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Phytoplankton Composition in Relation to Its Nutritional Value in Burullus Lagoon, Egypt

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BURULLUS Lagoon, also known as Lake Burullus, is a brackish water lake in the Nile Delta in Egypt. In this study, changes in environmental conditions were assumed to affect phytoplankton species composition and their biochemical structure. The biochemical content of phytoplankton in Lake Burullus was preliminarily explored. Winter cruises were compared with summer cruises from 12 sites representing the main eastern, middle, and western lake basins in 2018. Results revealed that phytoplankton exhibited seasonal variations. In particular, it attained the lowest value in winter (72300 units/L) and the highest value in summer (88700 units/L). This observation was consistent with the high total protein content (2692.5mg/L) in summer. The first major class was Chlorophyceae (37.9%) followed by Bacillariophyceae (29.31%) and Cyanophyceae (20.7%). By comparison, Euglenophyceae and Dinophyceae were rare classes constituting 8.63% and 3.4%, respectively. The maximum total biochemical contents were found in the middle of the lake in winter (870.5, 57.6, and 6.1 mg/L of proteins, carbohydrates, and lipids, respectively), indicating the increase in the total density of phytoplankton, especially Chlorophyceae (13700 units/L), in the central basin (29200 units/L). The optimum total biochemical structure was obtained in the western basin in summer (1909.1, 55.4, and 6.5mg/L of proteins, carbohydrates, and lipids, respectively), suggesting that the phytoplankton density increased to 56000 units/L. Q index showed that the middle and western basins were in mesotrophic to eutrophic states. These findings demonstrated that excessive nutrient loads of drainage water into Burullus Lagoon significantly affected the phytoplankton biodiversity. Therefore, highly efficient management strategies must be developed and implemented in Burullus Lagoon.

Keywords: Biochemical contents, Biodiversity, Burullus Lagoon, Environmental variables, Mediterranean Coast, Phytoplankton.

Introduction

Coastal lakes in the Nile River Delta in Egypt are the main lakes in the north of Africa, accounting for approximately 25% of total lagoons in the Mediterranean Sea (Massoud, 2003). The Nile Delta is characterized by four shallow coastal lakes: Manzala, Edku, Maryout, and Burullus.

Lake Burullus, also known as Burullus Lagoon, has an economic and environmental significance because it is connected to the Mediterranean Sea through the El-Boughaz opening (Melegy et al., 2019). It is the second-largest one in the middle of the two Nile branches forming the Delta; it is also considered a vulnerable area along the delta's coastline (El-Zeiny & El-Kafrawy, 2017). Burullus is one of the sites of the International Conventions on Wetlands (known as Ramsar) and recognized as a national protected area in 1998 (Shaltout & Al-Sodany, 2008). The lagoon has six main habitats, namely, drains, lake cuts, salt marshes, sand formation, lake proper, and islets, which are dominated by plant vegetation, birds, and aquatic

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fauna and flora (Shaltout & Khalil, 2005). Recent studies have shown the rich biodiversity of higher plants, plankton, and rare endemic and threatened fauna species (Shaltout, 2010; Hegab et al., 2020). This lagoon is considered one of the most important areas for fishing resources and wintering ground of migratory birds (El-Asmar et al., 2013). However, it is a vulnerable Egyptian lake that suffers from expansion in fish farming, agricultural drainage, high levels of aquatic plants, and increasing human activities (Younis & Nafea, 2012).

The Brimbal Canal located in the western part of the lake is the source of freshwater flowing to Burullus Lagoon (Samaan et al., 1989). It is also considered the drainage water reservoir of seven drains collecting urban and agricultural wastewater (El-Asmar et al., 2013). The lake water, especially the southern part, contains the maximum concentrations of pollutants because of fertilizer, runoff animal wastes, and domestic sewage (Elsayed, et al., 2019; Eid et al., 2021; El-Metwally et al., 2021). Negm et al. (2019) indicated that the lake receives up to 4 billion m3 of agricultural drainage annually, which represents about 97% of water inflow into the lake.

The governorates of Gharbia, Menoufia, Kafr El-Sheikh, and Dakahlia discharge their municipal and agricultural wastes through the eight main drains into the lagoon, with a total capacity of 3904 million m3/year. (Zingstra, 2013; Sameh et al., 2015). Therefore, this aquatic ecosystem has unique characteristics.

The phytoplankton community and its biological characters in Burullus Lagoon have been investigated. Kobbia (1982) identified 49 algal species with six divisions. El-Sherif (1993) identified 113 algal species with different divisions. El-Sherif et al. (1989) also indicated that diatoms are dominated by *Nitzschia* spp. and *Cyclotella meneghiniana*. Zalat & El-Sheekh (1999) observed 76 diatom taxa among 26 genera in Lake Burullus. Radwan (2002) recorded 65 phytoplankton species. Okbah & Hussein (2006) recorded an increase in the total algal density of 170 species among which diatoms were the most common species recorded. Ali & Khairy (2012) identified 156 phytoplankton species.El-Kassas & Gharib (2016) obtained the same results, but they identified 163 species belonging to five classes. Hegab et al. (2020) recorded 89 species belonging to eight classes with the dominance of Bacillariophyceae constitute (42%), followed by Chlorophyceae with 23% then, Cyanophyceae with 17% of the total phytoplankton species. Previous studies demonstrated that this variation in phytoplankton distribution as represented by the number of species and classes in the lagoon mainly depends on sampling season, selected sites, depth, and environmental parameters.

Data on the cellular biochemical composition of phytoplankton in Lake Burullus are limited. Understanding the biochemical changes in the phytoplankton in the lake is fundamental because of their potential influence on the food web. Algae have been incorporated in various applications, such as biotechnology, agriculture, and pharmacology. Because of the presence of many bioactive compounds which have certain secondary metabolites of antiviral, antibacterial, antifungal, and anticancer activities and store food materials as an internal nutrient reserve, was considered more important for grazers (Tan, 2007; Peter & Sommer, 2012). Algae can also degrade environmental pollutants and serve as a promising alternative energy source (Ananya & Ahmad, 2014). The organic molecules of phytoplankton are composed of proteins as the main component, carbohydrates, and lipids, which are considered remarkable bioactive compounds. Biochemical molecular components in cells may differ in terms of algal growth phase and species composition (Suárez & Marañón, 2003; Finkel et al., 2016). The biochemical concentration of phytoplankton is affected by many environmental factors, such as grazing effects, temperature, and nutrient availabilities. As such, the processes of phytoplankton performance should be elucidated.

This study was conducted to compare the species abundance, diversity, and production of the cellular constituents of nutritive substances of phytoplankton in winter and summer in 2018 in relation to environmental changes in Lake Burullus.

Materials and Methods

Site description

Burullus Lagoon is located in the western region of the Nile Delta between the two Nile River branches, namely, Damietta and Rosetta (longitude 30°33′–31° 07′ E and latitude 31°22′–31°26′ N). It has an irregular elongated shape and dimensions of 47km in length, 6–14km in width, and 0.4–2.1m in depth. The total area of the Burullus region is about 163961.4ha (1639.614km^2), with an approximate surface area of 410km^2 (Hossen & Negm, 2016; Shaltout, 2017). This lagoon is very shallow in the eastern basin with a depth varying between 0.4 and 2m (El-Zeiny & El-Kafrawy, 2017). The basin contains an outlet of an approximately 250 m-long canal that connects the lagoon to the sea, whereas the deepest part lies in the western basin (Dumont & El-Shabrawy, 2007).

