Phytoplankton Composition and its Biochemical Contents in a Subtropical Reservoir (Lake Nasser, Egypt) during Flood Season.

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ABSTRACT

A major task for categorizing an ecological flood is establishing the effects of environmental enrichment on nutrient availability, which may affect phytoplankton species composition and internal biochemical contents. The current study seeks to analyze the interaction between environmental variables, phytoplankton composition and its internal biochemical content during the flood season at Lake Nasser, Egypt. Samples were collected from four water depths (surface, 10 m., 20 m. and bottom) at five sites along the main channel of Lake Nasser during flood season in August 2017. A major bloom of Cyanobacteria was detected along with retardation of biopolymeric particulate organic carbon availability. Principle component analysis indicated that the most significant parameters affecting total phytoplankton distribution, especially Cyanobacteria, were temperature, dissolved oxygen, nitrite, and phosphate. Moreover, a negative correlation was reported between protein content, organic carbon and total biochemical content with nitrate. The highest biopolymeric particulate organic carbon value (37.15 mg/l), protein (88.64 mg/l) and lipid contents (1.5 mg/l), were recorded at El-Madiq site with total biochemical content of 91.29 mg/l and associated optimum nutrient levels. This interpreted with an increase of Chlorophycean species biomass (812.5×10^3 cell l^{-1}). Flood causes an elevation in the minor lipid cellular composition more than carbohydrates at all sites. Flooding in Lake Nasser altered its water quality through introducing oxygen and nutrients, along with changes in phytoplankton species composition and internal biochemical content.

INTRODUCTION

Flooding is an environmental stress that is often triggered in flood-prone environments by natural phenomena such as snowmelt, rainfall, and tides. Human activity, including construction and usage of hydropower and tidal water conservancy projects, may initiate flooding events **(Lopez & Kursar, 1999; Liu *et al*., 2013**) . River flooding may have a negative impact on the aquatic ecosystem that could potentially impact local populations infrastructure, and may result in loss of crops, and promote discharge of raw sewage and industrial waste **(Euripidou & Murray, 2004)**. However, there are positive aspects of flooding, including increases in dissolved oxygen and

nutrient supply to aquatic ecosystems, enhancement of fish production, creation of wildlife habitat, rejuvenation of soil fertility, in addition to the productive effects on plant growth and physiological rhythms **(Poff, 2002; Liu *et al*., 2014).** Flooding affects phytoplankton abundance and community composition, whereas fluctuations in water levels cause quick growth of certain algal species **(Avigliano *et al*., 2014)**. Nevertheless, there are very few studies regarding the effect of flood stress on aquatic ecosystems **(Lake, 2011)**.

Flooding of Lake Nasser in Egypt occurs once a year during August because of high outflow from the Ethiopian highlands instigated by the yearly monsoonal weather pattern. It is worthmentioning that the greatest factor affecting the ecosystem of Lake Nasser is the yearly flood of the Nile River, which, in turn, affects the resident phytoplankton abundance and components **(Hussian *et al*., 2016)**.

Many studies have examined plankton community structure and biochemical constituents of Lake Nasser **(Mageed & Heikal 2006; Khalifa *et al*., 2015; Hussian *et al*., 2016; Abd El-Hady *et al*., 2016; AbdelGawad & Abdel-Aal 2018; Hegab *et al*.,2020).** Phytoplankton represent at least one quarter of the biomass of the world's vegetation, and any changes in phytoplankton composition affect the abundance and diversity of food web structures in aquatic ecosystems **(Leterme *et al*., 2006)**. The major phytoplankton community structure in Lake Nasser belongs to Cyanobacteria, followed by Bacillariophyceae and Chlorophyceae. Total phytoplankton numbers is reported to be higher in the post-flood period **(Abdel Gawad & Abdel-Aal, 2018)**. Remarkably, Phytoplankton abundances of Lake Nasser under the present flood regime are similar to flood systems in South America **(Train & Rodrigues, 1997)** where sporadic peaks of phytoplankton occur during high water loading. Nevertheless, the general pattern of phytoplankton abundance differs considerably in the Amazon River **(Huszar & Reynolds, 1997)**, where high planktonic density during low water is altered to a sparser community structure by the dilution effect of high water **(Cardoso *et al*., 2012)**.

Phytoplankton biochemistry and physiological condition determine the quality of food for consumers **(Lee *et al*., 2017)**. The relative amounts of metabolic products (proteins, carbohydrates, and lipids) are closely linked to environmental and nutrient conditions **(Juneja *et al*., 2013)**. Protein is the primary biochemical constituent of phytoplankton at some khors along the shoreline of Lake Nasser; an evidence that indicates a physiologically healthy phytoplankton population with high growth rates **(Abd El-Hady *et al*., 2016)**. Organic matter contents of phytoplankton extensively used to indicate the trophic state of the ecosystems **(Akhil *et al*., 2013; Renjith *et al*., 2013)**. Fixation of carbon, the primary element in organic matter **(Sayre, 2010)** has been demonstrated to control the size and biochemical composition of phytoplankton species (Armstrong *et al*., 2001). The present study was conducted to analyze the phytoplankton species composition and their biochemical constituents during flooding of Lake Nasser.

