, respectively. While lowest values were recorded at 2010/2011 and 2014/2015 (848 & 896 units /ml) as shown in Table (2).

Regarding to the distribution of the phytoplankton density during seven years (Figure 2), it showed a high count during most of the study period except during the years of 2011/2012 and 2014/2015 as shown in Table 2. Generally speaking, the highest density of stations was attained at sites 1 and 2, since they are affected by adjacent fish farms, in times at station 9 in 2009/2010 and 2012/2013 and with station 8 during 2010/2011. While the lowest counts for all investigated periods was recorded at station 6 (which is the collection of drains) as shown in Figure (2).

Diversity Index: During 2009/2010, the highest phytoplankton counts were attained at different stations except at sites 6 and 7 (Fig. 2), where the lowest density (394 and 833 units /ml) and number of species (94 & 91 Sep.) were recorded. However, higher diversity values were recorded (2.98 & 3.15). This is attributed to the many species shared in community composition: *Melosira* spp. (28.3% &19. 6% by number of the total phytoplankton density of the two stations, respectively); *Cyclotella* spp. (10% & 16.2%, respectively); *Chlorella vulgaris* (22.3% & 3.5%); *Ankistrodesmus* spp. (6.3% & 8.7%); *Scendesmus* spp. (6.9% & 4.7%); *Euglena* spp. (3.4% & 2.8%) and *Phacus* spp. (1.1% & 1.3%).

In the year 2010/2011, the highest phytoplankton density was recorded at stations 1, 2 and 8 (Fig. 2), while the lowest counts was attained at station 6 (369 unit /ml) as well as the lower number of species (77) and diversity value (1.22). The community was dominated by only one species, *Melosira* spp., since it contributed 77.6% by number of the total phytoplankton standing crop at station 6. The phytoplankton standing crops at both stations 1and 2 are higher in counts (1355 & 1589 units /ml at the two stations, respectively), species richness (106 & 108) and diversity values (3.07 &2.38). This was accompanied with many species shared in the community composition; *Merismopedia* spp. (24.2% & 11.7%, respectively), *Chlorella vulgaris* (14.6% & 46.9% respectively), *Scendesmus* spp. (19.2% &7.4%), *Ankistrodesmus* spp. (8.5% & 9.9%), *Cyclotella* spp. (8.5% & 3.9%), *Melosira* spp. (6.1% & 3.7%) and *Nitzschia* spp. (4.8% & 4.3%).

During the year 2011/2012, although the highest standing crop was observed at station 1 (3260 unit/ml), yet the species richness was the lowest (88), as well as diversity value (1.86) as shown in Fig. (2). This is attributed to the dominance of two species; *Ankistrodesmus* spp. (73.4% by number of the total phytoplankton density) and *Nitzschia* spp. (12.1%). However, the lowest phytoplankton counts were recorded at station 6 (230 unit /ml), the diversity, value attained the highest one (3.0). Such high diversity, value is attributed to the dominance of several species; *Scenedesmus* spp. (48.8%), *Chlorella vulgaris* (12.2%), *Melosira* spp. (8.7%), *Cyclotella* spp. (6.2%), *Ankistrodesmus* spp. (6.4%) and *Euglena* spp. (2.7%).

Although the phytoplankton density during the year 2012/2013 attained high counts at all stations except station 6 (Fig. 2), yet the species richness is different, being; 101, 102 and 101 at stations 7, 8 and 9, respectively. Station 6 recorded only 76 species. In spite of these differences, the diversity values are high at all stations. These were coincided with dominance of several species in the community composition.

During 2013/2014, the phytoplankton densities are high at all stations except stations; 5, 6 and 7 (Fig. 2). Although the lowest count was reached at station 6 (112 unit/ml), species richness (91), yet the diversity value attained to the highest value (3.34). This is attributed to the presence of several species with comparable percentage. At station 6 the recorded species, namely; *Scendesmus* spp. (15.9%), *Melosira* spp. (11.6%), *Cyclotella* spp. (11.6%), *Chlorella vulgaris* (10.4%), *Carteria* (9.1%), *Ankistrodesmus* spp. (6.2%), *Phacus* spp. (4.1%) and *Euglena* spp. (3.7%).