Sampling examination and biochemical analysis of phytoplankton

Twelve sampling sites were selected to cover the different localities of Burullus Lagoon as much as possible in winter and summer in 2018. The lake was divided into three basins to assess the effect of sea water on the lagoon. The eastern basin (sites 1–3) receives agricultural water discharged from drains 3, 4, 5, and 7 and lies near Boughaz El-Burg. The middle of the lake (sites 4, 5, 6, 7, and 8) receives waste effluents from drains 8 and 9. The western basin represents the western side (sites 9–12), where drains 11 and 12 discharge their effluents, in addition to Brimbal Canal, which receives estuarine Nile water (Fig. 1).

The collected phytoplankton samples were preserved in 4% formalin for the identification of different algal groups. Organic matter was removed from diatom samples by using the hot H_2O_2 method. Then, the samples were mounted in permanent slides in accordance with previously described methods (Taylor et al., 2007). They were examined, identified, and counted under a trinocular microscope (Microstar AO), i.e., under an oil immersion lens (100×) for diatoms and 40× lens for other algal taxa. Algal taxa were identified in accordance with previously described methods (Desikachary, 1959; Prescott, 1961; Patrick & Reimer, 1966, 1975; Jensen, 1985; Krammer, 1986; Round et al., 1990; Steidinger & Tangen, 1996). Afterward, 1 L of lake subsurface water was collected in polyethylene plastic bottles for physical and chemical analysis for in situ measurements at all sampling sites before midday at each sampling occasion. Temperature, pH, and electrical conductivity (EC) were determined using Hydrolab Multi Set 430i WTW. Transparency was observed with a Secchi disk. Total dissolved solids (TDS), dissolved oxygen (DO), BOD, alkalinity, sulfate, ammonium, nitrite, nitrate, and phosphate were measured in accordance with previously described methods (APHA, 2005). About 1L of water sample was collected for the detection of the biochemical contents of phytoplankton. A fixed volume of the water sample was filtered with GF/F filter paper to detect proteins, carbohydrates, and lipids then calculated to 1L (/l). Phytoproteins, phytocarbohydrates, and phytolipids were explored using the Biuret method (Holme & Peck, 1994), a phenol-sulfuric acid test (Dubois et al., 1956), and sulphophosphovanillin procedure (Chabrol & Castellano, 1961), respectively.

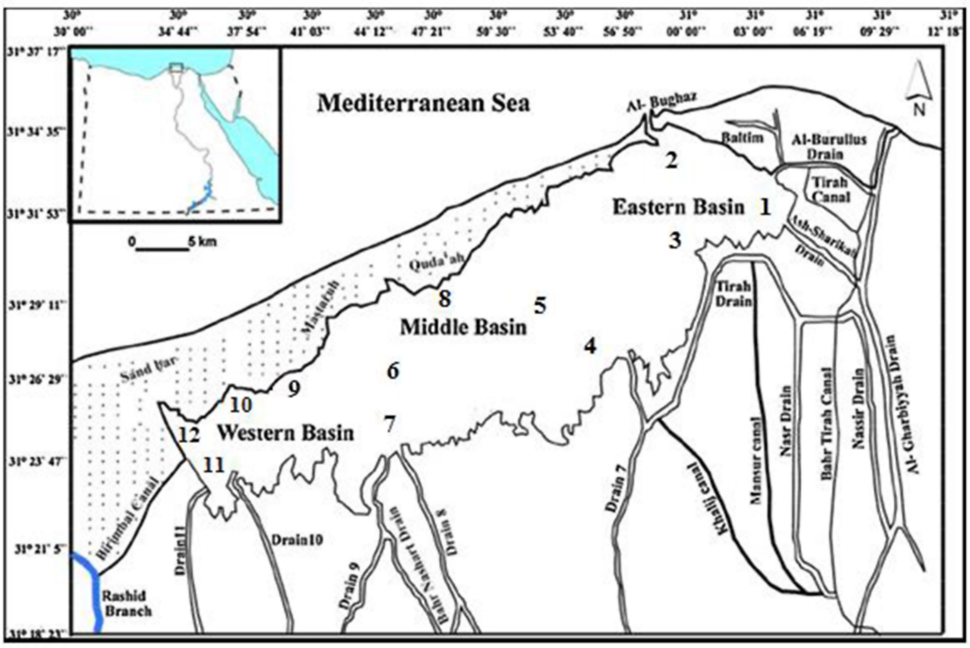

Fig. 1. Sampling localities along the main route of El Burullus Lagoon

Statistical analysis

Phytoplankton ecological studies have been widely conducted, so Q index, which was basically established by the Water Framework Directive, was also used to determine the ecology of Burullus Lagoon. It was calculated using the following equation (Padisák et al., 2006):

$$Q = \sum_{i=1}^{n} p_i F_i$$

where, p is the relative share of the ith functional group equal to n/N (where n is the biomass of the ith group, and n is the total biomass), and (F) is the factor number of each functional group.

Diversity index (H; Shannon & Wiener, 1963) and evenness (J; Pielou, 1975) were used to estimate the community structure of the lagoon.

Canonical correspondence analysis (CCA) was applied to explore the distribution of the most common phytoplankton taxa and their biochemical content along major environmental gradients. CCA was carried out with Canoco for Windows version 4.5 of phytoplankton taxa whose average frequency was ≥1000 units/L. The CCA triplot of species, environmental variables, and months of collection were drawn with Cano Draw for Windows.

Results and Discussion

Physico-chemical characters of Burullus Lagoon

The physicochemical properties of Burullus Lagoon (Table 1) were checked analog to the phytoplankton abundance and nutritive value at the selected sectors during the time of investigation.

Air temperature was close to the corresponding values of water temperature along the studied sectors because of the shallow depth of the lake, where the mean air temperatures were 30.2°C–33.4°C and 17.7°C–19.3°C. Water temperatures in summer and winter were 29.5°C–31.7°C and 15°C–17°C, respectively. Generally, air and water temperatures in Burullus Lagoon are in the range of the normal seasonal fluctuations in the southeastern coast of the Mediterranean Sea (Nassar & Gharib, 2014; Khairy et al., 2015; Elsayed et al., 2019). The lagoon water is well mixed except that in the link between the lagoon and the sea, and the bottom and surface water temperatures slightly differ (El-Adawy et al., 2013).

Water transparency slightly varied between winter and summer. Its mean value in winter ranged from 22cm to 30cm. In summer, its range was 29–39cm. Khairy et al. (2015) recorded an average water transparency of 29.9cm in 2010 and 2011. Our results revealed that the middle part of the lagoon had the lowest water transparency possibly because of the high load of suspended silt particles from the drainage water inflow (Radwan, 1997; El-Kassas & Gharib, 2016; Elsayed et al., 2019). By contrast, the western basin had the highest transparency likely because of the high density of *Potamogeton pectinatus* (Van Dijk & van Vierssen, 1991). Conversely, Elsayed et al. (2019) recorded a high transparency at the northern part facing the Al-Boughaz outlet.

