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The relationship between phytoplankton and fish in nutrient-rich shallow Lake Qarun, Egypt

by

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Abstract

The present study focused on the determination of the baseline data and correlations between biological and physicochemical variables, including the assessment of trophic conditions in Lake Qarun. The concentrations of nutrients were high, with the maxima usually in the east subarea (total nitrogen 6.40 mg dm^{-3}, mineral nitrogen 2.34 mg dm^{-3}, orthophosphates 0.22 mg dm^{-3}). A total of 134 phytoplankton species were recorded. Bacillariophyceae and Dinophyceae co-dominated spatially and seasonally in phytoplankton assemblages. The highest phytoplankton density (935 × 10^{4} cells dm^{-3}) and chlorophyll *a* content (69.3 µg dm^{-3}) were recorded in the east subarea of the lake, whereas the largest total and dominant fish (*Mugil cephalus* and *Solea* spp.) were in the west. *Tilapia zillii* and *Engraulis encrasicolus* were most abundant in the east and in the middle part, respectively. When phytoplankton density decreased from the east toward the west subarea, the Secchi disk depth increased. The TLI-based assessment indicated hypereutrophic waters at most sites of Lake Qarun. Statistically significant positive or negative correlations were found between the dominant fish species: *T. zillii* and *Solea* spp., and the phytoplankton density, Dinophyceae density, concentrations of TP, chlorophyll *a*, ammonium, nitrite and nitrate. Such correlations may be helpful to better understand how to enhance the sustainable fish production.

Key words: phytoplankton, chlorophyll *a*, nutrients, saline waters, fish, Egypt

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Introduction

Lake Qarun is considered to be the oldest natural lake in Egypt and is used as a natural reservoir of drainage water collected from irrigated cultivated lands in El-Fayoum (Fathi & Flower 2005). At present, Lake Qarun is a shrunken remnant of freshwater Lake Moeris (Ball 1939 cited in El-Shabrawy et al. 2015). Due to the impact of human activity, the lake water quality has been deteriorating as a result of increasing salinity (probably in connection with soil salinization) and eutrophication, caused by chemical fertilizer discharge. Water salinity, in particular, changed from slightly brackish to saline condition (35 PSU), with a seasonal fluctuation. The salinity can further increase with global warming (Abdel Wahed et al. 2014). Most freshwater fish originally occurred in the lake (Boraey 1980), but they gradually disappeared except for *Tilapia zillii*. The commercial catch decreased from 4,000 tons in 1920 to an average of 1,000 tons in subsequent years, resulting from fish disappearance. To compensate, the lake has been stocked with Mediterranean fish since the 1920s (El-Maghraby & Dowidar 1969). Based on the studies by Gabr (1998) and El-Shabrawy & Fishar (1999), the lake fisheries were also characterized by a large stock of native species: *Lates niloticus* (Nile perch), *Clarias anguillaris* (mudfish), *Labeo niloticus, Barbus bynni, Anguilla vulgaris* (common eel), *Tilapia zillii* (redbelly tilapia) and *Oreachromis niloticus* (Nile tilapia). The lake was then restocked with fish of marine origin, i.e. mullets (*Mugil cephalus, Liza ramada, L. saliens, L. aurata*), *Atherina mochon*, *Solea aegyptiaca* and marine prawns (Ishak et al. 1982, El-Shabrawy & Fishar 1999).

The lake was considered an important environment supporting the main fishing grounds and had a rich biological diversity, including birds, plants and fish (Fouda 2012). Since the early 20th century, the lake has been highly modified and gradually become ecologically unstable. For example, the physicochemical parameters documented by Shaaban et al. (1985), Gad (1992), Sabae & Rabeh (2000), Mansour & Sidky (2003), Abdel-Satar et al. (2010) indicated such changes. In biological studies, Abd El-Monem (2001), Mansour & Sidky (2003) and El-Shabrawy et al. (2015) presented considerable changes in plankton communities, and Abdel-Malek & Ishak (1980) and Fishar (2000) reported similar findings for benthic fauna. El-Shabrawy & Taha (1999) reported on the positive effect of zooplankton grazing pressure on phytoplankton assemblages in Lake Qarun.

