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Phytoplankton nutrition quality and chlorophyll a-nutrient relationships in Lake Nasser, Egypt

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Abstract

Lake Nasser plays an important role in the local and national economy. Phytoplankton is the main base for organic matter production for different consumers in Lake Nasser. The present study investigated the variation in phytoplankton biomass, chlorophyll a, and biochemical contents, lipid, protein and carbohydrates. The samples were collected from three different regions, the main channel and two Khors, Tushka and Dahmeit in mid autumn-2014 and late spring-2015. Chlorophyll a, carbohydrate, lipid and protein levels were non-significantly differed among the three regions of the lake ($P = 0.13$). Total protein constitutes the major part of the biochemical contents of the phytoplankton while total lipid constitutes the minor one. In general, average chlorophyll a, carbohydrate, lipid and protein were 4.27 $\mu\text{g/l}$, 2.89 mg/l, 0.2 mg/l and 38.91 mg/l, respectively, in the main channel, 7.86 $\mu\text{g/l}$, 1.74 mg/l, 0.16 mg/l and 30.68 mg/l, respectively, in Khor Tushka, whilst they were 4.2 $\mu\text{g/l}$, 1.34 mg/l, 0.28 mg/l and 39.36 mg/l, respectively, in Khor Dahmeit. Results of the principle components analysis and Spearman correlation matrix indicated that responses of biochemical composition and chlorophyll a to the changes in nutrient concentrations were dissimilar depending on the location and time of sampling which indicated that, in addition to nutrients, many other factors regulate chlorophyll a and biochemical contents in Lake Nasser. The regression analysis revealed a lack of correlation between chlorophyll and both reactive phosphorus and total inorganic nitrogen (TIN) in Khor Dahmeit, whereas slight correlations were found with PO_4 in the main channel and Khor Tushka. PO_4 significantly explained 22% ($P = 0.019$) and 11% ($P = 0.008$) of the observed chlorophyll a variability in Khor Tushka and main channel, respectively.

Keywords: Lake Nasser, phytoplankton, biochemical contents, chlorophyll a, principle component analysis, regression analysis

1. Introduction

Deep and Large reservoirs exhibit a large degree of spatial heterogeneity in phytoplankton productivity and biomass as a result of longitudinal gradients in basin morphology, water residence time, flow velocity, suspended solids, depth and availability of light and nutrients [1]. In such huge ecosystems where littoral zone production is very constricted in a very narrow strip, phytoplankton is the main source of organic substances and carbon cascade in higher trophic levels [2]. Microalgae are the primary food for mollusks, zooplankton, and crustacean larvae and remain essential to the production of fish and their larval [3, 4]. The role of phytoplankton as a main source of fish nutrition is well known, and in order to develop the fish economy it is necessary to study the phytoplankton and the factors affecting its biomass, nutritional quality and productivity [5].

Nevertheless, chlorophyll a (Chl a) and biochemical contents are important indicator of phytoplankton nutritional quality. As live food, nutritional compositions in algae are critically important because they can affect the growth and reproduction of aquatic animals [6]. Nutrient availability in the environment can regulate the growth and biochemical composition of algae [7]. Phosphorus (P) and nitrogen (N) are the two major elements limiting primary productivity, and their availability can alter the biochemical composition particularly protein and lipid content of algae [8, 9]. N limitation usually results in low protein content and high carbohydrate or lipid storage while P limitation can also shift the relative contents of protein, lipid and carbohydrate in algal cells [10, 11].

Chlorophyll a serves as an integrative measure of phytoplankton biomass and photosynthetic potential, and thus a number of trophic-state prediction models are based on phosphorus-chlorophyll relations [12]. In Lake Nasser, principal nutrient inputs occur in late summer till

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mid-autumn as a consequence of Nile flood [13]. Under this situation, external loads are mixed within the water column and these inputs set for the rest of the year conditions when flood is typically stopped. An example of how this nutrient input well incorporate into phytoplankton biomass is shown by the empirical relationship that predicts chlorophyll concentrations [14]. This approach has provided an appropriate framework for lake evaluations for phytoplankton biomass and lake management [15].

The purpose of this paper is therefore to determine the phytoplankton nutrition quality, as main source of organic matter in the lake, through investigation of its total protein, carbohydrates and lipid contents and their response to the changes happen in nutrient concentrations. Meanwhile, investigate how are the relations between Chl-a concentrations and changes in phosphorus and nitrogen concentrations through linear regression models.

2. Materials and Methods

2.1. Site of the work

Lake Nasser is one of the largest man-made lakes in the world. The lake plays a large role in the local and national economy of Egypt. Lake Nasser lies between 22° 00' N and 23° 58' N in Egypt, and extends southward in Sudan to 20° 27' N as Lake Nubia (Fig. 1). The reservoir is designed to have a maximum water level of 183 m above sea level (ASL) and a total capacity of $162 \times 10^9 \text{ m}^3$ [13]. At this level, the reservoir has a length close to 500 km, an average width of 12 km and a surface area of 6,540 km². The lake shoreline is very irregular, with numerous side channels known as khors. There are about 85 khors, 48 on the east and 37 on the west side. Their surface area covers about 4900 km², i.e. 79% of total Lake Surface, while their volume is 86.4 km³, i.e. 55% of total Lake Volume [16].

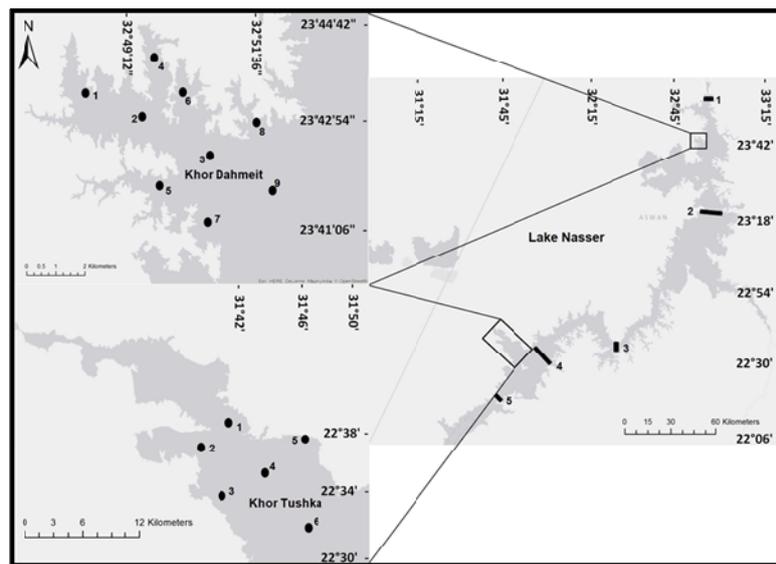


Fig 1: Map showing the sampling sectors in the main channel and sampling stations in the Khors