MATERIALS AND METHODS

1. Study area and sampling sites

Lake Nasser, a monomictic subtropical lake, located at 20.45-23.97^o N, 30.12-33. 25° E, is the second largest man-made lake in the world. It is distinguished by its long narrow shape with dendritic embayments called khors. A single circulation period occurs from November through March **(Craig, 2000)**. This area is classified as hyper-arid with infrequent rainfall events **(Kottek *et al.*, 2006)**. Water samples, obtained from Lake Nasser's main channel during the flood period in August 2017 including surface, 10 m and 20 m depth and two meters before the bottom of the lake (depth of each site showed in table 1), were collected from 5 sites (Fig. 1). These sites include: The High Dam (Site 1), Wadi-Abyad (Site 2), El-Madiq (Site 3), Tushka (Site 4), and Abu-Simble (Site 5).
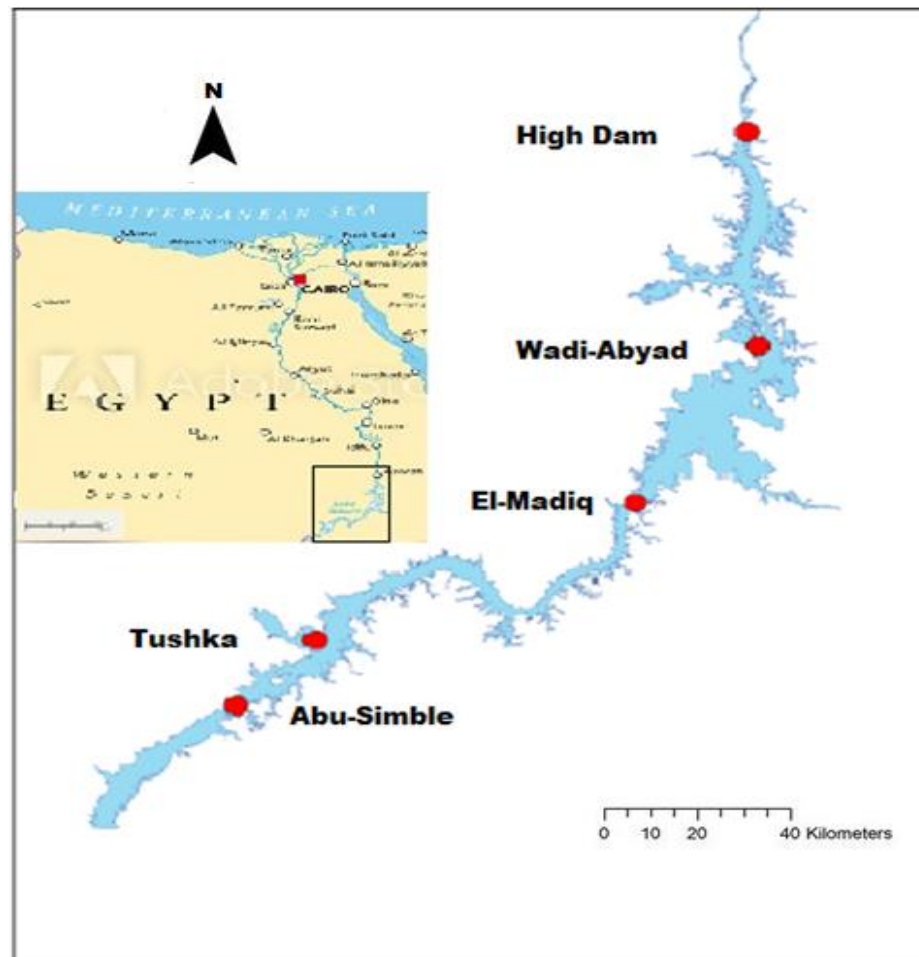

Fig. 1. Map of Lake Nasser showing the selected sites at the main channel.

2. Abiotic parameters

Water temperature and pH were measured in situ using a Hydrolab Multi Set 430i WTW. Transparency was then measured using a black-white Secchi disk. Total dissolved

solids (TDS) and dissolved oxygen (DO) were measured according to methods described in **ABHA (2005)**. The results of the nutrients (nitrite, nitrate and phosphate) were obtained with the chemistry laboratory of the Freshwater and Lakes Division from the work plan of the National Institute of Oceanography and Fisheries (NIOF). Physico-chemical parameters, phytoplankton standing crop and its biochemical constituents, including carbohydrates, proteins, lipids, total biochemical content and biopolymeric particulate organic carbon, were determined as an average of the results obtained at different water levels.

3. Biotic parameters
3.1. Phytoplankton

Phytoplankton identification and abundances were determined by first collecting ~1 liter water samples that were immediately preserved with formalin. In the laboratory, each sample was poured into a 1 litre capacity cylinder and left for five days with an addition of Lugol's iodine solution. Identification and enumeration (cells l^{-1}) of phytoplankton species was accomplished using 100 ml aliquots of each examined sample using an inverted microscope following the methods of **APHA (2005)**. phytoplankton species were identified according to published protocols of **Hendey (1964)**, **Bourrelly (1968), Bourrelly (1981), Sheath and Wehr (2003)** and **Taylor *et al*. (2007)**.