The autotrophic pathway, including mainly phytoplankton, may be considered one of the food pathways, especially for the aquaculture systems. Most tilapias can feed on phytoplankton or periphyton and their fish-grazing activity can successfully reduce algae (Dempster et al. 1993; Dýkel et al. 2005; Abwao et al. 2014). In natural water bodies, the phytoplankton was found as a food component, e.g. diatoms, chlorophytes, cyanobacteria and dinophytes were identified in Nile tilapia's guts (Abd El-Karim et al. 2009). Fish may positively, directly or indirectly, affect the phytoplankton (Lacerot et al. 2013) or be closely correlated with chlorophyll *a* (Friedland et al. 2012). Comprehensive information on the environment, including physicochemical and biological relationships, may support further management of waters, where phytoplankton is fish's natural food (Hussian et al. 2015).

The aim of the present study was to describe the general features of the phytoplankton and fish communities in Lake Qarun and to assess the relationships between selected physicochemical and biological parameters and the variety of fish quality and quantity.

Materials and Methods

Site description

Lake Qarun is the major inland saline and turbid lake in the northern part of El-Fayoum Depression (central Egypt, ~80 km southwest of Cairo, at the margin of the Nile Valley, 29°30'N, 30°40'E). The length of this lake from east to west is about 40 km and the breadth at the widest point is about 6.7 km. The surface area of the lake is about 243 km^2, the volume is 924 million m^3 and it is located at 43 m below sea level (Anonymous 1995). The deepest point (8.3 m) is located in the northwest. The non-irrigated northern shores of the lake are virtually devoid of vegetation and mark the beginning of the Western Egyptian Desert. The lake has no connection with the sea, being located 320 km south of the Mediterranean coast of Egypt, and is directly supported by the Nile River via the Bahr Yussef canal. Since the early 18th century, the lake has received mainly agricultural wastewater (Anonymous 1995). An increase in the water level can be attributed to the leakage from adjacent groundwater aquifers and from the Wadi El-Rayan Depression (El-Sayed & Guindy 1999; Mansour & Sidky 2003). The total water draining annually into the lake is about 395 million cubic meters (data provided by the Irrigation Department, El-Fayoum). Previously, the lake supported a moderate level of fisheries and caused a decline in water quality (Meininger & Atta 1994).

Sampling sites

Water samples were collected seasonally from the subsurface water layer using a 1.5 dm^3 Ruttner sampler from ten sites in Lake Qarun in winter (February), spring (May), summer (August) and in autumn (September) 2012. The lake comprises three main subareas, where water-sampling sites 1, 2 and 3 represent the east, while 4, 5, 6 and 7 represent the middle and 8, 9 and 10 represent the west of the lake (Fig. 1). The fish catch in the lake was carried out at 11 landing sites (Senoris, Abu-Neema, Shakshouk, Abu-Soliman, Abu-Shanab, Kahk, El-Lokanda, El-Rawashdia, El-Saaida, Ayuob and Qarun, from east to west respectively), located in the southern part of the lake. The landing sites 1-3 belong to the east, sites 4-8 to the middle and 9-11 to the west subareas.

Physicochemical analysis

During sampling, pH was measured using an Orion Research Ion Analyzer (399A), electrical conductivity – using a conductivity meter (S.C.T.33 YSI), salinity – a portable Hydro Lab equipment, mod. Multi 340I/SET WTW, transparency – a black-white Secchi disk and water temperature – an ordinary thermometer. Water samples were analyzed according to the APHA (1996) procedures. Colorimetric techniques were used for the analysis of nutrients: formation of a reddish purple azo-dye for NO_2, Cd reduction for NO_3, the phenate method for NH_4 and stannous chloride reduction for PO_4. Total nitrogen and total phosphorus (after mineralization) were also analyzed colorimetrically.

A defined volume of water was filtered through a glass microfiber filter (GF/F) and the filter with