2.2. Sampling program

Two field cruises were performed during the highest water level, mid autumn-2014, and least water level, late spring-2015. Five sectors in the main channel and six and nine stations in Tushka and Dahmeit khors, respectively, were sampled (Fig.1). At each sector, water samples were collected from the east, middle and west stations. At the middle of the main channel, surface, 5m, 20m and 40m depths were collected, whereas only surface and bottom samples were collected at the east and west as well as the stations of both khors (Fig. 1).

2.3. Chlorophyll a and biochemical contents sampling

Water samples were collected in plastic bottles, immediately 10 ml were filtered through Whatman GF/F glass filter fiber for chlorophyll a and biochemical contents analyses.

2.4. Biochemical analysis

Total protein was determined by Biuret method [17]. Carbohydrate was hydrolyzed and measured by colorimetric method [18, 19]. Total lipid was determined by SPV method [20]. Chlorophyll a was extracted and measured using PerkinElmer (LS45) fluorescence spectrometer at an excitation wavelength of 430 nm and an emission wavelength of 663 nm and compared to standard curve [21].

2.5. Data analyses

Spearman's rank correlation analysis was carried out to elucidate relationships amongst chlorophyll a, protein, lipid, carbohydrates and nitrogen salts, reactive phosphorus and silicate. Relationships were considered to be significant when $P < 0.05$. One way ANOVA was used to compare seasons and depths or layers in the khors. One way ANOVA with Tukey's Honest Significant Difference (HSD) post hoc tests were then used to determine among group (stations, in the khors, sectors and depths in the main channel) differences for significant ANOVAs. Spearman's rank correlation analysis and one way ANOVA were carried out using SPSS v 20.

Principal Components Analysis (PCA) was applied to the variables of chlorophyll a, protein, lipid, carbohydrates and nitrogen salts, reactive phosphorus and silicate. A bi-plot was used to project variables from the PCA in two dimensions. The observations (stations and depths) are depicted as points, and variables as arrows from the intersection of the axes. The direction of an arrow represents where samples with high positive values of the corresponding variable occur. Arrows which point in similar directions are positively associated with each other in the dimensions depicted. The relative lengths of the arrows represent how well the variables are represented in the reduced dimensions depicted. Chlorophyll

a and biochemical contents were written in black and projected onto the plot as a black arrow. Each environmental parameter was written in red and projected onto the plot as a red arrow. The observations (stations and depths) of spring were represented in the bi-plot in green color whilst those of autumn were represented in the bi-plot in blue color.

The relative power of reactive phosphorus and total inorganic nitrogen (TIN, sum of NO₃-N, NO₂-N and NH₄-N) was investigated to predict Chl a for lake main channel and khors using linear regression. Both PCA and regression analyses were conducted using xlstat software 2014. 5. All the data of nutrient salts used in the statistical analysis were supplemented from our colleagues in the Chemistry Lab., Freshwater and Lakes Division, National institute of Fisheries and Oceanography.

3. Results

3.1. Chlorophyll a and biochemical contents of phytoplankton in main channel

Chlorophyll a and biochemical contents (Table 1) showed clear significant differences between the two sampling cruise ($P < 0.003$). Throughout the main channel, ANOVA indicated that chlorophyll a carbohydrates, lipid and protein had significant variations between seasons ($P < 0.03$, $P < 0.03$, $P < 0.0005$ and $P < 0.005$, respectively). ANOVA with Tukey Post-Hoc analyses indicated that there were significant variations between sectors with lack of significant variations between depths in both seasons. Chlorophyll a was lower at sector 2 than the other sectors in autumn (Tukey Post-Hoc, $P < 0.005$), whereas chlorophyll a showed no significant differences between sectors in spring. Carbohydrate contents were higher at sectors 4 and 5 compared with the other sectors in both autumn and spring (Tukey Post-Hoc < 0.0005 and < 0.05 , respectively). Protein contents were higher at sectors 2 and 5 in autumn (Tukey Post-Hoc, $P < 0.05$); with no significant differences between

sectors during spring, as well as lipid contents in both seasons. In general, average chlorophyll a, carbohydrate, lipid and protein were 4.27 µg/l, 2.89 mg/l, 0.2 mg/l and 38.91 mg/l, respectively. Chlorophyll a was negatively affected by NH₄ ($r = -0.32$, $P < 0.0005$) and PO₄ ($r = -0.31$, $P < 0.05$) but was positively affected by NO₂ ($r = 0.52$, $P < 0.0005$), NO₃ ($r = 0.32$, $P < 0.05$) and SiO₄ ($r = 0.3$, $P < 0.05$) (Table 2). Lipid contents did not show any correlation with nutrient salts in the main channel. Carbohydrates had negative relation with NO₂ ($r = -0.31$, $P < 0.05$) and NO₃ ($r = -0.52$, $P < 0.0005$), whereas protein contents had positive relations with both NO₂ ($r = 0.25$, $P < 0.05$) and NO₃ ($r = 0.36$, $P < 0.0005$), respectively (Table 2).

Principal component analysis (PCA) analysis differentiates the spring samples on the left hand and the autumn samples in the right hand (Fig. 2). The first two components of the PCA explained 33.44 and 17.73% of the variation in the data (i.e. 51.18% of the total variation). The autumn samples in the right hand differentiated into two groups; the first composed mostly of stations from fifth and fourth sectors samples (south of the lake). This group negatively correlated with axis 2 and was characterized by increase of nitrite and silicate and high yield of chlorophyll. The second right hand group composed mainly of stations of the northern sectors of the lake. This group was positively correlated with the second axis and characterized by increase of nitrate and associated with high yield of protein. Spring samples, in the left hand, differentiated into two groups. The first group composed mainly of stations of the northern sectors of the lake and negatively correlated with axis 2. This group associated with increase of lipid and carbohydrates, but did not respond to change in nutrient concentrations. The second left hand group constituted mostly from south sectors and was positively correlated with the second axis. Members of this group had high affinity towards the increase of ammonium and reactive phosphorus.