Consistent with previous findings (Melegy et al., 2019), our results showed that pH was alkaline (8.6–9 and 7.8–8.8 during winter and summer, respectively) probably because of the increased photosynthetic activity of phytoplankton in the lake or the chemical nature of water (Al-Sheikh & Fathi, 2010; Nassar & Gharib, 2014).

TABLE 1. Average values of physicochemical parameters in Burullus Lagoon during winter and summer seasons

Parameter	Summer	Winter	Parameter	Summer	Winter
Air temperature ^{0}C	30.2 – 33.4	17.7 – 19.3	**CO_3 mg/L**	30 - 44.2	5.0 - 9.3
Water temperature ^{0}C	29.5 - 31.7	15 - 17	**HCO_3 mg/L**	160 - 313	110 - 281
pH	7.8 – 8.8	8.6 – 9.0	**NO_2 µg/l**	30.5 - 72.6	78.2 - 124.7
Transparency cm	29 - 39	22 - 30	**NO_3 µg/l**	58.5 - 114.9	150.9 - 201.7
DO mg/L	8.3 – 15.2	4.8 - 7.1	**NH_4 µg/l**	321.4 - 935.4	899.6 - 1772.9
BOD mg/L	7.9 – 10.5	3.3 - 6.6	**SO_4 mg/L**	94.3 - 137.1	187.3 - 208.9
TDS mg/L	3549 – 6693	2344 – 5986	**SiO_3 mg/L**	7.3 - 10.5	9.5 - 11.2
EC µS/cm	9383.3 - 13471.6	3720.3 - 9581.6	**Orth-PO_4 µg/L**	178. 9 - 324.8	184.9- 394.5

The water of Burullus Lagoon was considered a well-oxygenated ecosystem in both seasons in this study (DO= 8.3–15.2 and 4.8–7.1mg/L in summer and winter, respectively). These results suggested that the lake was more highly oxygenated in summer than in winter likely because of the highest phytoplankton abundance in summer (88700 units/L). With a high phytoplankton abundance, the dissolved oxygen content remarkably increased; as such, Burullus Lagoon has an extremely high dissolved oxygen content (Elsayed et al., 2019).

The biological oxygen demand ranged from 3.3mg/L to 6.6 mg/L in winter and further increased in summer (7.9–10.5mg/L). BOD reflects the amount of oxygen required by living aquatic organisms for their metabolic function, so this parameter is a direct indication of water pollution. In this study, the mainly elevated levels of BOD were recorded at the southern ends of the lagoon. This finding was attributed to the high load of organic matter from the drains facing these parts, where they receive high amounts of agricultural and sewage discharge (El-Zeiny & El-Kafrawy, 2017).

The mean TDS varied between 2344 and 5986mg/L in winter and increased to 3549–6693mg/L in summer. Variations in TDS might be harmful because the difference in water density is a factor determining the water flow in and out of cells. In this study, TDS in the east–southern part of the lagoon increased possibly because of the increasing drains following the southern edge of the lagoon (Soussa, 2010). EC ranged from 3720.3µS/cm to 9581.6µS/cm in winter and from 9383.3µS/cm to 13471.6µS/cm in summer. Consequently, EC and municipal wastewater disposal increase (El-Zeiny& El-Kafrawy, 2017). Elsayed et al. (2019) indicated that the increase in EC in winter is due to the fresh water input of the lake during the drought period and an increase in seawater inlet through El-Boughaz outlets. They also observed that EC in southern and western sectors decreases because of mixing with wastewater from drains.

Phytoplankton composition and abundance

The phytoplankton composition and abundance in Burullus Lagoon and their influence on different physicochemical parameters and other anthropogenic stress were studied in 2018. In previous studies, the phytoplankton abundance in the lagoon showed spatial variation in the number of taxa, species distribution, and density depending on the selected sites, seasons and impact of environmental conditions (Eissa, 2013; Khairy et al., 2015).

In the present study, phytoplankton in Burullus Lagoon varied in terms of the number and abundance of taxa. A total of 58 taxa from 33 genera were related to five algal divisions. Bacillariophyta (17 taxa), Chlorophyta (22 taxa), Cyanophyta (12 taxa), Euglenophyta (5 taxa), and Dinophyta (2 taxa) were identified from the study area during the investigation (Table 2). Chlorophyceae was the most abundant group, accounting for 37.9% of the total phytoplankton densities. The dominant and subdominant organisms were *Scenedesmus* spp., *Ankistrodesmus* spp., and *Oocystis* spp. Bacillariophyceae ranked second (29.31%) and highly represented by *Cyclotella* spp. and *Nitzschia* spp. Cyanobacteria constituted 20.7% of the total phytoplankton densities, and they were dominated by *Oscillatoria* spp. and *Anabaenaopsis* spp. Euglenophyceae corresponded to about 8.63% of the total phytoplankton standing crop, which was represented by *Euglena* (three species) and *Phacus* (two species). Dinophyceae rarely existed during the study and accounted for 3.4% of the total community. Similarly, Abdel-Hamid & Galal (2019) recorded 89 algal species in Lake Mariut: 30 species were related to bacillariophytes; 27 were cyanophytes; 22 were chlorophytes; 6 were euglenophytes; and 4 were chrysophytes.

Phytoplankton attained the lowest values in winter (72300 units/L) and the highest levels in summer (88700 units/L). Hegab et al. (2020) recorded more abundant phytoplankton in summer than in winter in 2017. The total identified taxa in winter were 39 species, whereas the total abundance varied between 2000 unit/L at site 3 and 14800 unit/L at site 1 (Figs. 2 and 3). The dominant group was Bacillariophyceae (41.02%, 16 species) followed by Chlorophyceae (28.20%, 11 species) and Cyanobacteria (20.51%, 8 species). In summer, the average phytoplankton abundance was between 3200 and 16100 units/L and dominated by 42 species. Among them, the dominant group was Chlorophyceae (40.4%, 17 species) followed by Bacillariophyceae and Cyanophyceae (23.8%, 10 species). Euglenophyceae was well represented in summer season (16200 units/L). A relatively high abundance with an average of 18.2% of the total abundance was recorded at the western site. High frequencies of Euglenophyceae were highly correlated with the load of organic nutrients, especially ammonium and phosphate discharged into the lagoon from drains (stations 4, 7, 11, and 12); furthermore, the excessive nutrient supply of N relative to P may influence dominant phytoplankton classes (Ma et al., 2021). This finding was consistent with those of Zingstra (2013), who showed that the increase in phytoplankton is related to a high amount of effluents discharged into the lagoon.