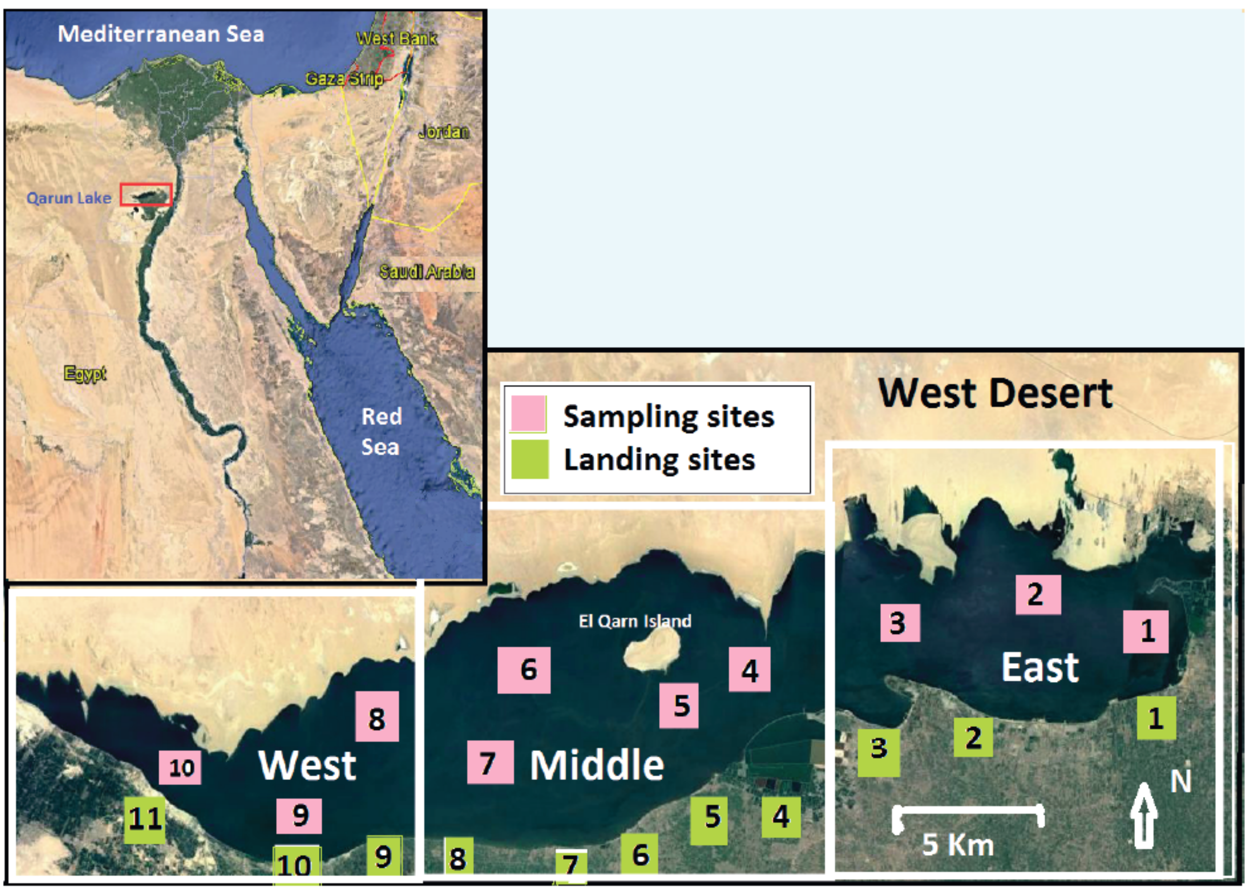

Figure 1

The water sampling sites in the east – sites 1, 2, 3, the middle – sites 4, 5, 6, 7 and the west subarea – 8, 9, 10 in Lake Qarun in 2012, and the main landing sites for fish catch: 1) Senoris, 2) Abu-Neema, 3) Shakshouk, 4) Abu-Soliman, 5) Abu-Shanab, 6) Kahk, 7) El-Lokanda, 8) El-Rawashdia, 9) El-Saaida, 10) Ayuob and 11) Qarun residue was then foiled and refrigerated for pigment analyses. The chlorophyll *a* (Chl *a*) concentration retained on filters was extracted in acetone (90%) overnight and then prepared and measured spectrophotometrically and calculated by applying the trichromatic equation. The Chl *a* was chosen as the best descriptive parameter of the total phytoplankton biomass.

Phytoplankton analysis

The phytoplankton samples were preserved with 4% neutral formalin and Lugol's iodine solution (Margalef 1974) and then transferred into a glass cylinder. Phytoplankton cells settled for 5 days (APHA 1996). The phytoplankton samples were then siphoned and concentrated to a fixed volume and transferred to plastic vials for microscopic examination. The drop method was applied to count and identify the phytoplankton species. Triplicate samples (5 µl) were taken and examined under an inverted microscope at magnifications of 400× and 1000×. The identification of taxa followed e.g. Huber-Pestalozzi (1961, 1983), Komárek & Anagnostidis (1986, 1989, 1999), Krammer & Lange-Bertalot (1986, 1988, 1991a, 1991b), Anagnostidis & Komárek (1988), Popovský & Pfiester (1990).