Table 1: Distributions of chlorophyll a (µg/l) and biochemical contents (mg/l) in main channel of Lake Nasser

Sectors	Stations	Autumn				Spring			
		Chlorophyll	Carbohydrate	Lipid	Protein	Chlorophyll	Carbohydrate	Lipid	Protein
Sector 1	MS	13.32	2.25	0.08	50	3.52	5	0.24	18.75
	M 10m	1.84	0.9	0.2	51.14	2.78	1.8	0.34	40.34
	M 20m	2.69	2.9	0.08	35.8	3.31	4.6	0.39	17.61
	M 40m	1.05	1.2	0.1	47.16	3.31	5.75	0.18	6.82
	ES	1.24	1.2	0.24	34.09	2.34	6.15	0.34	102.27
	EB	2.15	2.2	0.09	49.43	1.87	3.3	0.24	26.14
	WS	1.72	1.2	0.08	45.45	2.55	6	0.27	14.21
	WB	2.56	2.8	0.06	44.89	5.59	5.5	0.27	11.93
Sector 2	MS	2.22	2.6	0.24	36.93	4.7	4.6	0.27	47.16
	M 10m	2.96	0.75	0.15	35.23	3.33	4	0.11	8.52
	M 20m	2.83	1.2	0.26	34.66	5.13	5.75	0.18	5.11
	M 40m	2.71	0.2	0.18	46.59	2.67	6	0.22	9.66
	EB	3.52	0.6	0.19	68.18	11.65	4.8	0.24	16.48
	ES	2.35	3	0.25	48.3	8.42	5.5	0.24	26.71
	WS	2.28	2	0.18	41.48	6.6	5.75	0.53	5.68
	WB	2.22	2.8	0.2	48.3	4.23	5	0.92	3.98
Sector 3	MS	5.11	1	0.25	32.95	2.38	5.6	0.35	6.82
	M 10m	5.71	3.9	0.14	52.27	2.66	4.6	0.39	6.82
	M 20m	4.53	1	0.06	54.55	2.96	4.2	0.06	8.52
	M 40m	2.12	1.6	0.2	76.7	1.51	5	0.44	9.66
	ES	7.23	2.85	0.12	39.2	Sn	Sn	Sn	Sn
	EB	3.94	0.7	0.1	64.77	Sn	Sn	Sn	Sn
	WS	7.52	3.4	0.18	48.3	1.92	4.6	0.15	63.07
	WB	9.43	2.2	0.17	36.93	5.33	2.8	0.15	5.68
Sector 4	MS	7.55	1.2	0.92	50	2.93	0.6	0.21	17.61

	M 10m	6.26	0.8	0.25	7.39	1.27	2.8	0.17	52.84
	M 20m	5.14	2	0.35	21.59	3.92	2.6	0.31	52.27
	M 40m	5.14	1.8	0.25	76.7	0.73	2.2	0.17	53.98
	ES	6.39	1.6	0.21	64.2	2.61	2.15	0.23	50.57
	EB	4.77	0.95	0.45	28.98	3.5	3.35	0.22	51.7
	WS	10.25	0.6	0.21	46.59	4.61	2.9	0.24	32.39
WB	7.46	1	0.09	45.45	4.91	1.4	0.22	53.98	
Sector 5	MS	7.39	2.8	0.19	49.43	2.87	2	0.27	53.98
	M 10m	6.75	1.2	0.36	42.61	4.26	2	0.26	53.98
	M 20m	6.13	4.8	0.11	43.75	4.5	1	0.25	50.57
	M 40m	5.47	2.6	0.13	40.34	3.12	0.8	0.26	48.3
	ES	6.91	4	0.21	46.02	1.2	2.2	0.27	52.27
	EB	6.16	2.2	0.22	48.3	3.99	0.4	0.53	48.3

M; Main channel, E; East, W; West, S; Surface, B; Bottom, Sn; samples were not collected

Table 2: Correlation coefficient (r) between different biological parameters and nutrient salts in main channel, Tushka and Dahmeit Khors in Lake Nasser

	Chlorophyll a			Carbohydrates			Lipid			Protein		
	MC	Dt	T	MC	Dt	T	MC	Dt	T	MC	Dt	T
PO ₄	-0.31*							-0.45**			0.52**	0.75**
NO ₃	0.32*			-0.52**	0.46**					0.36**		-0.42*
NO ₂	0.52**			-0.31*						0.25*		-0.52*
NH ₄	-0.32**		-0.46*	0.3*	0.62**			-0.34*			0.47**	0.51*
SiO ₄	0.3*				-0.55**			0.51**			-0.61**	-0.52*