The phytoplankton density during 2014/2015 were higher at stations 1, 2, 4 and 7 (Fig. 2). The lowest counts were reached at station 6 (154 unit /ml) as well as species richness (57). Highest diversity; value was recorded at station 6 (3.01). This is similar to the result during 2013/2014. Station 3 recorded a lower value of phytoplankton count (709 unit /ml), species richness (59) and diversity value (1.38). This is attributed to the dominance of two species, namely: *Chlorella vulgaris* (73.0%) and *Melosira* spp. (12.6%).

The phytoplankton density during 2015/2016 attained higher counts at stations 1, 2 and 3, the lowest one was recorded at station 4 (Fig. 2). However, the number of species richness was similar (72 & 71) at station 1 & 4, respectively. Yet the diversity values were different, since the lowest diversity, value was recorded at station 1 (1.96) and the highest one was observed at station 4 (3.05). Low diversity, value of station 1 was accompanied with the dominance of three species, namely: *Nitzschia* spp. (33.6%), *Chlorella vulgaris* (24.3%) and *Melosira* spp. (20.9%). However, higher values of diversity at station 4 are attributed to dominance of many species, namely: *Cyclotell*a spp. (28.3%), *Nitzschia* spp. (15.7%), *Scendesmus* spp. (10.5%), *Eugellna* spp. (9.6%), *Merismopedia* spp. (9.5%), *Melosira* spp. (5.2%) and *Chlorella vulgaris* (4.3%). The rate of organic pollution was estimated according to Palmer's index[12] at the different stations. The results showed that stations 3, 4, 5, 6, 7, 8 and 9 rated lack of organic pollution, while stations 1 and 2 rated a pollution score; as the effect of fish farms in their vicinity. The indicator genera; *Ankistrodesmus*,*Chlorella*, *Cyclotella*, *Euglena* and *Secnedesmus*.

Figure 2: Distribution of phytoplankton standing crop and its main components at different stations and diversity values in Lake Edku during the years from 2009-2016.

Similarity Index: The dendrogram with complete linkage correlation coefficient distance during the investigated period, showed that the similarity level of the nine stations varied from 5% at 2013/2014, 10% during 2010/2011, 2011/2012 and 2012/2013, 15% in 2014/2015 and 2015/2016 to 20% in the year 2009/2010 (Fig.3). In which delineates two main groups all the investigated years, but the number of sub-groups are different from year to the others (Fig.3), as classified in homogeneous or inhomogeneous sub-groups. This classification based on mean the mean root-root transformed abundance of the phytoplankton community were estimated at different sites for each year using the Bray-Curtis measure of similarity and groups average sorting through seven years (Fig. 3). It showed that station 6 (which the collection of drains) was almost separate than the other sites during most of the investigated period except during 2010/2011 and 2015/2016. In general, cluster analysis of the different stations classified two main groups and sub-groups (homogenous or inhomogeneous) depending on the percentage of the similarity. According to the increase of similarity percentage between two stations, the phytoplankton standing was similar. As shown in Figure (3), it can be clearly seen that stations 2 and 3 showed homogenous subgroups with the similarity level of about 72% during 2009/2010 and 70% in the year 2011/2012. This reflects nearly the same phytoplankton density (Fig. 2). The same observation was recorded during 2010/2011, between stations 5 and 4 with the similarity level attained 70%. As well as, between stations

8 and 9 during 2013/2014 (80%) and 60% in 2014/2015. Stations 1 and 3 showed a similarity value of 60% in 2014/2015 and stations 7 and 8 (70%) at both 2012/2013 and 2015/2016. Stations 1 and 2 showed homogenous sub-groups at a similarity value of 80% during 2012/2013, 60% in 2010/2011 and 50% at 2015/2016.