Fish analysis

Thirteen field trips were conducted in the three subareas in 2012, in December and February (referred to as winter) and in July and September (referred to as summer) and 78 fishermen were interviewed. The fishing season in the lake lasted throughout the year except for 3 months (January, May and June) as a fishery management plan. The fish catch and species composition in each subarea were investigated. Fish from different types of fishing gears and methods were collected and identified to the species level according to Whitehead et al. (1986) and FishBase (2012).

Statistical and numerical analysis

Non-parametric methods (due to lack of normally--distributed data) were applied to test the significant changes of environmental variables in Lake Qarun using the Kruskal-Wallis test. The relationships between physicochemical and biological variables in Lake Qarun were confirmed by calculating the Spearman's rank correlation coefficient with STATISTICA version 10. The percent similarity of phytoplankton taxa was determined based on a cluster analysis (Multi-Variate Statistical Package, Kov. Comp. Serv. 1985-2009). As predicted, the relationships were statistically significant at the significance level of 0.05.

The trophic state of Lake Qarun was determined based on the Trophic Level Index (TLI) (Burns et al. 2005), which includes four partial modules based on the Secchi disk depth (SDD) and the concentrations of chlorophyll *a* (Chl-*a*), total phosphorus (TP) and total nitrogen (TN). The final TLI is an average from values obtained separately for each module: TLI_{SDD}, TLI_{Chl}, TLI_{TP} and TLI_{TN}. Models of the annual physicochemical and biological changes were determined from transformed data on phytoplankton density, chlorophyll *a* concentration, Secchi disk depth, total and dominant fish catches from all sampling sites.

Results and Discussion

Physicochemical variables

Lake Qarun is a saline inland lake characterized by a significantly differentiated salinity (K-W test, p=0.001) across the lake, which varied between 11.1 PSU and 37.8 PSU during the study period of 2012, with some increasing tendency from the east to west subareas. The electrical conductivity (EC, 16.5-49.1 mS cm^{-1}) and the mineral forms of N and P were statistically significantly differentiated between the sampling sites (Fig. 2). Similar findings with a high EC and large spatial variability in nitrite, nitrate and ammonium concentrations were recorded in August 2011 (El-Shabrawy et al. 2015). The lowest values of EC were related to the highest total nitrogen (max 6.45 mg dm^{-3}), mineral nitrogen (the sum of nitrite, nitrate and ammonium; max 2.34 mg dm^{-3}) and total phosphorus (max 0.63 mg dm^{-3}) concentrations and the lowest salinity at sites 1 and 7, i.e. the east and middle subareas, respectively. The separation of nutrient-rich sites 1 and 7 from the others is connected with the agricultural water discharge from the drainage systems of El-Bats and El-Wadi mentioned by El-Shabrawy et al. (2015). Regarding such a division of areas, the Secchi disk depth (0.3-1.5 m) significantly increased (K-W test, p=0.010), whereas the chlorophyll *a* concentration (2.7-69.3 µg dm^{-3}) significantly decreased (K-W test, p=0.004) along the sites i.e. from east to west. The water temperature ranged from 12.1 to 29.1°C and pH varied from 7.9 to 8.6. The other parameters were approximately similar. According to the TLI-system (a trophic state monitoring tool) proposed by Parparov et al. (2010), the assessment indicated hypereutrophic waters at almost all sampling sites in Lake Qarun, excluding sites 6 and 8 (eutrophic) (Table 1). Such a high trophic level was caused