3.2. Biochemical content of phytoplankton

For biochemical constituent analysis, water samples were filtered using 100 μm zooplankton net to remove macrozooplankton, and then filtered using GF/F Whatman filter paper (0.7 μm). Filtered samples were preserved in ice. A Biuret test was used for total protein analysis using bovine albumin as a standard (**David James & Hazelm, 1994**). Total carbohydrate content was determined by the phenol-sulfuric acid hydrolysis method as described by **Dubois *et al*. (1956),** using glucose as standard, whereas lipid content was estimated by the sulphophosphovanillin procedure using cholesterol as the calibration standard (**Chabrol & Castellano, 1961**). Protein, carbohydrate, and lipid concentrations were converted to equivalent carbon using 0.40, 0.49, and 0.75 mgC/l conversion factors, respectively (**Fabiano & Danovaro, 1994**). Biopolymeric carbon abundance refers to the sum of carbon in proteins, carbohydrates and lipids (**Fichez, 1991; Fabiano *et al*., 1995**).

4. Data analysis

The physico-chemical parameters, the phytoplankton data and the biochemical components were drawn up in the form of one matrix and were analyzed by Principle Component Analysis (PCA) using XLstat 2016 software.

RESULTS AND DISCUSSION

1. Abiotic paramerters

Physico-chemical parameters of the aquatic environment of Lake Nasser are dependent on flood events **(Hussian *et al*., 2016)**. Principle Component Analysis (PCA) was initially performed on 8 environmental variables with total phytoplankton species, five phytoplankton classes and their biochemical constituents (Fig. 2). Limnological flood characteristics indicated that the average depth values ranged from 57.5 m at Site 5 (Abu-Simble) to 106 m at Site 1 (High Dam). The decrease in the depth of water in the southern sites of the lake may be attributed to the deposition of large amounts of silt loaded with flood water. **Hegab *et al*. (2020)** concluded that flood affects the riverine region (southern part) of Lake Nasser which, in turn, changes its ecosystem.
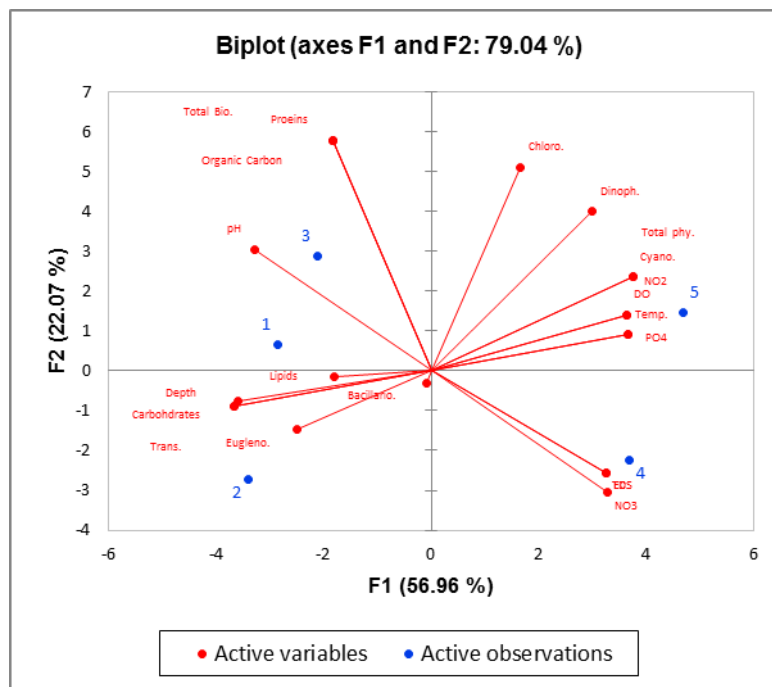

Fig. 2. Principal component analysis (PCA) between environmental and biological variables in the different sampling sites of Lake Nasser during the flood. Abbreviations are: water temperature (Temp.), dissolved oxygen (DO), transparency (Trans.), total dissolved solids (TDS), nitrite (NO_2), nitrate (NO_3), phosphate (PO_4), total phytoplankton (Total phy.), total biochemical content (Total Bio.), Cyanophyceae (Cyano.), Bacillariophyceae (Bacillario.), Chlorophyceae (Chloro.), Dinophyceae (Dinoph.), and Euglenophyceae (Eugleno.)

Water temperature average values ranged from 26.3 to 27.4°C. Moreover, transparency values fluctuated from 0.6 cm at Site 5 to 420 cm at Site 1, noting that low water transparency in upstream sites (southern part) is due to the effect of high turbidity resulting from the flood **(Gharib & Abdel-Halim, 2006)** . **Salem (2011)** related the less

turbidity values in the northern sites (lacustrine portion) of Lake Nasser to the decrease of water velocity which leads to settling of silt. pH, always in the alkaline side, varied between7.8 and 8.0. Dissolved oxygen is one of the main factors affecting the survival of aquatic organisms (bacteria, plankton and fish). Lake water was well oxygenated during flood time as dissolved oxygen ranged between 5.8 mg/l at Site 2 to 6.6 mg/l at Site 5. As shown in PCA analysis, DO was positively correlated with total phytoplankton, Cyanobacteria, Dinophyceae, Chlorophyceae, water temperature and TDS (r= 0.70, 0.70, 0.67, 0.31, 0.52 and 0.80, respectively), where it correlated negatively with Euglenophyceae, total biochemical contents, transparency and pH (r=-0.87, -0.40, -0.77 and -0.70 respectively). The differences in values of TDS in different sampling sites during the flood period were very slight (Table1). They correlated positively with total phytoplankton and negatively with all components of biochemical contents of phytoplankton.