*, $P < 0.05$, **, $P < 0.0005$, MC; Main channel, Dt; Dahmeit, T; Tushka,

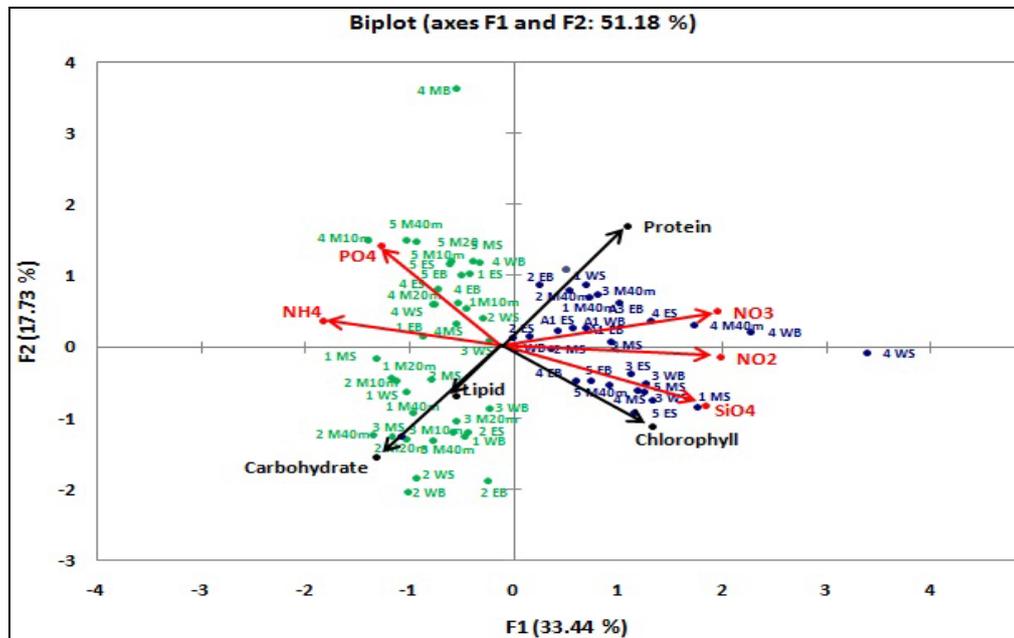


Fig 2: Principal Components Analysis showing a bi-plot representing the two axes which account for the largest amount of variation in the data from main channel of Lake Nasser (for description of arrows, colors and points see data analysis)

3.2. Biochemical contents of phytoplankton in Khor Tushka

Chlorophyll a and protein contents were distinct between seasons (Fig 3), while lipid and carbohydrates had no significant differences. Chlorophyll a values were significantly higher in autumn (ranged from 10.5 to 3.78 $\mu\text{g/l} \pm 1.76$) in comparison with spring (ranged from 10.02 to 3.17 $\mu\text{g/l} \pm 1.69$, $P < 0.05$). On the other side, protein contents were higher in spring (ranged from 80.68 to 22.73 $\text{mg/l} \pm 91.02$) in comparison with autumn (ranged from 29.55 to 6.25 $\text{mg/l} \pm 9.79$, $P < 0.0005$). Chlorophyll a and different biochemical contents showed non-significant variations between stations and water depth except for protein which showed pronounced significant variations between surface and bottom layers in both spring and autumn ($P < 0.01$ and $P < 0.0005$, respectively). In general, average chlorophyll a,

carbohydrate, lipid and protein were 7.86 $\mu\text{g/l}$, 1.74 mg/l , 0.16 mg/l and 30.68 mg/l , respectively (Fig.3). Lipid and carbohydrates showed no significant relations with the studied environmental variables in Tushka Khor (Table 2), whereas chlorophyll a was negatively affected by NH_4 ($r = -0.46$, $P < 0.05$). Protein contents were negatively affected by NO_2 , NO_3 and SiO_4 ($r = -0.52$, $P < 0.05$, $r = -0.42$, $P < 0.05$ and $r = -0.52$, $P < 0.05$, respectively) but was positively affected by NH_4 ($r = 0.51$, $P < 0.05$), and PO_4 ($r = 0.75$, $P < 0.0005$).

PCA analysis suggested that the samples collected in autumn differed from those collected in spring. The first axis of the PCA explained 46.63% of the variability among samples. The variables causing this separation were mostly ammonium, reactive phosphorus, nitrate and silicate which obviously separated the spring samples from autumn

samples. Spring samples were clustered to the right hand side, in reverse way to the main channel, and separated mainly because of high concentrations of ammonium and reactive phosphorus (in average, 156.1 $\mu\text{g}\text{l}^{-1}$ and 36 $\mu\text{g}\text{l}^{-1}$,

compared with 74.8 $\mu\text{g}\text{l}^{-1}$ and 10.9 $\mu\text{g}\text{l}^{-1}$ in spring and autumn, respectively). Spring samples were associated with high content of protein and