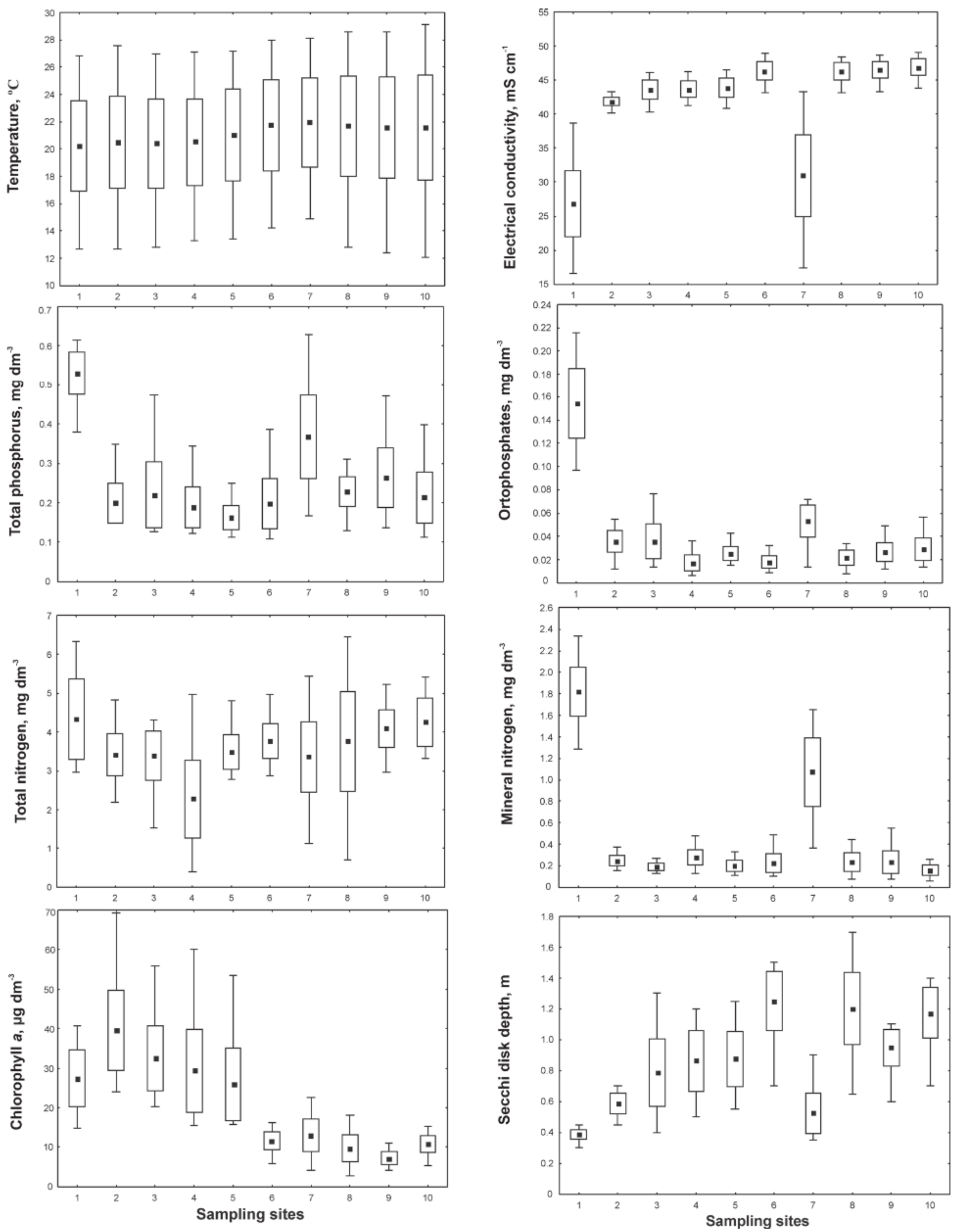

Figure 2

Environmental parameters (mean, mean±standard error, min.-max) in Lake Qarun in 2012, the codes of 10 sampling sites were given in Fig. 1

Table 1

The trophic-level based (TLI – Trophic Level Index) assessment of Lake Qarun in 2012 compared to partly available data on SDD, TP and TN from 1995 to 2006[1]

Subareas	Sites[2]	TLI_{SDD}	TLI_{Chl}	TLI_{TP}	TLI_{TN}	TLI	Trophic state
East	1	6.03	5.87	8.17	8.08	7.04	HYP
	2	5.61	6.28	6.93	7.02	6.46	HYP
	3	5.32	6.06	7.06	7.02	6.36	HYP
Middle	4	5.22	5.95	6.86	6.49	6.13	HYP
	5	5.21	5.81	6.67	7.05	6.19	HYP
	6	4.85	4.92	6.92	7.15	5.96	EUT
	7	5.72	5.05	7.71	7.00	6.37	HYP
West	8	4.89	4.74	7.10	7.15	5.97	EUT
	9	5.13	4.40	7.28	7.26	6.02	HYP
	10	4.91	4.85	7.02	7.31	6.02	HYP
1995	average for the whole lake	5.69	-	6.29	8.05	6.68[4]	HYP
1999-2000		5.59	-	6.82	-	6.21[4]	HYP
2003		5.68	-	7.71	-	6.70[4]	HYP
2006		5.57	-	8.30	-	6.94[4]	HYP
2012[3]		5.23	5.56	7.25	7.17	6.30	HYP

[1]Based on data cited in El-Shabrawy & Dumont (2009), Satar et al. (2010) and El-Shabrawy et al. (2015)