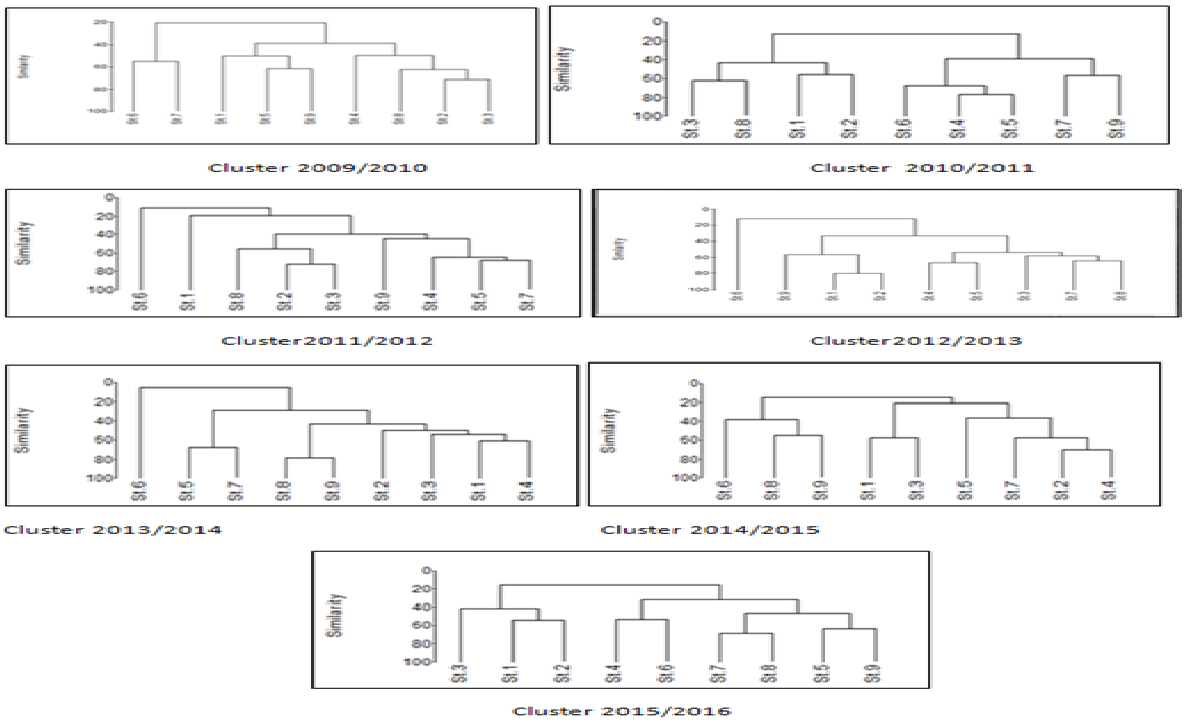

Figure 3: Cluster analysis of phytoplankton composition between sampling sites of Lake Edku for seven years.

Seasonal variations of phytoplankton: Over the 7 year study period, Bacillariophyceae, Chlorophyceae and Cyanobacteria were three dominant classes (Fig. 4). Generally speaking, phytoplankton dominance in different stations varied from year to year, and also from season to another.

During 2009/2010, the highest phytoplankton counts were recorded during spring season; particularly at stations, 1,3,5,8 and 9 (Fig. 4); being; 3592 unit /ml, an algal bloom dominated by Chlorophyceae (34.3%); *Chlorella vulgaris* (17.08%) of the total count. Bacilariophyceae (61.6%) dominated by *Nitzschia* spp. (33.7%), *Melosira variens* (13.8%) and *Cyclotella* spp. (10.8%).While the lowest phytoplankton counts were recorded in autumn season (533 unit /ml), winter season counted 832unit /ml and the summer season 976 unit /ml. The species diversity values ranged from 1.03 to 3.36 at station 9 during winter and summer 2009, respectively, with an average of 2.58. Species evenness (j) varied between 0.345 (station 9, winter 2010) and 0.848 (station 8, autumn 2009).

During 2010/2011, the highest counts were measured during spring (Fig. 4), while the lowest were recorded in summer (790 unit /ml). The phytoplankton in spring showed a pronounced increase; diatoms (47.8%), *Melosira* spp. (28.6%) and *Cyclotella* spp. (11.6%). As well as Cholorophyceae; *Chlorella vulgaris* (19.9%), *Ankistrodesmus* spp. (10.1%) and Scendesmus spp. (7.7%). As for the phytoplankton communities during autumn changed since Cholorophyceae was predominated (49%) followed with Cyanophyceae (26.3%); *Merismopedia punctate* (18%) and *Gloecapsa minima* (2.3%). The species diversity values ranged from 0.52 to 3.38 at station 6 and 8 during summer 2010 respectively, with an average of 2.36. Species evenness (j) varied between 0.139 (station 6, summer 2010) and 0.967 (station7, winter 2011).