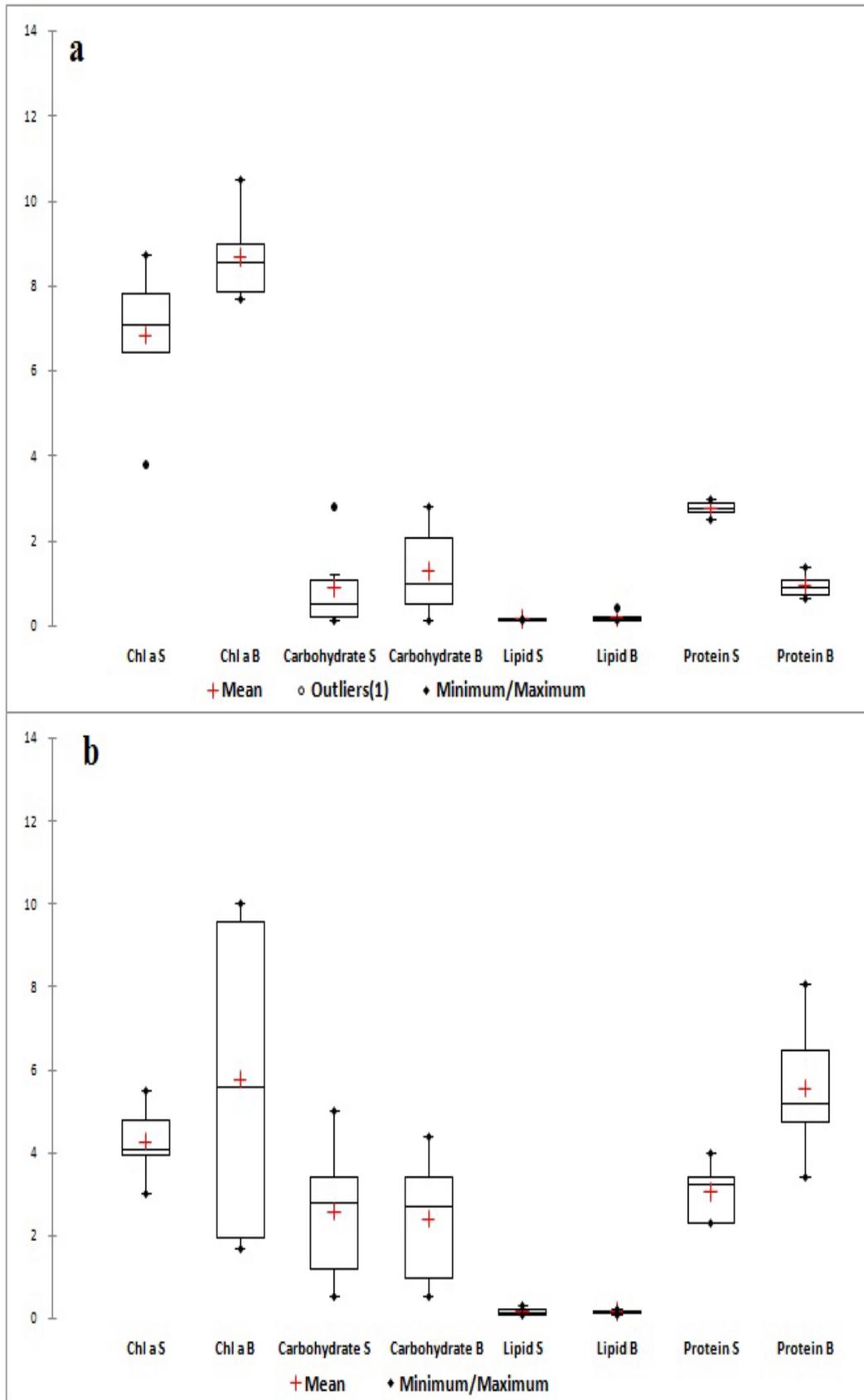


Fig 3: distribution of chlorophyll a ($\mu\text{g}/\text{l}$) and biochemical contents (mg/l) in Khor Tushka in a) autumn and b) spring (as protein values are very high compared to other parameters, its values divided by 10)

carbohydrates and all positively correlated with axis one (Table 2, Fig. 4). Autumn samples were clustered to the left

hand side and negatively correlated with the first axis and separated mainly due to the high concentrations of nitrate and silicate (in average, 176.9 $\mu\text{g/l}$ and 5.85 mg/l , compared with 17.22 $\mu\text{g/l}$ and 2.88 mg/l in autumn and spring, respectively), and characterized by high content of chlorophyll a. The second axis of the PCA explained 14.91%

of the variability among sampling stations and was associated with high content of lipid. The bottom samples of station 2 in spring and station 3 in autumn were differ from the other samples, these samples were collected at the most southern side of the khor and characterized by their high shallowness and sandy bottom.

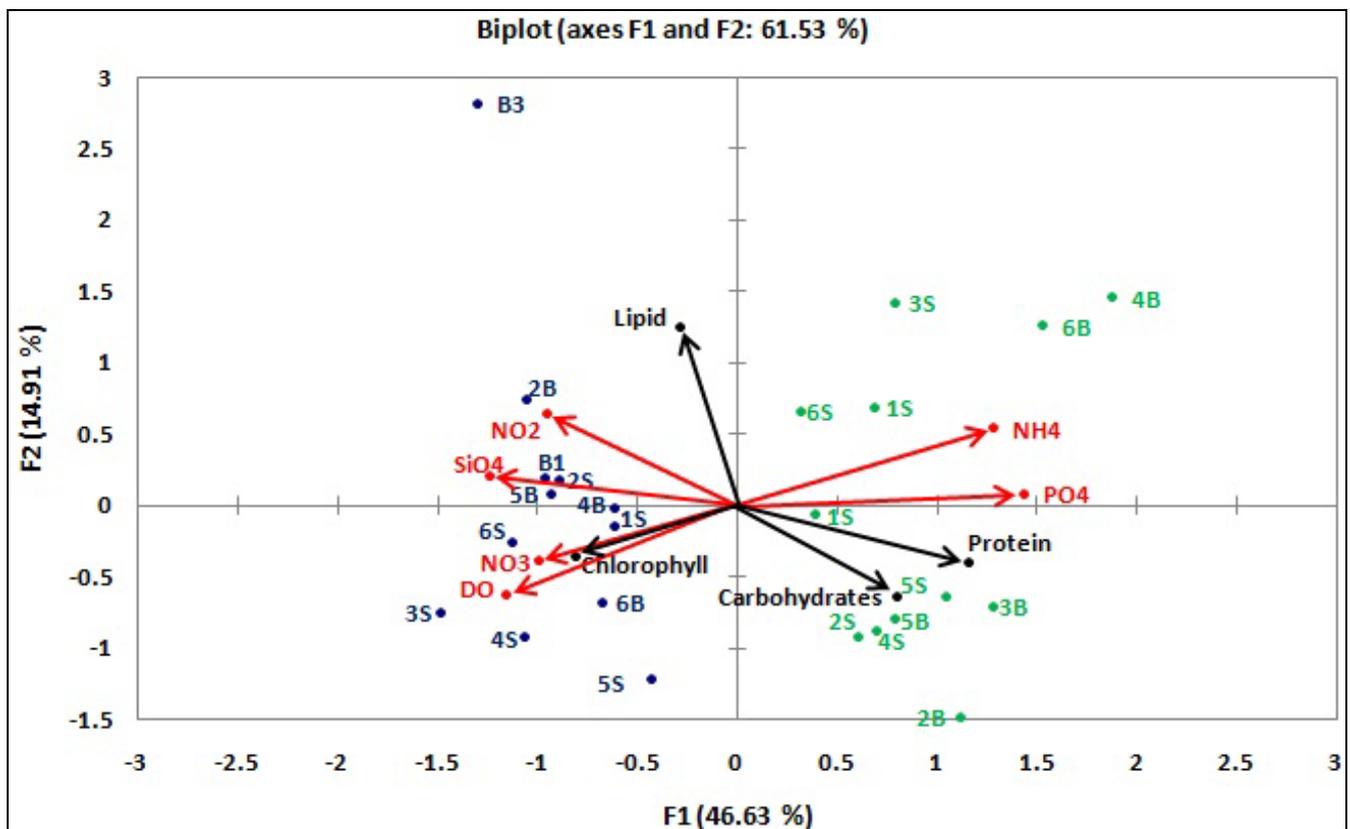


Fig 4: Principal Components Analysis showing a bi-plot representing the two axes which account for the largest amount of variation in the data from Khor Tushka (description of arrows, colors and points, see data analysis)