[2]The codes of sites' names are given in Fig. 1, TLI – the trophic level index based on Secchi disc depth – TLI_{SDD}, chlorophyll *a* concentration – TLI_{Chl}, total phosphorus concentration – TLI_{TP}, total nitrogen concentration – TLI_{TN}, HYP – hypereutrophic, EUT – eutrophic according to Parparov et al. (2010), – no data

[3]Average per lake based on the current data

[4]Average of available partial TLI

mainly by high concentrations of TN and TP, which is consistent with findings from other water bodies (Napiórkowska-Krzebietke et al. 2013, Napiórkowska-Krzebietke & Dunalska 2015). Comparing the data on nutrient enrichment in Lake Qarun, summarized by El-Shabrawy & Dumont (2009), Abdel-Satar et al. (2010) and El-Shabrawy et al. (2015), a clear increasing trend occurred in the concentrations of nitrites, nitrates, ammonium, orthophosphates and total phosphorus from 1955 to 2006. The assessment of trophic conditions also indicated a more advanced eutrophic level of this lake in the period of 1995-2006 (Table 1).

Phytoplankton density and composition

In total, 134 species were recorded in Lake Qarun, including 60 species of Bacillariophyceae, 35 species of Chlorophyceae, 13 species of Cyanophyceae, and less than 10 species each of Dinophyceae, Chrysophyceae, Cryptophyceae and Euglenophyceae. Previous studies suggested that the species richness was much lower, e.g. in 2001 only 49 phytoplankton taxa were recorded (Fathi & Flower 2005).

The phytoplankton density in Lake Qarun ranged from 75 to 140 × 10^4 cells dm^{-3} in the spring (Fig. 3A). A similar density was noted in autumn. The most abundant phytoplankton was observed in summer and winter – its density reached 935 × 10^4 cells dm^{-3} and 815 × 10^4 cells dm^{-3}, respectively. The annual phytoplankton growth in Lake Qarun indicated the enhanced density in its east subarea and a decreasing tendency toward the west subarea with the minimum at site 8. The spatial variation of the phytoplankton density could refer to local trophic conditions, especially inflows of contaminants (Abdel-Satar et al. 2010). Such findings are reported for large lakes situated within urban or agricultural catchments (e.g. Dembowska et al. 2015). Comparing the annual variation in phytoplankton taxonomic composition at the class level, Bacillariophyceae and Dinophyceae co-dominated in phytoplankton assemblages (Fig. 3B), with a similar decreasing tendency toward the west as it was observed in the total density. The highest contribution of Dinophyte was recorded at the first site, and diatoms dominated in assemblages at the other sites in the Bacilariophyceae:Dinophyceae ratio of up to 3:1 (site 9). Furthermore, such a large difference between sites 1-5 and 6-10 was confirmed by the cluster analysis based on the percentage similarity in the taxonomic structure (Fig. 4).

The seasonal variation of phytoplankton structure indicated that diatoms predominated in spring and winter, whereas dinophytes predominated in summer assemblages (Fig. 5). In autumn, both groups co-dominated. The contribution of other groups was much smaller, with a distinct and seasonally similar presence of Chlorophyceae and Cyanophyceae. Bacillariophyceae were dominated by *Cyclotella glomerata* Bach. (up to 37.2% of the total density), *C. operculata* (C.Agardh) Bréb. (up to