Table 1. Average ± SD of physico-chemical Characteristics of Lake Nasser during the flood season.

	Site 1	Site 2	Site 3	Site 4	Site 5
Depth (m)	106	79	73	60	57.5
Temp. (°C)	26.3±3.99	26.8±4.41	27.0±4.75	27.4±4.08	27.4±4.8
Trans. (cm)	420	410	160	1.3	0.6
pH	8.0±0.48	7.9±0.69	8.0±0.69	7.8±0.51	7.8±0.59
DO (mg/l)	6.24±1.87	5.78±2.8	6.0±2.78	6.47±1.49	6.60±1.06
TDS (mg/l)	163.8±6.2	162.3±10.7	159.9±8.2	166.9±6.2	166.9±2.0

Nitrite ranged between a low value of 0.3 µg/l at Site 2 to a high of 9.3 µg/l at Site 5; nitrates average values varied from 22.7 to 82.17 µg/l whereas, phosphates ranged from 4.48 to7.11 µg/l. Furthermore, temperature, pH, and high nutrient concentrations were the most important factors affecting phytoplankton species distribution in Lake Nasser. These parameters affect other characteristics of water, including photosynthetic activity of phytoplankton and solubility of certain gases, which, in turn, influence other aquatic organisms **(Abd El-Hady *et al*., 2016; Abdel Gawad & Abdel-Aal, 2018)**.

2. Biotic paramerters
2.1. Phytoplankton
A total of 68 phytoplankton taxa were identified in Lake Nasser during flood, including Cyanobacteria (12 taxa), Bacillariophyceae (18 taxa), Chlorophyceae (22 taxa), Dinophyceae (9 taxa), and Euglenophyceae (7 taxa); all of which are listed in Table 2. Phytoplankton dominated by Cyanobacteria nearly at all lake depths (Table 3), followed by Bacillariophyceae, except for El-Madiq (Site 3) where Chlorophyceae attained the

Table 2. List of phytoplankton species recorded in Lake Nasser during the flood season.

Species

Cyanobacteria

Microcystis. aeruginosa Kutz.
M. flosaquae (Wittrock) Kirchner
Microcystis viridis (A.Braun) Lemmermann
Merismopedia tenuissima Lemmermann

M.glauca (Ehrenberg)Nageli
Snowella lacustris (Chodat) Komárek & Hindák
Chroococcus minutus (Kutzing) Nageli
Planktolyngbya limnetica Lemmermann

Oscillatoria princeps Vaucher
Phormidium lucidum Kützing
Oxynema acuminatum (Gomont) Chatchawan
Aphanizomenon flosaquae Ralfs ex Bornet &
Flahault

Bacillariophyceae
Aulacoseira granulata (Ehr.) Sim
A. granulata var. *angustissima* (O.Müller)
Simonsen
Cyclotella kutzingiana var. *meneghiniana*
(Kützing) Brun
Epithemia operculata (C.Agardh) Ruck & Nakov
Pantocsekiella ocellata (Pantocsek) K.T.Kiss &
Ács
Lindavia glomerata (H.Bachmann) Adesalu &
Julius
Cyclotella kutzingiana var. *meneghiniana*
(Kützing) Brun
Lindavia bodanica (Eulenstein ex Grunow)
T.Nakov

Ulnaria ulna (Nitzsch) Compère
U. acus (Kützing) Aboal
Microcostatus krasskei (Hustedt) J.R
Kobayasiella subtilissima (Cleve) Lange-Bertalot
Achnanthidium pyrenaicum (Hustedt)
H.Kobayasi
Platessa conspicua (Ant.Mayer) Lange-Bertalot
Epithemia turgida (Ehrenberg) Kützing
Encyonema minutum (Hilse) D.G.Mann
Nitzschi. acicularis W.Smith
N. filiformis (W. Smith) Grun
Chlorophyceae
Chlorella vulgaris Beijerinck
Auxenochlorella pyrenoidosa (H.Chick) Molinari

Crucigenia quadrata Morren

Willea rectangularis (A.Braun) D.M.John

Crucigenia tetrapedia(Kirchner)W.& G.S.West
Monoraphidium convolutum (Corda)
Ankistrodesmus falcatus RalfsCorda
A. falcatus var. mirabilis West
Neglectella solitaria (Wittrock) Stenclová &
Kastovsky
Oocystis elliptica W. West
O. lacustris Chodate
Mucidosphaerium pulchellum (H.C.Wood) C.Bock
Staurastrum anatinum var. *longibrachiatum* West &
G.S.West
Tetradesmus dimorphus (Turpin) M.J.Wynne
Scenedesmus ecornis (Ehrenberg) Chodat

Tetraëdron caudatum (Corda) Hansgirg
*T. minimum (*A.Braun) Hansgirg
Pediastrum. duplex Meyen

Roya obtusa (Brébisson) West & G.S.West

Actinastrum hantzschii Lag.