3.3. Biochemical contents of phytoplankton in Khor Dahmeit

Significant variations of total protein ($P < 0.0005$), lipid ($P < 0.005$) and carbohydrates ($P < 0.01$) were found between seasons, whilst no significant differences of chlorophyll a were detected between the two sampling dates. No significant effect of spatial distribution was detected neither for chlorophyll a, nor for protein, lipid or carbohydrates (one-way ANOVA followed by Tukey Post Hoc-test, $P = 0.46$). Significant differences were found between surfaces vs. bottom samples for lipid ($P < 0.002$) and protein ($P < 0.02$), whereas chlorophyll a and carbohydrate results showed no significant variations between water depths. In general, average chlorophyll a, carbohydrate, lipid and protein were 4.2 $\mu\text{g/l}$, 1.34 mg/l , 0.28 mg/l and 39.36 mg/l , respectively (Fig. 5). Biochemical contents were higher correlated with nutrient salts than chlorophyll a in Khor Dahmeit (Table 2). Carbohydrates contents were negatively affected by SiO_4 ($r = -0.55$, $P < 0.005$) but were positively

correlated with NH_4 ($r = 0.62$, $P < 0.005$) and NO_2 ($r = 0.46$, $P < 0.005$). Lipid and protein showed significant opposite relations with NH_4 , PO_4 and SiO_4 (Table 2).

PCA factors explained 54.55% of the total data variance. Fig. 6 shows that all spring samples are grouped with positive loading on factor 1 (40.18% of total variance) with negative loadings mainly of littoral stations on factor 2 (14.36% of total variance) and positive loading of middle stations to the same factor. Negative loadings of littoral stations on factor 2 associated with increase of nitrogenous salts and characterized by increase of carbohydrates whereas positively loaded of middle stations on factor 2 associated with increase of dissolved reactive phosphorus and characterized by increase of chlorophyll and protein. A second group of stations in the PCA is formed by the autumn samples, with negative loadings in factor 1 (Fig. 6). Autumn samples were associated with increase of SiO_4 and NO_2 and were characterized by increase of lipid.

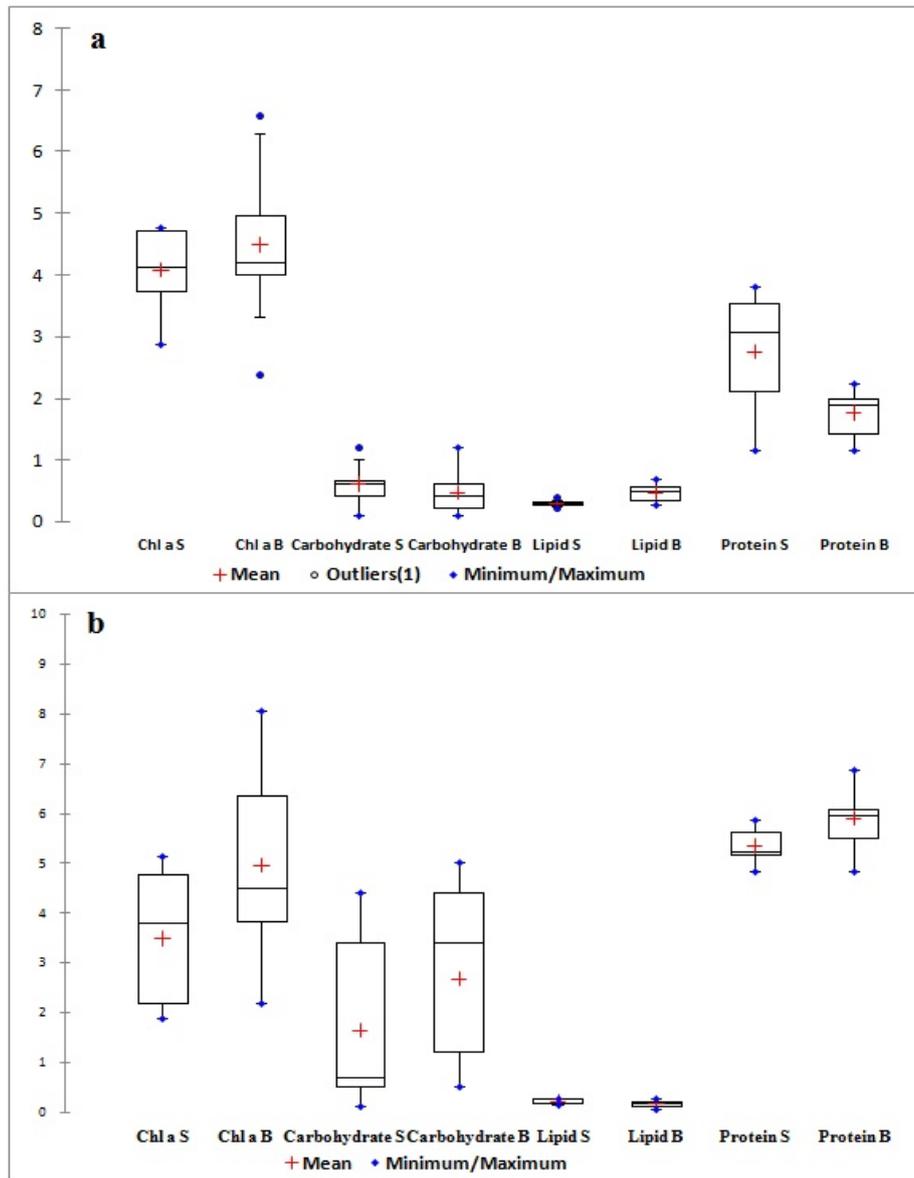


Fig 5: distribution of chlorophyll a ($\mu\text{g/l}$) and biochemical contents (mg/l) in Khor Dahmeit in a) autumn and b) spring (as protein values are very high compared to other parameters, its values divided by 10)