During 2011/2012, the highest cell concentrations were measured during spring (Fig. 4). The most significant contributors to the species composition were *Melosira variens* (21.3%), *Cyclotella meneghiniana* (16.1%), *Nitzschia microcephila* (7.9%), *Ankistrodemus falcutus* (11.9%), *Chlorella vulgaris* (10.8%) and *Pediastrum simplex* (6.8%). The species diversity values ranged from 1.06 to 3.09 at stations 1 and 9 during winter 2012 respectively with an average of 2.36. Species evenness (j) varied between 0.278 (station 1) and 0.821 (station 6) during winter 2012.

During 2012/2013, highest cells, concentrations were measured during summer season (2110 unit /ml, Fig. 4), while low counts were recorded in winter (969 unit /ml). The phytoplankton showed a pronounced increase of *Cyclotella meneghiniana* (24.1%), *Melosira variens* (6.1%), *Chlorella vulgaris* (20.9%), *Scendesmus acutus* (5.1%), *Scendesmus quadricoda* (5.2%), *Anabenopsis circulars* (12.1%) and *Merismopedia punctate* (1.4%). The species diversity values ranged from 0.95 to 3.0 at station 1 during summer 2012 and winter 2013, respectively, with an average of 2.04. Species evenness (j) varied between 0.229 (station 2, summer 2012) and 0.844 (station 6, Spring 2013).

During 2013/2014, the highest phytoplankton counts were recorded during spring season (Fig. 4), while lower density was recorded in winter (969 unit/ml). The phytoplankton showed a pronounced increase of *Cyclotella meneghiniana* (21.8%), *Nitzschia frustulum* (17.0%), *Nitzschia acicularis* (15.9%), *Melosira variens* (14.9%), *Chlorella vulgaris* (11.5%), *Ankistrodesmus flacutus (*7.4%) and *Ankistrodesmus flacutus vari. mirabile* (3.4%). The species diversity values ranged from 1.33 to 3.23 at station 2 during spring 2014 and station 5 during autumn 2013, respectively, with an average of 2.27. Species evenness (j) varied between 0.343 (station 2, spring 2014) and 0.847 (station 6, autumn 2013).

During 2014/2015, the highest count was recorded during winter season (960 unit /ml). The phytoplankton in winter showed a pronounced increase; *Melosira variens* (14.8%), *Cyclotella glomerata* (11.9%), *Cyclotella meneghiniana* (10.4%) and *Chlorella vulgaris* (29.2%). The species diversity values ranged from 0.87 to 3.15 at station 3 during winter 2015 and station 2 during summer 2014, respectively (Fig. 4), with an average of 2.21 .Species evenness (j) varied between 0.247 (station 3) and 0.837 (station 6) during winter, 2015.

During 2015/2016, highest cells, concentrations measured during winter season (2559 unit /ml), while low counts recorded in summer (Fig. 4). The most significant contributors to the species composition were *Melosira variens* (21.3%), *Nitzschia acicularis* (19.2%), *Melosira granulata* (15.8%), *Cyclotella glomerata* (4.2%), *Chlorella vulgaris* (27.3%) and *Euglena caudate* (7.0). %). The species diversity values ranged from 1.52 to 3.15 at station 3 during summer 2015 and station 4 during winter, 2016, respectively with an average of 2.31. Species evenness (j) varied between 0.452 (station 5) and 0.797 (station 8) during winter, 2016 and summer, 2015 respectively.