Lagerheimia citriformis (J.W.Snow) Collins
Stauridium tetras var. tetraodon (Corda) J.D.Hall &
Karol

Dinophyceae

Ceratium hirundinella (O.F.Müller) Dujardin

Ceratium brachyceros Daday
Ceratium hirundinella f. *austriacum* (Zederbauer)
Bachmann
Peridiniopsis kulczynskii (Woloszynska) Bourrelly
Glenodiniopsis steinii Woloszynska
Gonyaulax apiculata Entz
Palatinus apiculatus (Ehrenberg)
Craveiro,Calado,Daugbjerg& Moestrup
P. gatunense Nygaard
Parvodinium umbonatum (F.Stein) Carty
Euglenophyceae
Euglena viridis Ehrenberg
E. sanguinea Ehrenberg
E. gracilis Klebs
E. clara Skuja
Lepocinclis acus (O.F.Müller) B.Marin & Melkonian
Euglenaformis proxima (P.A.Dangeard) M.S.Bennett
& Triemer
E. subehrenbergii Skuja

second highest class. Dinophyceae and Euglenophyceae are rare classes in the studied area (Fig. 3). The dominance of Cyanobacteria over other classes is attributed to the flood effect, a verification that coorelates with that of **Mccullough *et al*. (2012)** who developed and evaluated a remote monitoring protocol for water clarity in large lakes from May to September for three years, recording the most consistent results in August. This suggests that, during the other months, unstable seasonal lake conditions and inter-annual differences in algal productivity occurred. The dominance of Cyanobacteria was assessed by **Jekatierynczuk-Rudczyk *et al*. (2014)** in determining the trophic status of lakes. The current study confirmed conditions of high Cyanobacterial density, especially at Abu-Simbel (Site 5), where Cyanobacteria formed 97% of the total phytoplankton population and was accompanied by the highest value of major nutrients [nitrite (9.3 µg/l), nitrate (71.2 µg/l) and phosphate (7.1 µg/l], the lowest transparency (0.6 cm) and the highest reading of dissolved oxygen (6.6 mg/l). This suggests that increases in nutrient availability and dissolved oxygen during flooding may lead to proliferation of certain

Table 3. Density of different phytoplankton groups at various depths of different sites along the main channel of Lake Nasser during the flood period.

		Cyanophyceae (units.10^3l^{-1})	Bacillariophyceae (cells.10^3l^{-1})	Chlorophyceae (cells.10^3l^{-1})	Euglenophyceae (cells.10^3l^{-1})	Dinophyceae (cells.10^3l^{-1})
Site 1	Surface	11570	260	520	130	260
	10m	18190	130	650	260	260
	20m	9750	390	130	0	130
	Bottom	0	8060	0	0	0
Site 2	Surface	1950	0	130	130	130
	10m	13000	520	0	390	0
	20m	8450	260	260	260	260
	Bottom	6500	1820	0	130	0
Site 3	Surface	11700	0	260	390	390
	10m	13000	0	2470	0	0
	20m	3250	390	520	390	130
	Bottom	19760	650	0	130	130
Site 4	Surface	30550	520	910	130	130
	10m	10400	910	130	130	130
	20m	17550	130	0	130	390
	Bottom	10400	130	390	130	0
Site 5	Surface	131430	3120	1560	0	4290
	10m	61100	0	0	0	0
	20m	143650	0	0	0	0
	Bottom	0	130	520	130	520

Cyanobacteria species over other classes of phytoplankton. Paerl *et al*. (2016) attributed the dramatic increase in phytoplankton abundance to increased loading by phosphate and nitrogen sources during flood season.
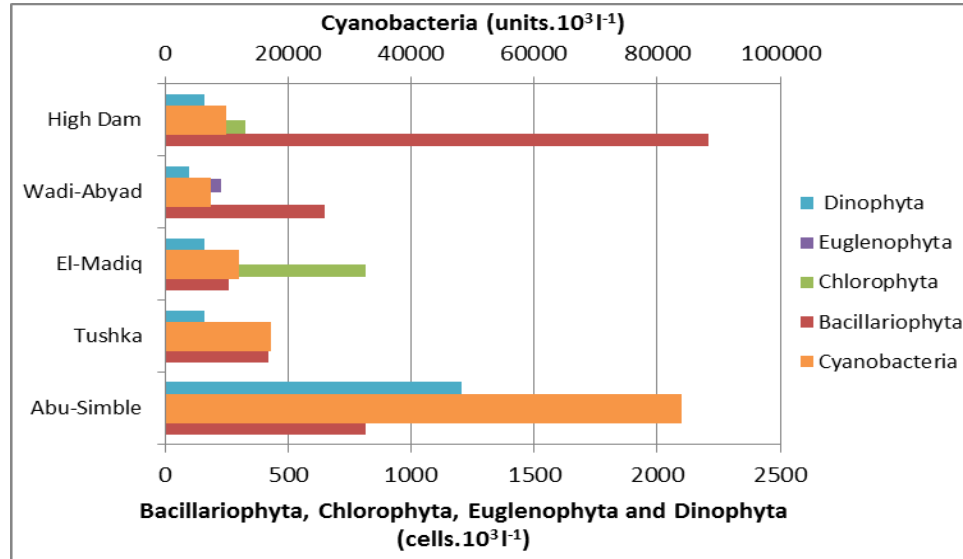

Fig. 3. Average density of different phytoplankton groups at the selected sites along the main channel of Lake Nasser during the flood.