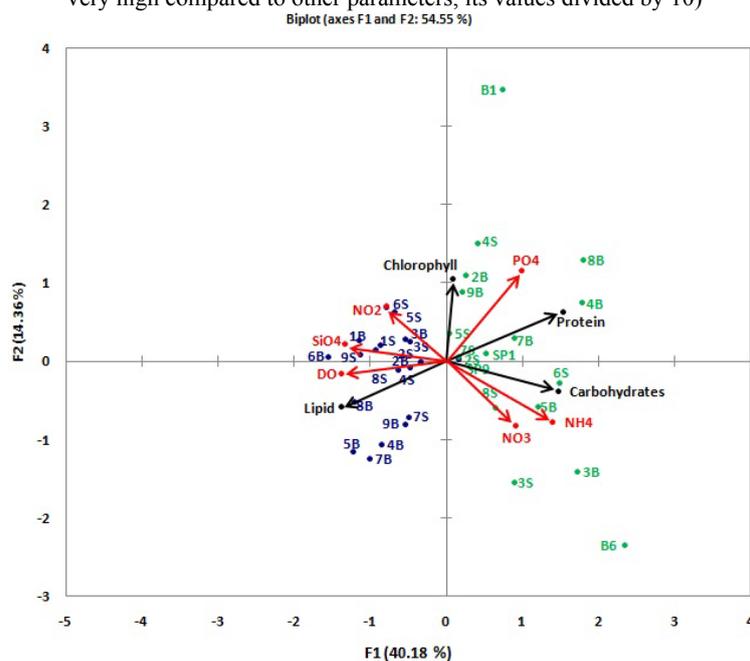


Fig 6: Principal Components Analysis showing a bi-plot representing the two axes which account for the largest amount of variation in the data from Khor Dahmeit (description of arrows, colors and points, see data analysis)

3.4. Regression of chlorophyll a against PO₄ and TIN

The results of this study revealed a lack of correlation between chlorophyll a and TIN, whereas slight correlations

were found with PO₄ in the main channel and Khor Tushka. PO₄ significantly explained 22% ($P = 0.019$) and 11% (P

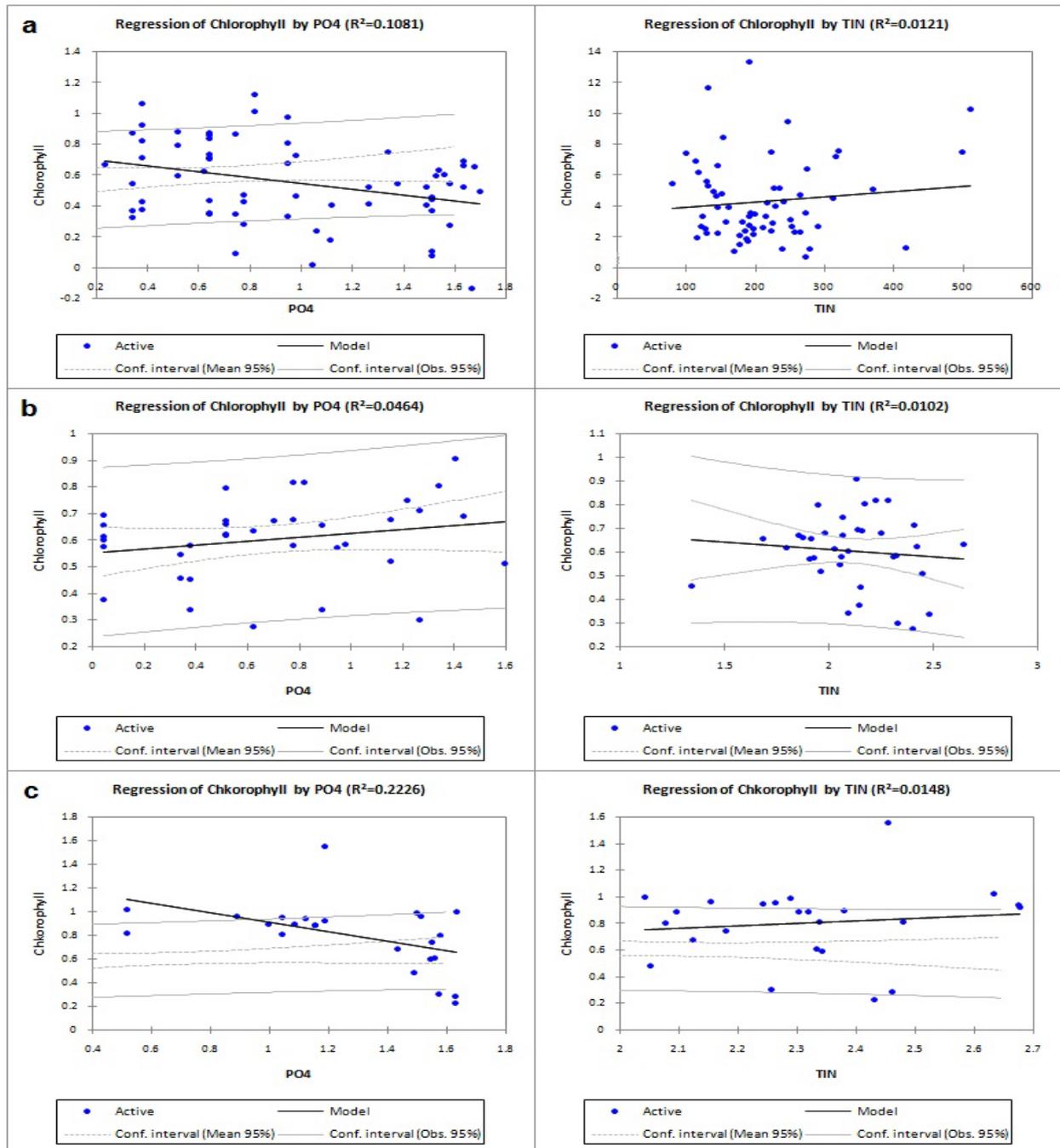


Fig. 7: Regression of chlorophyll a against dissolved reactive phosphorus, in the left, and total inorganic nitrogen, to the right, in a) main channel, b) Khor Dahmeit and c) Khor Tushka mean of chlorophyll a and PO₄ and/or TIN concentrations

= 0.008) of the observed chlorophyll a variability in Khor Tushka and main channel, respectively (Fig. 7). Regression coefficient was not differed when annual means were taken for calculations, when the bottom layers were excluded or when the two lake cruises were separated.