Lake Edku is affected by different kinds of water; drainage water and sea water, this creates a brackish ecosystem and great modifications in time and space [20]. Lake Edku has a low water transparency (25.5 ± 7.6) because of suspended materials[21]; this might describe the high density of *Potamogeton pectinatus*.

pH values usually lie on the alkaline side (8.37 ± 0.36) and a slight increase was noticed over the last two decades, as a result of the increased photosynthetic activity of planktonic algae [22]. Salinity distribution (2.42 ± 2.12) reflects a decreased gradient, this gradient depends on both the amount of drainage water and sea water. The recorded species in Lake Edku during the present investigation are mainly fresh or brackish water forms. Therefore, marine phytoplankton species are limited only at El-Boughaz (station 9). The high salinity and existence of marine forms, especially in winter could be due to the closure policy of the pumping drain stations which diminish the water level to be below sea level and permits sea water to invade the Lake.

The dissolved oxygen concentration in Lake Edku attained an average value of 9.37± 1.85 ml O_2/L. This value is higher than the minimum WHO (5 mg /l, Nkwo et al. [23]). Thus, the Lake water can be considered as well oxygenated ecosystem. Due to the barriers of macrophyte communities, the shallowness of the water, weakened wave action and the slight increase in temperature, all these factors make water column of the Lake to be vertically mixed, and so nutrients of sediment are easily diffuse into the overlying water and therefore there is an increasing the nutrient concentrations in the water content[24]. The high phosphorus levels (674.63 ± 261.24 µg /L) in the Lake create a good habitat for macrophyte communities. Rapid growth of these macrophytes could cause a restriction of nitrogen, but not of phosphorus[25]. The assessment performed in the seven years, showed progressively decrease in nutrient concentrations, except for the sudden increase in nitrite concentrations (average 237.59 µg /L) recorded during winter 2012 (Table 1). As a result, important changes in the phytoplankton population occurred with increased frequency of Chlorophyceae, which was predominant at all Lake stations. Further evidence of the high nutrient availability in the Lake Edku is the high concentration of Chlorophyll- a (90.23 ± 52.85 mg Chl-a/m^3), which showed a steady increase through the years similar to the reduction in numerical abundance. This means that, the majority of the biomass composed mainly of small cells (nanoplankton, 3–20 µm; picoplankton, < 3 µm) which were not counted during the present study and constituted a considerable amount of the photosynthetic biomass.