Cyanobacteria populations in Lake Nasser dominated by *Microcystis aeruginosa*, *Planktolyngbya limnetica*, and *Oscillatoria princeps* (Fig. 4). **Hamed (2000)** attributed the factors responsible for blue-green algae blooms in Lake Nasser to the high eutrophication of lake water with high percentages of phosphate and nitrate, in addition to pH values tending towards alkalinity and suitable water temperature. Moreover, the expected toxicity of the dominant species *Microcystis aeruginosa* and *Oscillatoria princeps* was assessed by **Marrez *et al*. (2016)** in different Egyptian aquatic ecosystems (Kafr El-Zayat, El-Rasua and El-Khadra) and by **Zaher (2012)** at Wadi El-Rayian Lake. Thus, the dominance of these species and the changes in the present flood regime by disturbances such as the Grand Ethiopian Renaissance Dam construction are predicted to influence the Lake Nasser aquatic ecosystem.

This study cannot conclusively confirm that the increases in population in the phytoplankton community are merely related to the flood effect; because there are other interacting variables including the limnological characteristics of the water (temperature, pH, transparency, and nutrient supply) and grazing rate. However, the potential for algal proliferation occurs after flooding when nutrient availability is increased and water residence time is sufficiently long to allow algal blooms to form and accumulate **(Paerl *et al*., 2016)**. Nitrite, nitrate, and phosphate are positively correlated (r = 0.95, 0.55, and 0.79, respectively) with Cyanobacteria blooms in the lake. The study of **Mihaljević *et al*. (1999)** on Lake Danubian concluded that flooding caused formation of dense algal

blooms of Cyanobacteria. Whereas, a decade later, the study of **Mihaljević *et al.* (2009)** on the same lake, concluded that flooding has a dual impact on development of phytoplankton. In their study **(2009),** the previous authors reported that flooding of Lake Danubian in early spring stimulated phytoplankton development, but flood pulses in May and June introduced a dilution affect whereby nutrient concentrations decreased, resulting in detection of a significantly lower phytoplankton biomass. Thus, flooding pulses can be considered as a type of ecosystem disturbance.

Within our data set, a strong positive correlation between total phytoplankton and Cyanobacteria (r = 0.99) as the dominant class, while DO (r = 0.70) indicates that oxygen production resulting from phytoplankton blooms exceeds ten times the amount consumed (Hardy 1973). Oxygen production supplies the heterotrophic organisms and the ecosystem in general with added energy because increases in phytoplankton biomass in the aquatic system result in an increase in the amount of DO as a result of photosynthesis during daylight **(Kunlasak *et al*., 2013)**. Proliferation of Cyanobacteria, however, increased the turbidity of water in the lake as confirmed by a strong negative correlation between transparency and blue-green algae populations (r = −0.6).
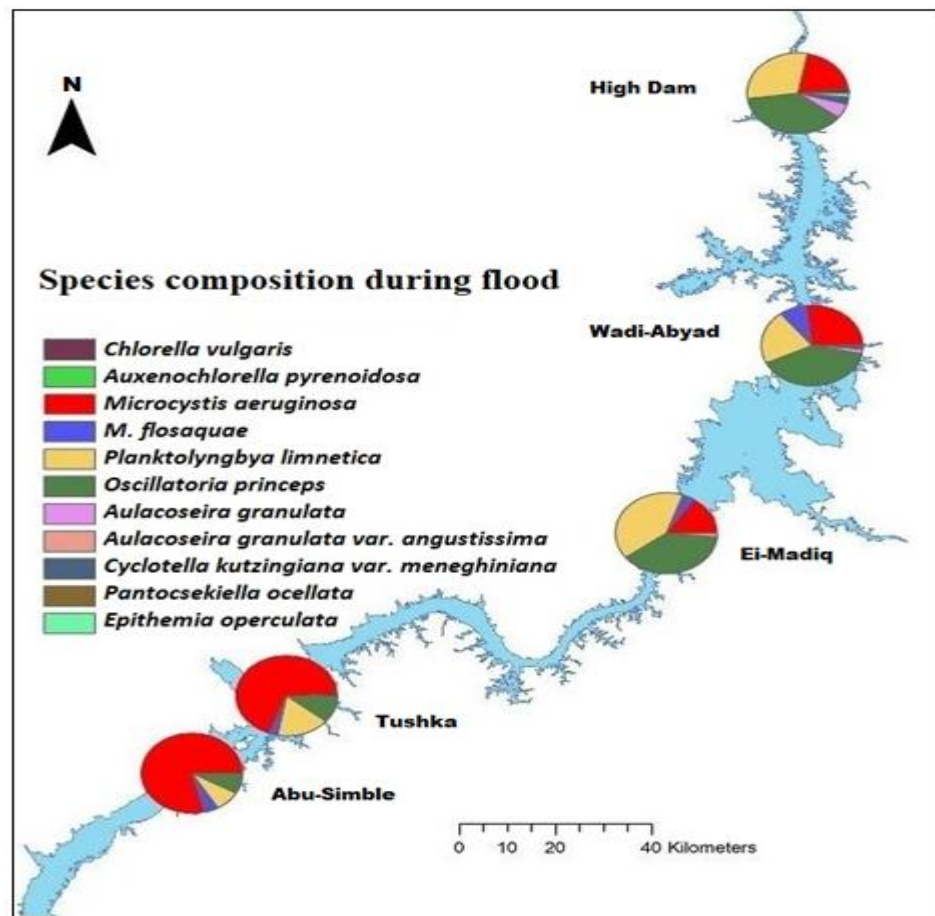

Fig. 4. Dominant phytoplankton species inhabiting Lake Nasser across different sites during the flood period.