4. Discussion

Chlorophyll a, carbohydrate, lipid and protein levels were non-significantly differed among different regions of Lake Nasser ($P = 0.13$). In general, average chlorophyll a, carbohydrate, lipid and protein were 4.27 $\mu\text{g/l}$, 2.89 mg/l, 0.2 mg/l and 38.91 mg/l, respectively, in the main channel, 7.86 $\mu\text{g/l}$, 1.74 mg/l, 0.16 mg/l and 30.68 mg/l, respectively, in

Khor Tushka, whilst they were 4.2 $\mu\text{g/l}$, 1.34 mg/l, 0.28 mg/l and 39.36 mg/l, respectively, in Khor Dahmeit. Biochemical contents measured in Lake Nasser were similar to the levels measured in River Nile sub-branches and Ismailia Canal [22, 23]. Lipid and carbohydrates were lower than the ranges detected in Bardawill Lagoon, Wadi El-Rayan Lakes and River Nile and Aswan Reservoir [24, 25, 26]. It worth to mention that, chlorophyll a levels in Lake Nasser are lower than the values detected in these regions except Bardawill Lagoon. Responses of biochemical composition and chlorophyll a to the changes in nutrient concentrations were dissimilar in the studied regions in Lake Nasser depending on the location and time of sampling. For example, protein relationship with

nitrate-nitrogen and nitrite-nitrogen was positive in the main channel, but negative in Khor Tushka (Table 2). Protein results showed high significant relations with reactive phosphorus and ammonium-nitrogen in the khors, but had no relationship with both nutrient levels in the main channel. Similar trends were observed to the other biochemical contents as well as chlorophyll a (Table 2 and Figs. 2, 4 and 6). Such dissimilar responses of phytoplankton biomass and biochemical composition to different nutrient sources are often a resultant of many other parameters associated with nutrients such as photic conditions, zooplankton grazing pressure, lake morphometry, phytoplankton species composition and fish catch composition [27]. Change of phytoplankton response to nutrients may be explained by factors other than nutrients concentration which can regulate phytoplankton community growth [28]. Changes in microalgae biochemical composition are likely to occur as a result of variations in temperature, light, and metal contents [29, 30, 31]. Despite of several studies made in attempt to understand the potential effects of N and/or P limitations on microalgae biochemical composition changes, the phenomena seem to be species dependent [32].

The results of this study revealed a lack of correlation between chlorophyll a, in one hand, and reactive phosphorus and TIN, in the other hand. Earlier papers demonstrated a lack of correlation between chlorophyll and phosphorus concentrations in the Great Masurian Lakes system [33, 34]. In these lakes, concentrations of summer epilimnetic chlorophyll seem to be related neither to phosphorus nor to nitrogen, which suggests limitations other than nutrient control of algal abundance [35]. The uncoupling of chlorophyll a and nutrients (PO₄ and TIN) has two main explanations. Firstly, different levels of grazing pressure of zooplankton on algae are expected to affect chlorophyll–nutrients relationships [36, 37]. Lake Nasser and its khors are characterized by large cladocerans (macrozooplankton) as *Bosmina longirostris*, *Ceriodaphnia dubia*, *Chydorus sphaericus*, *Daphnia longispina* and *Diaphanosoma mongolianum*. Mesozooplankton were represented by adult copepods as *Cyclopoid Copepodite*, *Calanoid Copepodite* and *Thermodiaptomus galebi*, whereas micrometazoa were mostly represented by copepod nauplii [38]. Concerning zooplankton biomass, adult and nauplii of copepods constituted 53%, cladocera constituted 36.5%, whilst the rest was composed of rotifer and protozoa [39]. This size structure of zooplankton in Lake Nasser can exhibit different levels of grazing pressure on phytoplankton in the way that can affect chlorophyll a–nutrients relationships as reported in Schelde estuary, Western Europe [40]. The correlation between chlorophyll a and total phosphorus was especially low ($R^2 = 0.21$) during an intense growth of zooplankton represented mainly by the large rotifer *Asplanchna priodonta* [41].

The second explanation is the high concentrations of calcium. Levels of calcium can affect the chlorophyll–phosphorus relationship, as phosphorus at the level of 30 mg/l can accelerate the precipitation of phosphorus as calcium phosphate [42]. Calcium concentrations in Lake Nasser water were above 35 mg/l throughout the lake, whilst its concentrations in the sediment exceed the value of 14 g/kg of lake clay sediment [43, 44] the settling velocity starts to increase in lakes with Ca concentrations higher than 10 mg/l and behave more and more as hard water lakes [42]. At Ca concentrations in the range of 10–30 mg/l, the chlorophyll–phosphorus correlation is affected [42]. For lakes with calcium

concentrations higher than 30 mg/l, Ca co-precipitates with phosphorus at super saturation levels [45]. Even though daily sedimentation of particulate phosphorus is not calculated in Lake Nasser, it is expected that particulate matter settling in Lake Nasser is rich in allochthonous phosphorus. Water flood are very rich in colloidal particles, mainly clay and mud, which are very rich in calcium [43]. These colloidal particles with their high contents of calcium may increase the daily co-precipitate of dissolved phosphorus with calcium or in the form of calcium-bound particles with particulate phosphorus which increases phosphorus settlement especially in the southern and middle regions of the lake [43]. Similar results were reported in Lake Mikolajskie [41]. For the reasons listed above, chlorophyll could not linearly follow nutrient changes in Lake Nasser, and the chlorophyll–nutrient uncoupling lies in the intrinsic properties of each studied lakes.

5. Conclusion

Chlorophyll a, carbohydrate, lipid and protein levels were non-significantly differed among different regions of Lake Nasser, main channel and Khors, but were significantly differed between seasons. Biochemical contents measured in Lake Nasser were similar as the levels measured in many other regions in Egypt, whereas chlorophyll a levels were lower than the values detected in most areas in Egypt. Spearman correlation matrix and PCA analyses indicated that responses of phytoplankton biomass and biochemical composition to different nutrient sources are often a resultant of many other parameters associated with nutrients such as photic conditions, zooplankton grazing pressure, lake morphometry, phytoplankton species composition and fish catch composition. The results of this study revealed a lack of correlation between chlorophyll a and both reactive phosphorus and TIN in Khor Dahmeit, whereas slight correlations were found with reactive phosphorus in the main channel and Khor Tushka which explained by the effect of multiple grazing levels and high concentrations of calcium.

6. References

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