TABLE 2. List of phytoplankton taxa recorded from different stations at El Burullus Lagoons during time of investigation

Sampling stations	1	2	3	4	5	6	7	8	9	10	11	12
Taxa												
Division : Cyanophyta												
Anabaena torulosa (Carm.) Lagerh. ex Born. et Flah.						+				+		
Anabaenaopsis circularis var. *javonica* Wolosz.	+	+				+			+	+	+	+
Chroococcus minutus (Kütz.) Näg.	+											
Gloeocapsa turgida (Kütz.) Hollerbach												
Merismopedia tenuissima Lemm.								+	+	+	+	+
M. punctata Meyen								+	+	+		
M. glauca (Ehrenb.) Nag.										+	+	+
Microcystis flos - aquae (Witlr.) Kirchner										+	+	+
Oscillatoria nigrovirids Thwaites ex. Gomont	+	+								+	+	+
O. pseudogeminata G.Schmid.	+	+	+		+	+			+	+	+	+
O. subbrevis Schmidle										+	+	+
Spirulina platensis (Nordst.) Gom.	+	+					+		+	+	+	+
Division: Chlorophyta												
Actinastrum Hantzschii Lagerheim							+		+	+	+	+
Ankistrodesmus falcatus (Corda) Ralfs.								+			+	+
A. falcatus var. *mirabilis* (West& West) G.S.West			+									
A. falcatus var. *spirilliformis* G.S.West					+	+		+		+	+	+
Crucigenia tetrapedia (Kirch.) West & West						+	+		+	+	+	+
Coelastrum microporum Naegeli							+	+	+	+	+	+
C. proboscideam Bohlin							+	+	+	+	+	+
Dictyosphaerium pulchellum Wood	+											
Eudorina elegans Ehrenberg							+		+			
Oocystis borgei Snow.	+				+	+		+	+	+	+	+
Pandorina morum (O. F. Müller) Bory de Saint-Vincent							+		+			
Pediastrum integrum Naeg.						+						
P. muticum Kuetzing	+											
P. simplex var. *duodenarium* (Bailey) Rabenhorst											+	+
P. tetras (Ehrenb.) Ralfs	+							+				
Scenedesmus acuminatus (Lagerh.) Chod.	+			+	+	+		+	+	+	+	+
S. acutus Meyen	+			+	+	+		+	+	+	+	+
S. acutus f. *alternans* Hortob.	+											
S. bijuga (Turp.) Lagerh.	+			+	+	+	+	+	+	+	+	+

TABLE 2. Cont.

Sampling stations	1	2	3	4	5	6	7	8	9	10	11	12
S. protuberans Fritsch et. Rich.										+	+	+
S. quadricauda Brébisson	+		+	+	+	+	+	+	+	+	+	+
Tetraëdron trigonum (Naeg.) Hansgirg										+	+	+
Division : Euglenophyta												
Euglena acus Ehr.				+			+	+	+		+	+
E. elongata Schewiakoff				+			+	+	+		+	+
E. gracilis Klebs											+	+
Phacus caudatus Huebner	+											
Phacus pseudoswirenkoi Prescott	+					+	+	+	+			
Division : Dinophyta												
Gonyaulax verior Sournia	+											
Peridinium cinctum (Muell.) Ehr.		+	+									
Division: Bacillariophyta												
Amphiprora alata Kütz.				+						+		
Bacillaria paxillifer (O.F. Müll.) Hendey										+		
Cyclotella Kützingiana Thwaites.	+									+	+	+
C. meneghiniana Kütz.	+	+						+		+	+	+
Diploneis elliptica (Kütz.) Cleve					+	+				+		
D. ovalis (Hilse) Cl.										+		
Gomphonema longiceps Ehr.										+		
Gyrosigma scalproides var *eximia* (Thwaites) Cl.										+		
Navicula cryptocephala Kütz.							+			+		
N. cuspidata (Kütz.) Cl.							+				+	+
Nitzschia acicularis W. Sm.	+											
N. amphibia Grun.	+		+							+		
N. longissima var. reversa W. Sm.										+		
N. obtusa var. *scalpelliformis* Grun.	+									+		
*N. palea (*Kütz.) W.Sm.	+											
Pleurosigma elongatum W. Sm.								+		+		
Synedra ulna var. *aequalis* (Kütz.) Hust.											+	+

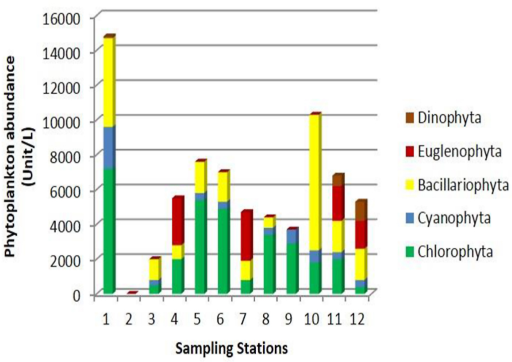

Fig. 2. Phytoplankton abundance of different algal divisions recorded along different stations of the lagoon during winter 2018

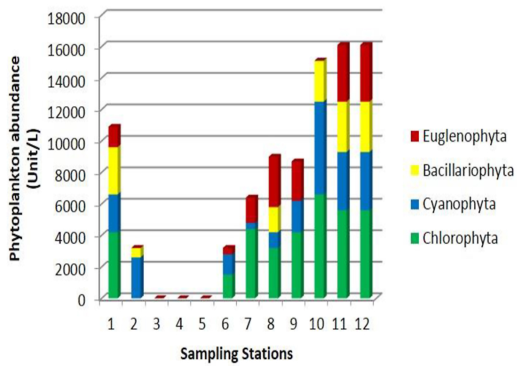

Fig. 3. Phytoplankton abundance of different algal divisions recorded along different stations of the lagoon during summer 2018

Along the lagoon sectors, the phytoplankton density was higher in the middle and western basins than in the eastern basin. This difference might be associated with the low density of submerged hydrophytes, creating an open area (Shaltout & Khalil, 2005; Hegab et al., 2020). The phytoplankton abundance in the eastern site of the lagoon was dominated by 7200 and 4200 units/L Chlorophyta in winter and summer, respectively, followed by 5100 and 1800 units/L Bacillariophyta (Figs. 4 and 5). The most dominant division at the middle of the lagoon in winter was Chlorophyta followed by Bacillariophyta, with an average 3600 and 1300 units/L, respectively. In summer, Euglenophyta ranked second after Chlorophyta, and they had average values of 1300 and 2300 units/L, respectively. Chlorophyta was the most frequent division at the western side in summer and had an average of 5500 units/L. It was followed by Cyanophyta (3300 units/L). In winter, Bacillariophyta was the most dominant (Av= 2900 units/L) in the whole lake.

Some algal species may act as an ecological assessment and monitoring tool with other aquatic parameters known as biological indicators (Aly et al., 2014). Our results indicated that the most dominant Bacillariophyta was *C. meneghiniana*, which is a good species indicator in northern lakes (Ali & Khairy, 2012). Chlorophyceae was the second-most dominant group dominated by *Scenedesmus* spp., including *S. quadricauda*, *S. acuminatus*, and *S. bijuga*, as well as *Crucigenia tetrapedia*, which grew near the drains (in the middle sector of the lagoon). The dominance of *Scenedesmus* spp. indicated the presence of excessive phosphate levels and organic pollution (El-Shinnawy, 2003).