Green algae in Lake Nasser were dominated by *Chlorella vulgaris, Auxenochlorella pyrenoidosa, Crucigenia quadrata, Ankistrodesmus convolutes*, and *Dictyosphaerium pulchellum* as well. Wadi-Abyad site is characterized by a considerable lower density and diversity of green algae compared to other examined sites (Fig. 3). This observation is accompanied with complete depletion of nitrite and high concentrations of ammonium, nitrate, and high water temperature. Nitrogen is considered a limiting factor affecting phytoplankton growth **(Livingston *et al*., 2002)** and the higher values of nitrogen inhibit growth of certain algal species **(Karthikeyan *et al*., 2010)**.

The highest abundances of diatoms documented at the High Dam site (2210×10^3 cell $^{-1}$) and the lowest value of 260×10^3 cell $^{-1}$ were noticed at El-Madiq site (Fig. 3). During the studied flood event, the most common recorded species of diatoms were *Aulacoseira granulata*, *Aulacoseira granulata* var. *angustissima, Cyclotella kutzingiana* var. *meneghiniana, Pantocsekiella ocellata* and *Epithemia operculata.* Habitat heterogeneity effects on plankton communities, particularly phytoplankton in flood plains, are direct results of the fluctuation of water levels in the aquatic system **(Junk *et al*., 2006)**. Similar to other higher planktonic organisms, phytoplankton density and abundance during flood periods are driven by the force of the flood pulse, which affect the limnological and biological properties of water **(Train & Rodrigues, 1997; Thomaz *et al*., 2007)**.

2.2. Biochemical content of phytoplankton

Biopolymeric particulate organic carbon, along all detected depths of the five sites, was related to the high extent of the high biopolymeric C of phytoplankton proteins (Table 4). High average values of biopolymeric particulate organic carbon (37.15 mg/l) and total biochemical content (91.29 mg/l) detected at Site 3 (Fig. 5), may be due to the optimum nutrient values of nitrite (0.479 µg/l) and phosphate (5.149 µg/l)] encountered there. However, total biochemical content and biopolymeric particulate organic carbon decreased at Site 5 (Abu-Simble) which associated with increases of nitrite and phosphate with values 9.31 and 7.11 µg/l, respectively, accompanied with a decrease in transparency to its lowest levels (0.60 cm). This may be attributed to the transport of large amounts of suspended solids and nutrients into Lake Nasser by floods, allowing nutrient replenishment and changes in the amount of light necessaryfor algal growth. Elevation in the suspended matter concentration in a lake leads to greater light attenuation and, hence, a decrease in biochemical content **(Tilzer *et al*., 1976)**. Light is the primary energy source during the photoautotrophic growth phase of algae to convert carbon dioxide to organic biochemical compounds **(Juneja *et al*., 2013)**. A physiologically healthy phytoplankton population with high relative growth rates has minor lipid content, whereas the present findings reflect higher lipid content at all studied lake sites relative to carbohydrates, especially at Site 3 (1.5 mg/l lipid versus 1.14 mg/l carbohydrate concentrations). An increase in suspended matter during flooding may lead to light-

limited conditions, an increase in total lipid content, and a decrease in free fatty acids, alcohol, and sterol **(Gordillo *et al*., 1998)**. Moreover, algae can be exposed to environmental conditions that influence growth rate and cellular composition; however, the amount of carbon fixed in lipids and carbohydrates is highly affected by nutrient availability **(Juneja *et al*., 2013)**.

Table 4. Density of different biochemical contents (mg l^{-1}) of phytoplankton at various depths of different sites along the main channel of Lake Nasser during the flood period.

		Proteins	Carbohdrates	Lipids	Biopolymeric particulate organic carbon
Site 1	Surface	102.3	1.28	1.4	42.6
	10m	95.5	1.10	0.8	39.3
	20m	111.4	1.20	1.0	45.9
	Bottom	38.6	1.28	0.7	16.6
Site 2	Surface	36.5	1.20	1.2	16.1
	10m	106.8	1.28	1.0	44.1
	20m	97.7	1.20	1.4	40.7
	Bottom	100	1.20	1.2	41.5
Site 3	Surface	75.0	1.12	1.8	31.9
	10m	99.9	1.12	1.9	42.0
	20m	88.6	1.20	1.4	37.1
	Bottom	91	1.15	0.9	37.6
Site 4	Surface	74.0	1.12	1.1	31.0
	10m	84.1	1.12	1.0	34.9
	20m	59.1	1.20	1.3	25.2
	Bottom	70.5	1.04	1.4	29.8
Site 5	Surface	97.7	1.12	1.2	40.5
	10m	81.8	1.12	1.1	34.1
	20m	84.1	1.20	0.9	34.9
	Bottom	81.1	1.12	0.5	33.4

Maximum protein and lipid contents of 88.64 and 1.5 mg/l, respectively, were detected at Site 3 in the lake (El-Madiq), which may be related to the increase of Chlorophyceae biomass (812.5 cells $\times$ 10^3 l^{-1}), where *Chlorella* was the dominant species. Many phytoplankton have the ability to produce triacylglycerols up to 50% of dry cell weight as a storage lipid under stressful environmental conditions **(Abou-Shanab *et al*., 2011; Yun *et al*., 2014)**. Chlorophyceae species, isolated from freshwater lakes in Hungary and Romania (Central Europe), may contain 40% dry weight of protein, whereas *Chlorella vulgaris* can accumulate a high lipid content (42.1%) with a 77.4% C^{16}-C^{18} fatty acid profile **(Selvarajan *et al*., 2015)**.