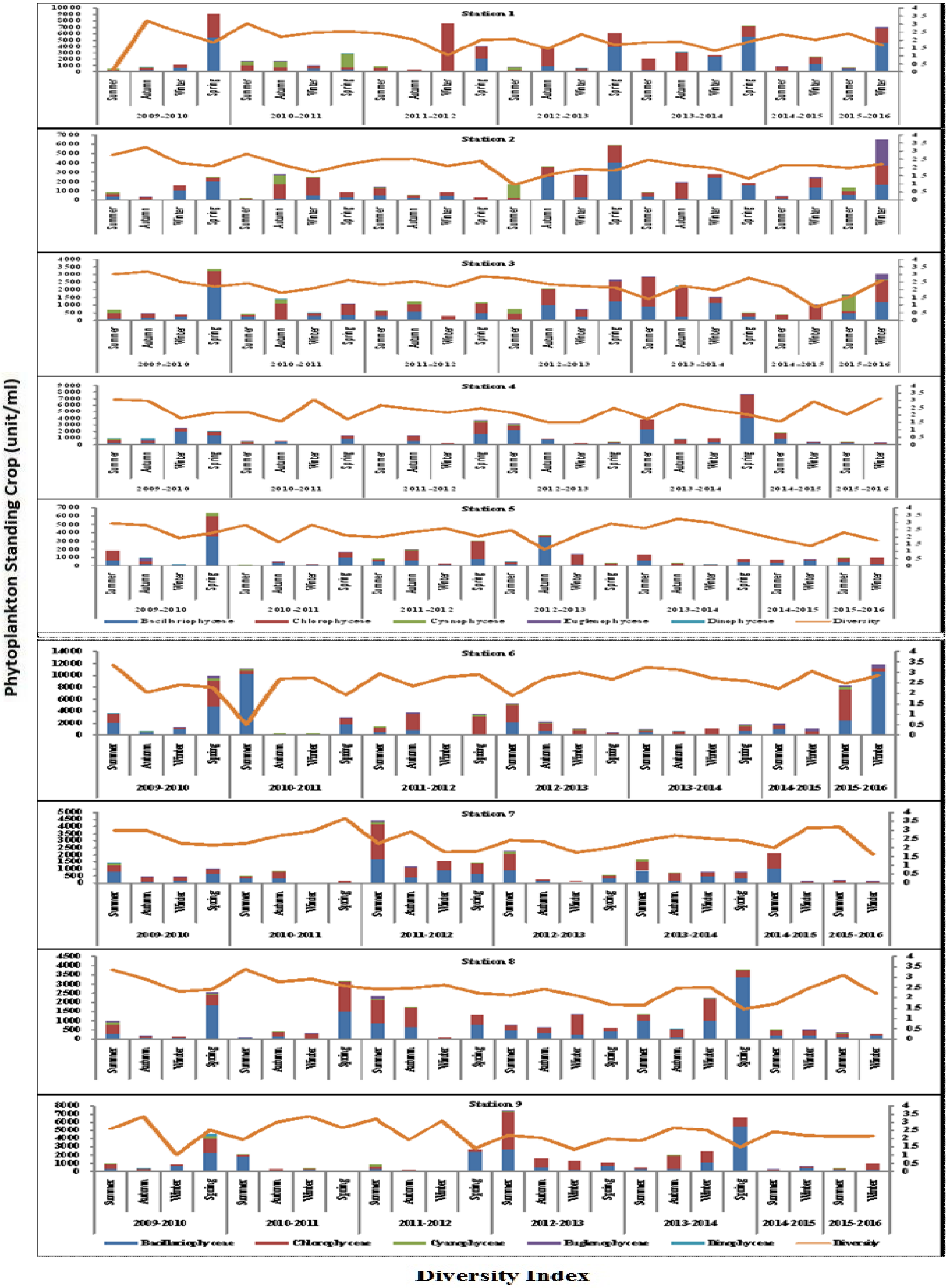

Figure 4: Seasonal variations of phytoplankton groups and diversity values.

Comparing with the previous data[26]; at the same lake who mentioned that it is characterized by high nutrient concentration with an annual average of NO_2-N (5.4 µg /l), NH_4-N (4.5 µg /l), PO_4-P (7.8 µg /l), SiO_2-Si (97.7 µg /l), as well as high concentration of dissolved oxygen (8.3 ml O_2/l). Such values are differed than the present results. This is due to the huge amounts of drainage, wastewater and agricultural water discharged into the lake.

Bacillariophycea were mostly predominantly of the phytoplankton community. Thus, the silicate concentrations are controlled with both biological removal by phytoplankton, particularly diatoms [27&28] and mixing between seawater and fresh water[29]. Diatoms such as Cyclotella spp. which is considered as a euryhaline form[30]. Likewise, the dominance of *Scenedesmus* spp. was another polluting of the environment indicative, particularly high phosphate concentrations [31&32].

Definitely, the aquatic ecosystem is dependent to a very large extent on phytoplankton density. There is no doubt that physical and chemical characteristics of the aquatic ecosystem play important functions impacting on the growth and the distribution in its communities. Consequently, the changes in these conditions must lead to changes in the phytoplankton community structure. These alterations in quantity and diversity of biota may be argued from various angles, such as a count of phytoplankton, their ratio composition, predominance and so on[33]. Nitrogen forms as main limiting nutrient in the algal growth was varied also in the action from station to another. Harper[34], found that the high nutrient concentrations decreased the species number to the half. The result of Zaghloul and Hussein[6], in Lake Edku, confirmed that, since they mentioned that the phytoplankton community in the contaminated environments reflects a decrease in both number of dominating species, species diversity and an increase in cell count of one or two species.

The present study, which carried out in Lake Edku throughout continuous seven years, showed that the differences in the phytoplankton community structure are affected by the surrounding environmental factors such as nutrient level, currents, temperature, grazing by zooplankton and benthos. This is agreeing with the finding of each Shen et al.[35]; Blanco et al.[36] and Song et al. [37].