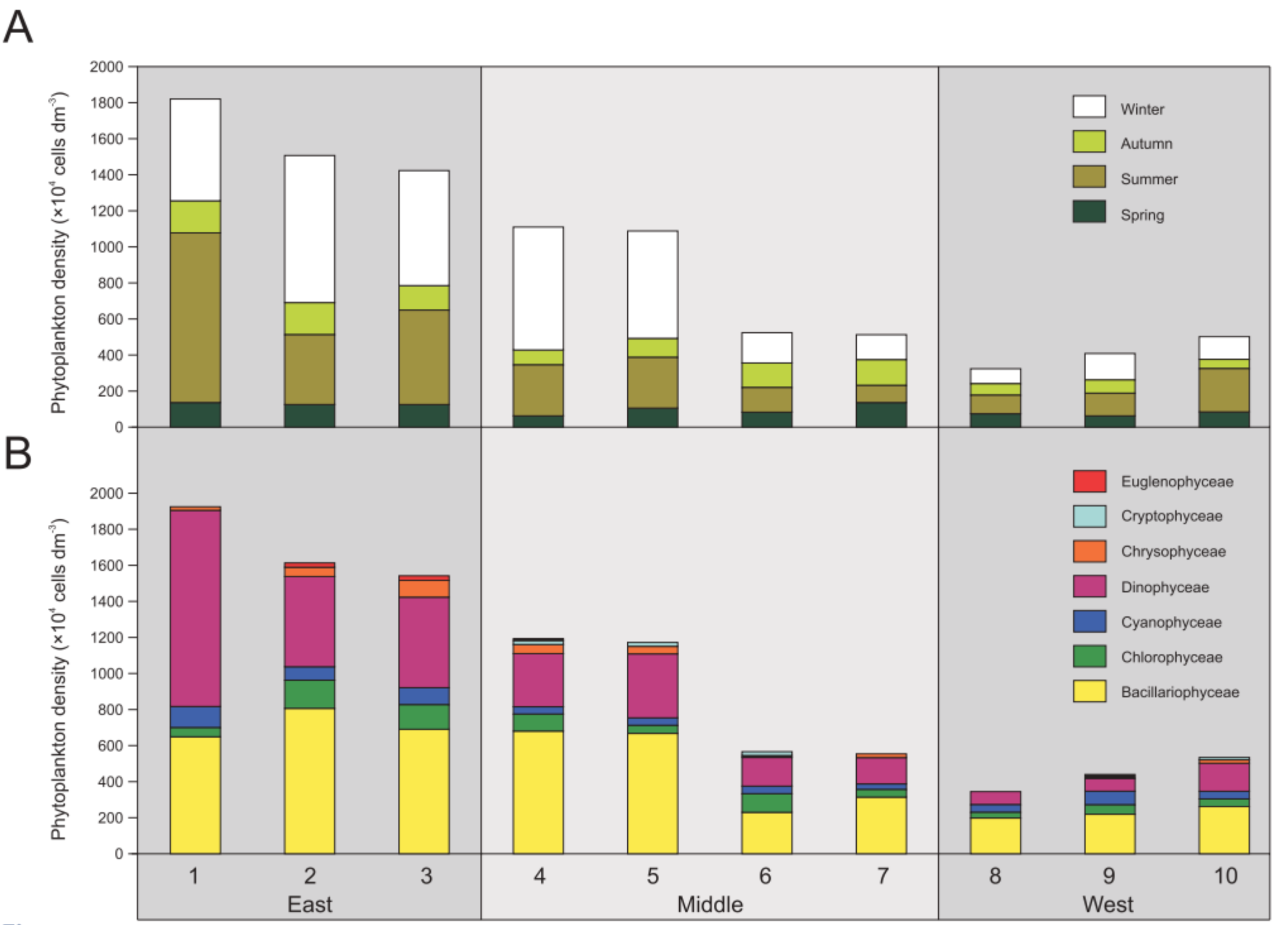

Figure 3

The annual phytoplankton density (A) and its composition (B) in Lake Qarun in 2012, the codes of 10 sampling sites were given in Fig. 1