Moderate frequencies of cyanophytes were recorded. They were dominated by *Oscillatoria nigrovirids*, *Spirulina platensis*, and *Anabaenaopsis circularis* var. *javonica*. Chlorophyta and cyanobacterial species flourished possibly because of the increased levels of organic nutrients and domestic sewage, which contain high amounts of nutrient salts (Radwan, 2002; Khairy et al., 2015). Dinoflagellates were rarely found and mainly present in the eastern part of the lagoon with saline water beside the outlet of the sea (Khairy et al., 2015). The phytoplankton community of Burullus Lagoon mostly comprises fresh or brackish forms and few saline water forms. Therefore, differences in the number and dominant species of phytoplankton population in the lagoon from 1982 to 2018 should be considered in determining the reasons for such changes.

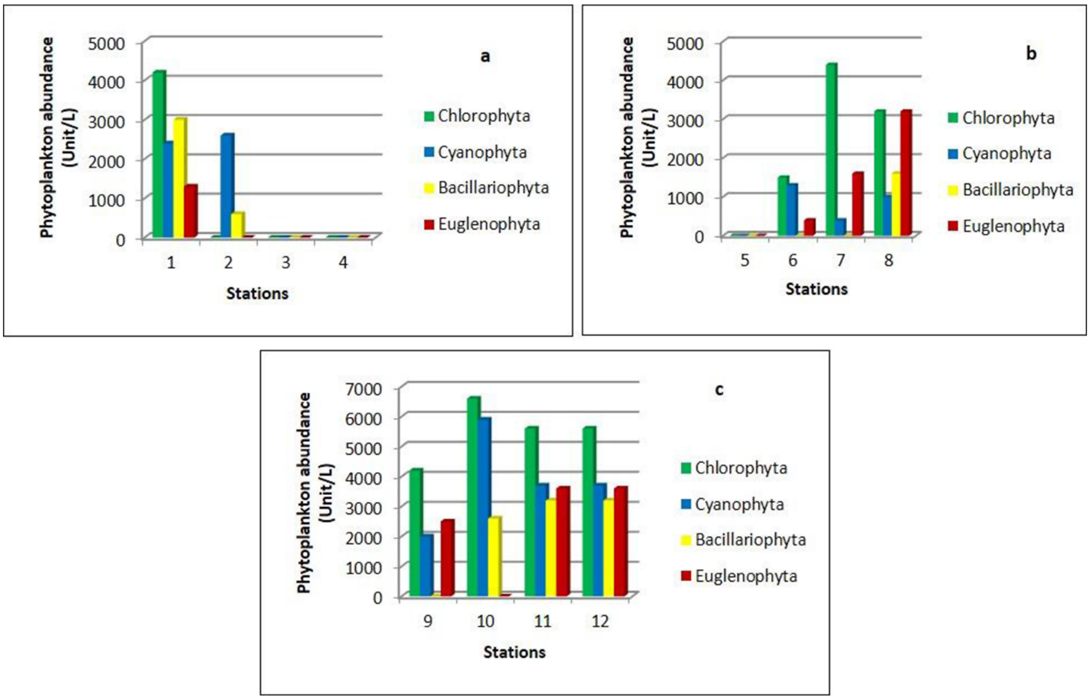

Fig. 4. Phytoplankton abundance of different algal divisions recorded along different stations of the lagoon during summer 2018 [a) Eastern basin, b) Middle basin, c) Western basin]

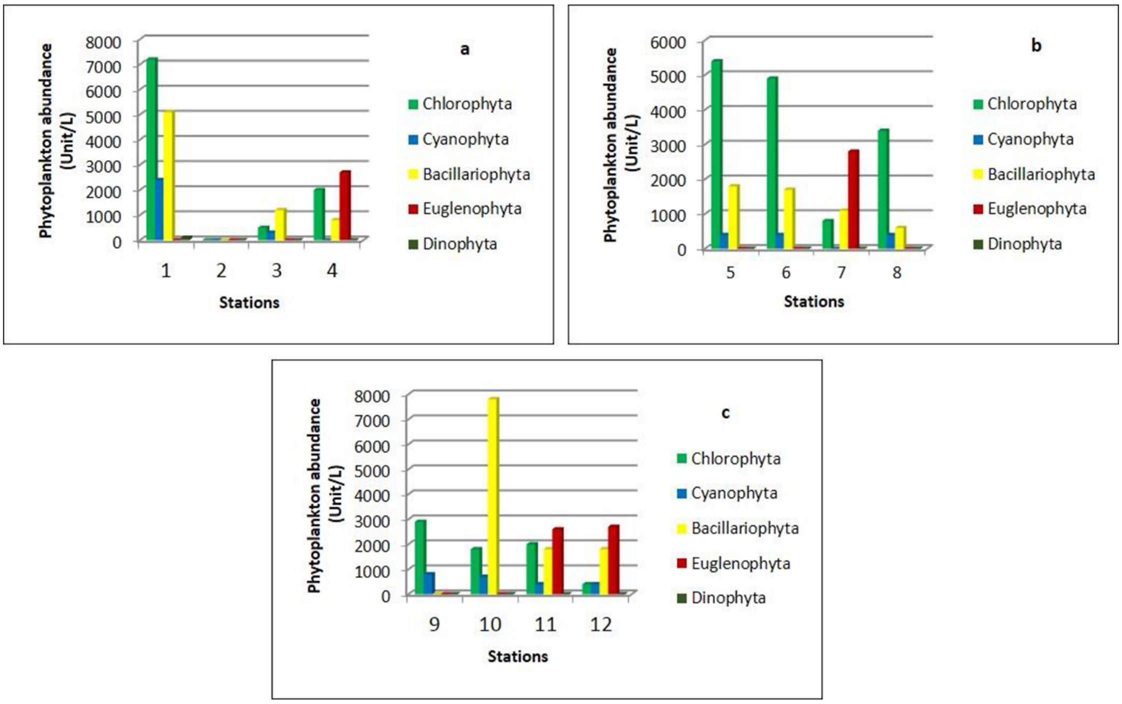

Fig. 5. Phytoplankton abundance of different algal divisions recorded along different stations of the lagoon during winter 2018 [a) Eastern basin, b) Middle basin, c) Western basin]

Phytoplankton biochemical contents

The intracellular patterns of phytoplankton should be explored to understand the metabolic action of naturally occurring phytoplankton. In this study, comparisons between biochemical concentrations during the study period showed different patterns along the selected lagoon basins. The nutritive values of phytoplankton in Lake Burullus were primarily explored (first record).

Summer was the optimum season, as indicated by the total protein contents of phytoplankton in the lake (2692.5mg/L; Fig. 6). This finding may be related to the increase in CO3 (30-44.2mg/L) and HCO3 (160–313mg/L) in the same season (Table 1). High carbon values of incorporation into proteins indicated that the growth of phytoplankton is close to the maximum growth rate (Fernández et al., 1994; Wagner et al., 2017). Protein elevation considered as an index for there is no nitrogen stress of metabolism of phytoplankton (Abd El-Hady et al., 2016; Ahn et al., 2019). The metabolic growth processes of algae are accelerated by the increasing temperature in summer and the increased protein synthesis (Rai et al., 1997). The addition of carbon dioxide also increases the algal protein content and decreases the carbohydrate contents (Araújo & Garcia, 2005). In our study, the increase in phytoproteins in the lagoon in summer might be related to the increase in the two main functional groups of phytoplankton, namely, Chlorophyta and Cyanobacteria (35300 and 23000 units/L, respectively). At high temperatures, phytoplankton produces the required amounts of cellular protein (Toseland et al., 2013).