Diversity is a function of the ecological processes (competition, predation, succession), and it reflects changes in evenness[38]. Rich phytoplankton species was recorded in Lake Edku (309 taxa). In such shallow Lakes high diversity may occur because these Lakes are always fully mixed with the bottom layer and therefore occurrence of numerous species is not restricted to mixing rather may be limited by other environmental factors such as nutrients[39]. The species diversity index of phytoplankton can be considered as an indicator of pollution or eutrophic stats for any ecosystem [40]. The present result showed that, lower diversity index values (average of 2.04) were recorded in the period 2012/2013 indicated that the Lake is under the influence of pollution. During the other six periods diversity values (average of 2.49 ± 0.3). This means that the water quality is recovered. Nevertheless, a low value of species diversity index showed that there is domination by a few species in the area [41]. The present results revealed a significant correlation between diversity index and evenness ($r = 0.962$, $p < 0.001$) as well as the relationship between species numbers and the diversity index was insignificant ($r = 0.43$, $p < 0.05$). This correlation is similar to the result of Reed[42]. As well as, the diversity, value was mainly influenced by species evenness ($r = 0.962$, $p < 0.001$), species number ($r = 0.426$, $p < 0.061$), and species richness ($r = 0.505$, $p < 0.023$). Equitability had a negative relationship with species numbers ($r = -0.474$, $p < 0.05$).

In general, it can be clearly seen that the similarity of station 6 (which is the collection of drains), was almost separate than the other sites (Fig. 3). Stations 1 and 2 showed a homogenous sub-group during 2010/2011 at similarity 60%, 2012/2013 (80%) and 2015/2016 (50%). This is may be due to the effect of water discharge from the adjacent fish farm. The same observation clearly appears at stations 2 and 3 during both 2009/2010 (72%) and 2011/2012 (70%). As well as, stations 4 and 5 during the 2010 /2011 (80%). Stations 8 and 9 (which are affected by sea water discharge) showed a homogenous sub-group during both 2013/2014 (80%) and 2014/2015 (60%).

Generally speaking, the stations with high pollution level, such as St.6 (which is the collection of drains) received untreated discharged waters, led to the increase in counts of Euglenophyceae which is considered as organically polluted[43] and become dominant (13.32% of the total count) during the 2015/2016 particularly at stations 1 and 2 (31.6% & 43.2%, respectively) which is subjected to huge amounts of fish farm effluents rich in nutrient salts. In general, the phytoplankton community fluctuated from 1995 till 2000. As well as during the present investigation (2009/2016) as shown in Table (2).

According to the Annual Fishery Estimation Report of National Institute of Oceanography and Fisheries and GAFRD[44]; the fish production of Lake Edku decreased from 2012 (5188 Tons /year); 2013 (4748 Tons /year); 2014 (4308 Tons /year) and during 2015

(3868 Tons /year). Moreover, many fishermen are suffering from skin diseases appeared due to the exposure to the contaminated water. Khan and Ansari [45]; studied the effect of submersed plants on the movement of water in the lake, which prevents the water circulation and increases the water pollution.

CONCLUSION: The investigated area received huge amounts of drainage water enriched with agricultural fertilizers in addition to domestic industrial effluents and fish farm wastes. These influenced directly and/or indirectly the water quality of the lake, which in turn affected the species composition, relative abundance and dominance of the major components of phytoplankton community and diversity values of phytoplankton population. This was companied by certain preference on the dominance of some species considered as indicators of water pollution and altering the community composition from Bacillariophyceae to Chlorophyceae.

Phytoplankton abundance indicated that the maximum density occurred in springtime, 2014. On the other hand, the highest density of Chlorophyceae was recorded in the winter, 2012. While Cyanophyceae reached highest counts during spring, 2014, the shifting dominancy to Bacillariophyceae in the last study period means a healthy trophic status. The high concentrations of dissolved oxygen means no sign of eutrophication occurred in the Lake Edku. The increasing concentration of Chlorophyll-a means the dominance of nanoflagellates which will not seem to represent in the community composition. Therefore, this study promotes the mechanical removal of the intensive hydrophytes, which enhances the mixing well of Lake water.

It is highly recommended to control discharge from fish farm effluents, optimizing the amount of fertilizer applied to crops in addition to the establishment of a secondary treatment for sewage water due to its recycling. This will help Edku water to revive for the well being of the community and all its inhabitants.

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