A high positive correlation was detected between carbohydrates and transparency as well as pH in Lake Nasser (r = 0.97 and 0.79, respectively). Moreover, Bacillariophyceae correlate positively with carbohydrates (r = 0.61). Diatoms produce large quantities of extracellular polymeric substances including polysaccharides and glycoproteins, thus providing organic carbon to heterotrophs **(Haynes *et al*., 2007)**.
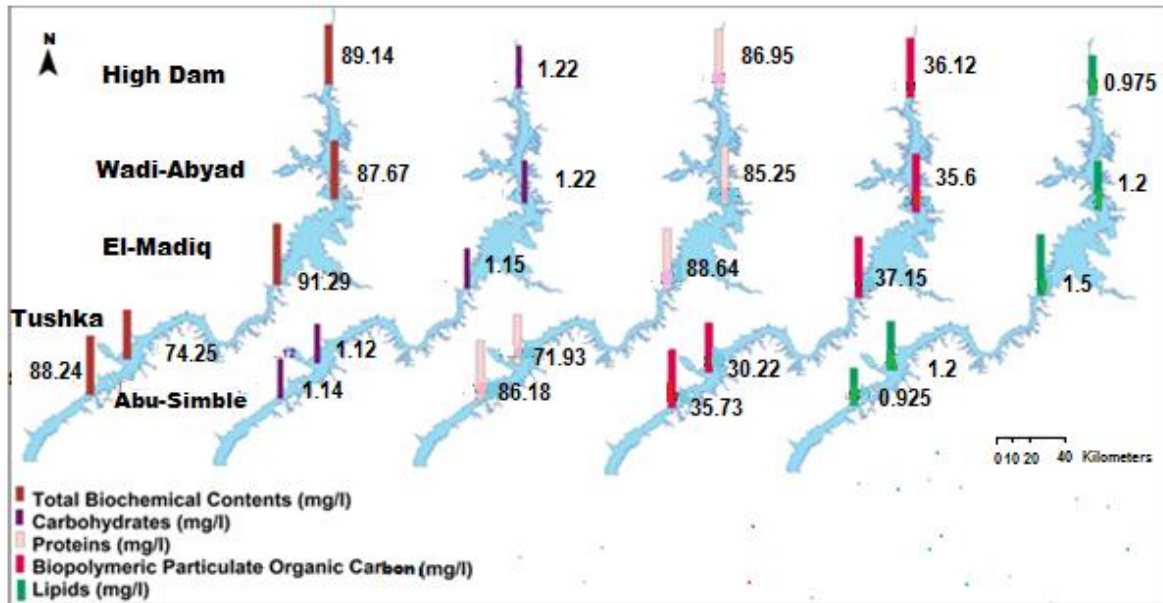

Fig. 5. Average of total biochemical content, carbohydrate, proteins, biopolymeric particulate organic carbon and lipids of phytoplankton during the flood season at Lake Nasser.

Generally, PCA (Fig. 2) shows that the distribution of all variables with axis F1 (56.96%) and F2 (22.07%) determined the significant relationship between variables. It suggested that the most significant parameters affecting total phytoplankton distribution especially Cyanobacteria were: temperature, DO and the major nutrients (NO_2 and PO_4) especially in Site 5 (Abu-Simble) which confirmed the strong effect of flood on phytoplankton distribution especially at that specific site of the lake. A negative correlation between protein contents, organic carbon and total biochemical contents and NO_3. PCA indicate that there was correlation between Sites 1 and 3 with total biochemical contents, total proteins and organic carbon and pH as environmental parameter. At Site 2 transparency of water shows a correlation between carbohydrates and lipid contents of phytoplankton especially class Bacillariophyceae and Euglenophyceae.

CONCLUSION

Changes in flood pulses at Lake Nasser may cause changes in the entire aquatic ecosystem. The present results suggest that flooding of Lake Nasser positively changes

the lake water quality by adding more dissolved oxygen and nutrients, thereby affecting phytoplankton composition, distribution, and abundance at all sites. Moreover, flooding influences the biochemical structure of algae inhabiting Lake Nasser, leading to an elevation in the minor lipid cellular composition relative to carbohydrates. Remarkably, the high protein and lipid contents and high total biochemical content of algae inhabiting El-Madiq site, together with the high abundances of Chlorophyceae are highly noted. This study provides a baseline for the phytoplankton community structure in Lake Nasser during flood periods, prior to the anticipated effects of altered water flow as a result of filling of the Grand Ethiopian Renaissance Dam upstream along the Blue Nile.

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