Carbohydrate and lipid contents increased in winter (Fig. 6) possibly because of the increase in silicifiers (diatoms), whose silica content elevated to 9.5–11.2mg/L in the same season. SiO2 had the highest concentration among the dissolved salts in Lake Burullus (Younis & Nafea, 2012). Major inorganic silicon nutrients for diatoms are integrator the main controlling factors, and cellular phytoplankton responses were in terms of biomolecular composition (Kim et al., 2015; Finkel et al., 2016). Diatoms mainly participate in the biochemical cycles of silicon through which fatty acids are produced at low-temperature treatments (Basu & Mackey, 2018). The increase in the carbohydrate content of diatoms might be related to the increase in pH in winter (pH reaching 9, Table 1). The production of extracellular carbohydrates in diatoms increases in the pH range of 9–9.4 (Taraldsvik & Myklestad, 2000).

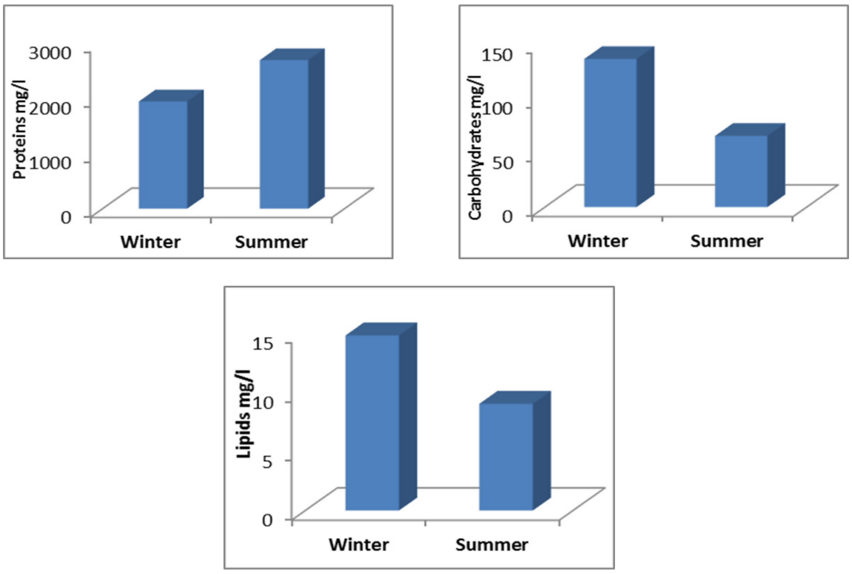

Fig. 6. Phytoplankton biochemical contents at Brullus Lake during winter and summer

According to the spatial distribution of phytoplankton biochemical concentrations, the middle basin of the lake had the maximum total biochemical contents (870.5, 57.6, and 6.1mg/L of proteins, carbohydrates, and lipids, respectively) in winter (Table 3). This result was associated with the increase in the total phytoplankton counting in the central basin (29200 units/L), especially Chlorophyceae (13700 units/L). It was also related to the increase in the orthophosphate and total phosphorus contents in the central sector. The dissolved salt (PO_4) concentrations in the middle basin were higher than those reported for the eastern and western sectors (Younis & Nafea, 2012; Melegy et al., 2019). Higher protein and carbohydrate concentrations were accompanied by the dominance of Chlorophyceae (Boëchat & Giani, 2000). Phosphorus is an essential nutrient involved in different metabolic processes of algal cells (Karl, 2014). An increase in algal lipids is linked to phosphorus availability (Kilham et al., 1997). The western basin had the optimum total biochemical structure in summer (1909.1, 55.4, and 6.5mg/L of proteins, carbohydrates, and lipids, respectively; Table 4). In particular, the total phytoplankton counting increased in this basin and reached 56000 units/L, which also corresponded to the increase in some major phytoplankton nutrients in the western side, such as NO_2 (180µg/L at St. 12), orthophosphate (864.25µg/L at St. 11), and total phosphorus (1225.5 µg/l at St. 11). Melegy et al. (2019) observed the highest concentration of phosphorous at sites facing the drains. El-Tohamy et al. (2014) stated that the concentration of water nutrients increases in summer because of excessive waste discharge into the lake during this period. By contrast, Eid et al. (2020) found that water N and P levels are high in western sites in winter and low in summer. They also indicated that the decrease in P and N in summer is a result of N and P consumption by phytoplankton and aquatic plants, which have a growing density in these seasons. Nitrogen is considered the most crucial nutrient affecting biochemical composition, which includes nitrite and nitrate favorable to the cell growth of microalgae (Kim et al., 2016). Nitrogen is the main constituent in all functional and structural proteins, such as peptides, chlorophylls, and enzymes, in algal cells (Cai et al., 2013). Algal phospholipids are the main phosphorus reservoirs from water basins and essential energy molecules in algal cells (Dyhrman, 2016).

Phytoplankton assemblage index (Q index)

In different sites, Q index indicated that the water of the lagoon had medium to good quality (mesotrophic status) in winter and medium quality in summer (Fig. 7). More phytoplankton assemblages were observed in the western and middle sectors of the lagoon. This result indicated mesotrophic to eutrophic conditions at the middle and western basins facing the drainage runoff and agricultural water. Conversely, the location far from the effect of drainage (St. 3–5) had the lowest phytoplankton assemblage (Q index = 0), indicating the oligotrophic status of this point in the lagoon. Therefore, phytoplankton distribution in the lagoon can be used as an indicator of its trophic status (Padisák et al., 2006; Borics et al., 2007). El-Sayed (2010) and Padisák et al., (2009) found that Burullus Lagoon lies between oligotrophic and mesotrophic states. Other reports have stated that it is classified as a hypereutrophic lake with poor to very poor environmental conditions (Okbah & Hussein, 2006; Ali & Khairy, 2012; Elsayed et al., 2019; Eid et al., 2021).

Diversity index (H) was calculated for each sampling site. In summer, the highest diversity index was recorded at the western part of the lagoon (H = 4.6, 4.5 at stations 11, 12, and 10, respectively), followed by the one recorded at the central sector and eastern site of the lagoon (H = 3.8, 3.5, and 3.7 at stations 9, 7, 8, and 1). The lowest diversity index was calculated at the stations in front of Boughaz El-Burullus of the lagoon (Fig. 7a). Similar to the observations in summer the diversity indices in winter were lower in the middle of the lagoon than in the other sections, and their values increased at the western and eastern sites of the Lagoon (Fig. 8a). Similar to the diversity index, evenness (J) was lower in the central sector than in the other sectors and reached the highest values in the western and far eastern sectors of the lagoon during the time of investigation (Fig. 8b).

Diversity index is an important aspect that indicates the distribution of phytoplankton and its relation to pollution. The highest diversity index in stations 10, 11, and 12 showed a more equilibrated ecosystem.

Pileou's evenness index signifies the distribution of plankton throughout the year and the relation between the frequency of species and their distribution in the Lagoon (Kumar & Hosmani, 2010). Therefore, the highest values of evenness in stations 1 and 10 referred to the most even ecosystem in the whole lagoon. In conclusion, ecological indices serve as important tools in algal biodiversity and pollution assessment in aquatic environments.

TABLE 3. Spatial differences in phytoplankton composition and their biochemical contents detected at eastern, middle and western basins of Lake Brullus during winter

Phytoplankton composition	East basin	Middle basin	West basin	Sum
Cyanophyta	2700	1200	2300	6200
Chlorophyta	7700	13700	7100	28500
Bacillariophyta	6300	6000	11600	23900
Euglenophyta	-	5500	5300	10800
Total phytoplankton	16800	29200	26300	72300
Total Bioche.cont. (mg/L)	764.08	934.16	397.02	2095.26
Proteins	727.3	870.48	346.58	1944.36
Carbohydrates	33.1	57.6	45.4	136.1
Lipids	3.68	6.08	5.04	14.8

TABLE 4. Spatial differences in phytoplankton composition and their biochemical contents detected at eastern, middle and western basins of Lake Brullus during summer

Phytoplankton Composition	East basin	Middle basin	West basin	Sum
Cyanophyta	5000	2700	15300	23000
Chlorophyta	4200	9100	22000	35300
Bacillariophyta	3600	1600	9000	14200
Euglenophyta	1300	5200	9700	16200
Total phytoplankton	14100	18600	56000	88700
Total Bioche.cont. (mg/L)	1056.38	1710.56	1971.02	4737.96
Proteins	1028.44	1664.08	1909.1	2692.52
Carbohydrates	24.2	41.2	55.4	65.4
Lipids	3.74	5.28	6.52	9.02

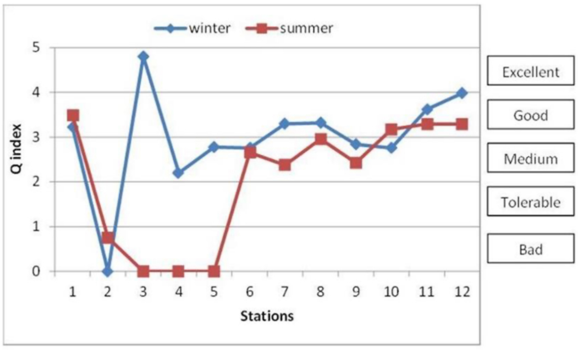

Fig. 7. Phytoplankton assemblage index (Q index) recorded along different stations of the lagoon during time of investigation

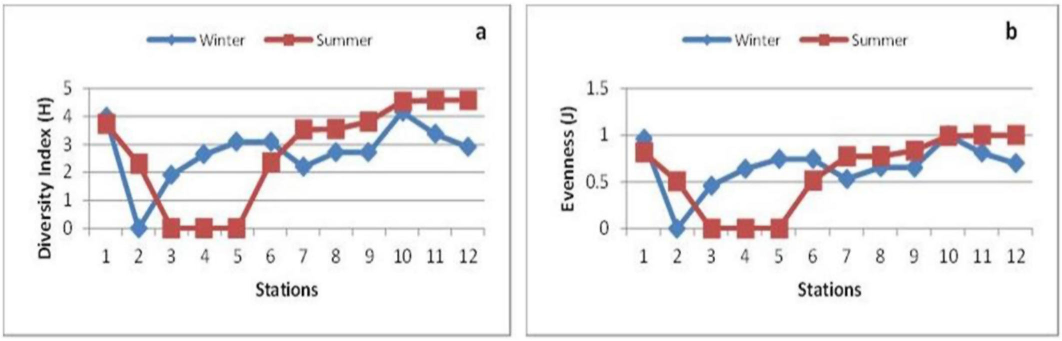

Fig. 8. a) Diversity Index (H), b) Evenness (J) referring to different sampling sites examined across Burullus Lagoon

Canonical correspondence analysis (CCA)

CCA was conducted to investigate the relationship of phytoplankton community structure, their biochemical contents, and environmental factors. The results revealed that the most common algal taxa in winter were found in the middle basin of the lake dominated by Chlorophyta. This finding was correlated with a high percentage of biochemical parameters (proteins, carbohydrates, and lipids), alkalinity, and pH (Fig. 9a). Euglenophyta was highly correlated with the increase in the levels of phosphate, nitrate, and nitrite in water in the western side of the lake. Bacillariophyta and Cyanophyta were positively correlated with water transparency in the sector. As for the relationship of phytoplankton species with environmental factors (Fig. 9b), the most dominant species in the central basin were greatly affected by pH and carbonate values. In the eastern part, TDS was the main factor influencing species composition possibly because seawater from the Al-Boghaz part enters this basin.

In summer, Bacillariophyta was the most abundant in the eastern part of the lake, where *Cyclotella* spp. were dominant (Figs. 10a, 10b). In the middle and western basins, Euglenophyta and Chlorophyta were dominant and positively correlated with water temperature, transparency, nutrients, and biochemical parameters. The western side was the richest part in summer, as indicated by the positive correlation of species composition with the total biochemical content.

The middle and western sectors had similar phytoplankton composition, biochemical contents, and physicochemical characteristics. Conversely, the eastern part differed, indicating that its water quality and algal composition prominently differed from those in the western and middle parts (Figs. 9 and 10).

Conclusion and Recommendations

This study shows the specific counting, diversity, and biochemical responses of phytoplankton to winter and summer dynamics and excessive nutrients loaded by drainage water in Burullus Lagoon, which is characterized by many fresh or brackish phytoplankton forms and few saline forms. Burullus Lake is classified as a hypereutrophic water body, and its western basin is considered the most trophic basin during summer, as indicated by the increase in phytoplankton population and biomolecular values. This biochemical study is a preliminary analysis to detect the internal biochemical contents of phytoplankton inhabiting the lake. Our results reveal that phytoplankton organic matter is dominated by proteins. Furthermore, the trophic profile of Burullus Lagoon changes because of its sensitivity to variations in environmental factors caused by the increase in human activities and the steady flow of Nile water and drains. Consequently, the water quality and the whole aquatic life in this lake are affected. Therefore, the biodiversity and nutritive structure of phytoplankton as the base of the food web in Lake Burullus should be efficiently maintained.

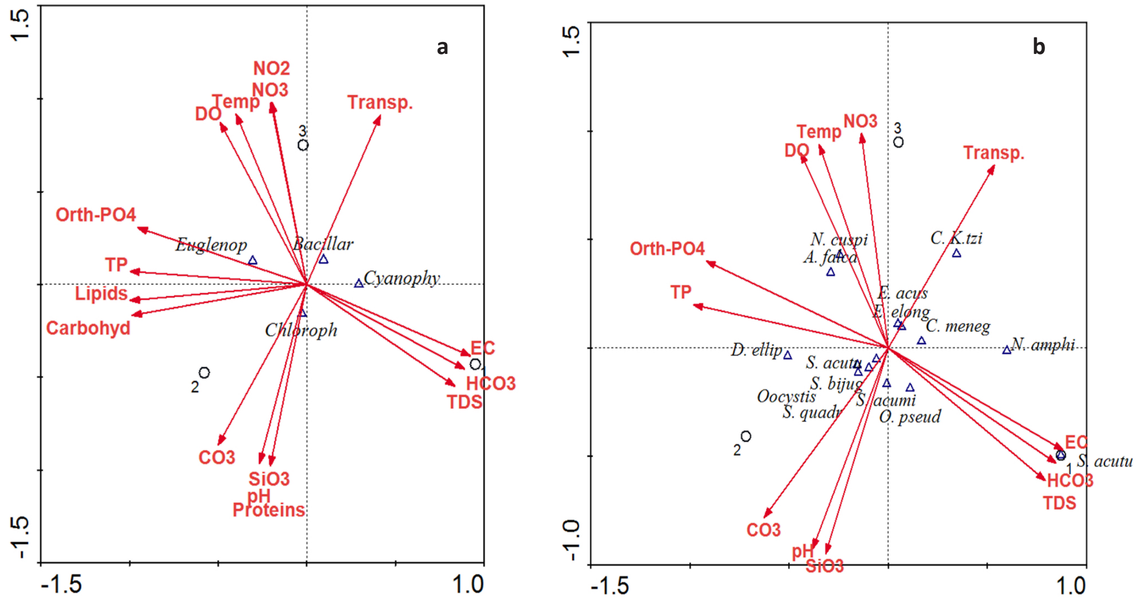

Fig. 9. Triplot of Canonical Correspondence Analysis showing the relationships between the three sectors of the lake (circles) 1. Eastern basin 2. Middle basin, 3. Western basin, water nutrients and biochemical contents (arrows) and a) Algal division (triangles), b) Most common algal species (triangles) of Burullus Lagoon during winter season

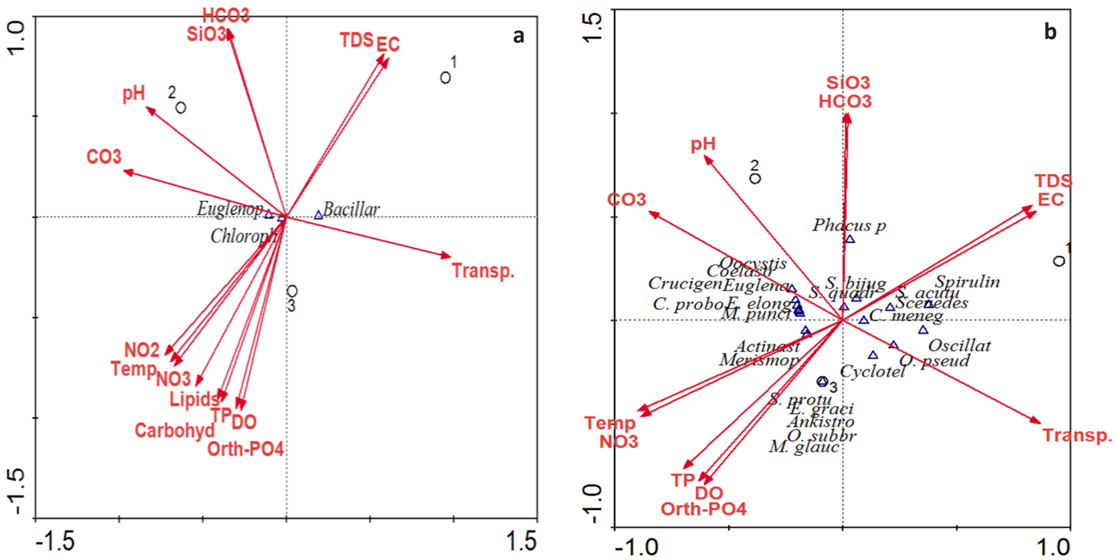

Fig. 10. Triplot of Canonical Correspondence Analysis showing the relationships between the three sectors of the lake (circles) 1. Eastern basin 2. Middle basin, 3. Western basin, water nutrients and biochemical contents (arrows) and a) Algal division (triangles), b) Most common algal species (triangles) of Burullus Lagoon during summer season

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Author contributions: Hesham M. Abd El Fatah and Shymaa S. Zaher conceived and designed research. Howayda H. Abd El-Hady and Dina M. Ali contributed analytical tools and analyzed data. Hesham M. Abd El Fatah and Shymaa S. Zaher wrote and revised the manuscript. All authors read and approved the manuscript.

Ethical approval: Not applicable

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تكوين العوالق النباتية فيما يتعلق بقيمتها الغذائية في بحيرة البرلس ، مصر

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بحيرة البرلس هي بحيرة معتدلة الملوحة تقع في دلتا النيل بمصر. افترضت هذه الدراسة أن التغيرات في الظروف البيئية تؤثر على تكوين أنواع العوالق النباتية ومحتواها الكيميائي الحيوي. تم دراسة المحتوى الحيوي للعوالق النباتية في بحيرة البرلس بشكل مبدئي. تم إجراء رحلات خلال فصل الشتاء و الصيف لتجميع عينات من اثني عشر موقعًا تمثل أحواض البحيرة الرئيسية الشرقية والوسطى والغربية خلال عام 2018 وكشفت النتائج أن العوالق النباتية أظهرت تغيرات موسمية حيث بلغ أدنى قيمة خلال فصل الشتاء (72300 وحدة / لتر) وأعلى المستويات خلال فصل الصيف (88700 وحدة / لتر). توافقت هذه النتائج مع محتوى البروتين الكلي (2692.5 ملجم / لتر) في الصيف. احتلت مجموعة الطحالب الخضراء المرتبة الأولى بنسبة (37.9٪) تليها مجموعة الدياتومات بنسبة (29.31٪)، ثم مجموعة السيانوبكتيريا بنسبة (20.7٪) ، وبالمقارنة كانت اليوجلينات والطحالب ثنائية الأسواط (الدينوفلاجيلات) من الفئات النادرة بنسبة 8.63٪ و 3.4٪ على التوالي. سجل الحد الأقصى للمحتوي الحيوي الكلى بوسط البحيرة في الشتاء (870.5 و 57.6 و 6.1 ملغم / لتر من البروتينات والكربوهيدرات والدهون على التوالي)، مما يشير إلى زيادة الكثافة الكلية للعوالق النباتية في هذا الجزء (29200 وحدة / لتر) ، وكانت تلك الكثافة نتيجة زيادة الطحالب الخضراء (13700وحدة / لتر). تم الحصول على المحتوى الحيوي الكلى الأعلى في الحوض الغربي في الصيف بنسبة (1909.1 و 55.4 و 6.5 ملغم / لتر) من البروتينات والكربوهيدرات والدهون على التوالي، مما يشير إلى أن كثافة العوالق النباتية زادت إلى 56000 وحدة / لتر. وفقًا لمؤشرات التلوث فقد تبين أن الجزء الوسطى والغربي من البحيرة يعتبرا متوسطين إلى أغنياء بالمغذيات الطبيعية. وأظهرت هذه النتائج أن كميات المغذيات الزائدة من مياه الصرف في بحيرة البرلس أثرت بشكل كبير على التنوع البيولوجي للعوالق النباتية. لذلك ، فإن هناك حاجة مُلحة لإيجاد وتطويراستراتيجيات جديدة لإدارة بحيرة البرلس بكفاءة للحفاظ عليها.