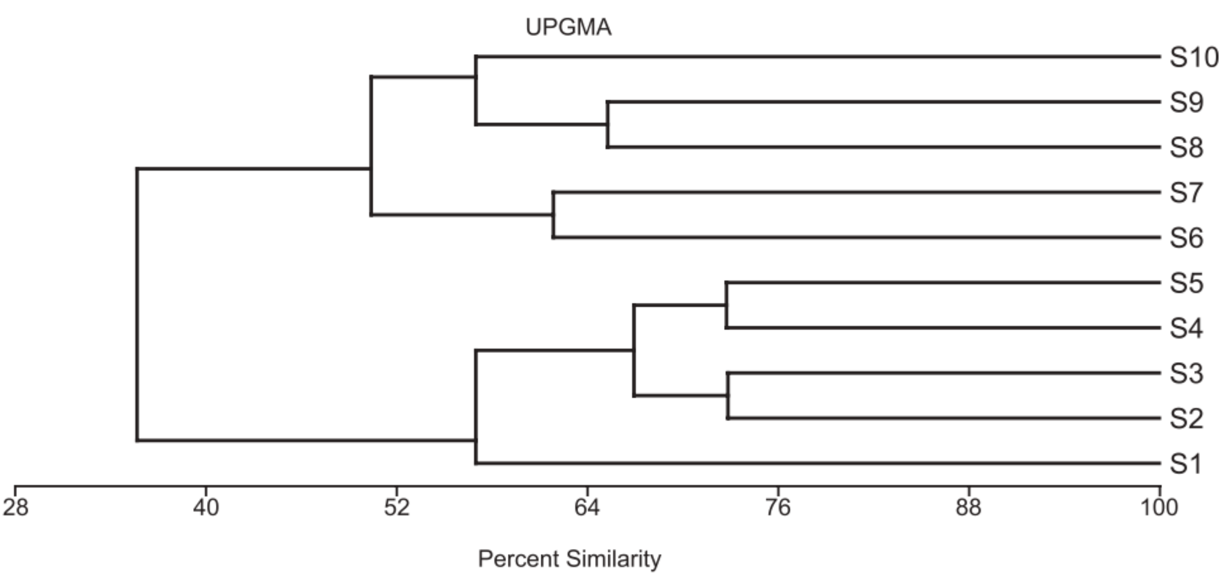

Figure 4

Cluster analysis based on phytoplankton taxa similarity in Lake Qarun in 2012, the codes of S1-10 sampling sites were given in Fig. 1

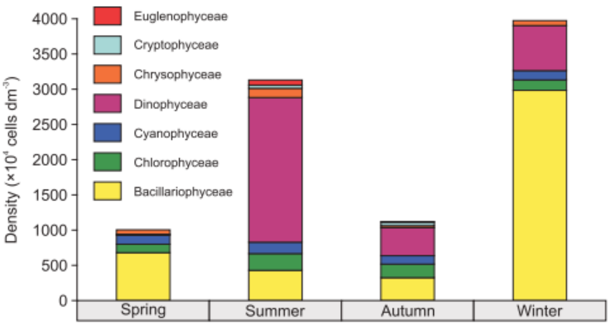

Figure 5

Seasonal structure of phytoplankton in Lake Qarun in 2012

22.2%), *Lindavia ocellata* (Pant.) T. Nakov et al. (up to 20.2%), *L. kuetzingiana* (Thwait.) T. Nakov et al. (up to 12.0%) and *Ulnaria ulna* (Nitzsch) P. Comp. (up to 25.0%) (Table 2). These species abundantly occurred mainly in spring and winter. The small-sized *Cyclotella* have generally low nutrient and temperature requirements (Brettum, Andersen 2005). The species were also described as dominants in other Egyptian lakes (Gharib & Abd El-Halim 2006; Hussian et al. 2015). The second predominant class was Dinophyceae, which was mostly represented by *Nusuttodinium aeruginosum* (F. Stein) Y. Tak. & T. Hor. and *Prorocentrum micans* Ehr. with the maximum density of 77.5% and 46.4% (of the total density) in summer and autumn, respectively. Chlorophyceae were dominated by e.g. *Chlamydomonas globosa* J. W. Snow, *Crucigenia tetrapedia* (Kirch.) Kuntze and *Schroederia nitzschioides* (G. S. West) Korsch. Among Cyanophyceae, chroococcales *Aphanocapsa elachista* var. *conferta* West & G. S. West and *Chroococcus dispersus* (Keiss.) Lemm. were most abundant, whereas *Mallomonas ploesslii* Perty and *Mallomonas helvetica* Pasch. were most abundant among Chrysophyceae.

Fish community

The main fishing gear used in the lake were trammel nets, beach seines, handlines and traps. There were four types of trammel nets which differed in their design, characters, dimensions and mesh sizes according to their target species. The first trammel net (Ghazl Bolti) targeted mainly tilapias, particularly *Tilapia zillii*. This worked effectively in the east and middle subarea of the lake. The second trammel net (Ghazl Bory), which targeted *Mugil cephalus* worked mainly in the northern part of the lake and in deeper water. The third trammel net (Ghazl Mossa) was set mainly on the bottom to catch sole fish, e.g. *Solea solea* and *S. aegyptiaca*. It operated mainly in the middle and western part of the lake. The fourth trammel net (Ghazl Fahhar) targeted mullet fish species, other than *M. cephalus*, such as *Liza ramada*, *L. aurata* and *L. saliens*. It was mainly active in the middle subarea. Beach seines with two main types, Gorafet Bory and Gorafet Zardina, were also set in the lake. Gorafet Bory targeted mainly *M. cephalus* and it operated in the northern beach of the lake, while Gorafet Zardina was present mostly in the southern beach and targeted anchovy. Other fishing gears, handlines and traps targeted mostly *T. zillii* in the eastern and middle subarea.

The total catch of fish and seafood was estimated using the yearbook statistics of GAFRD (2013). A significant increase in the Lake Qarun catch was recorded from 2003 to 2012 (excluding 2006) (Fig. 6). By analogy, an increasing trend of the total national production

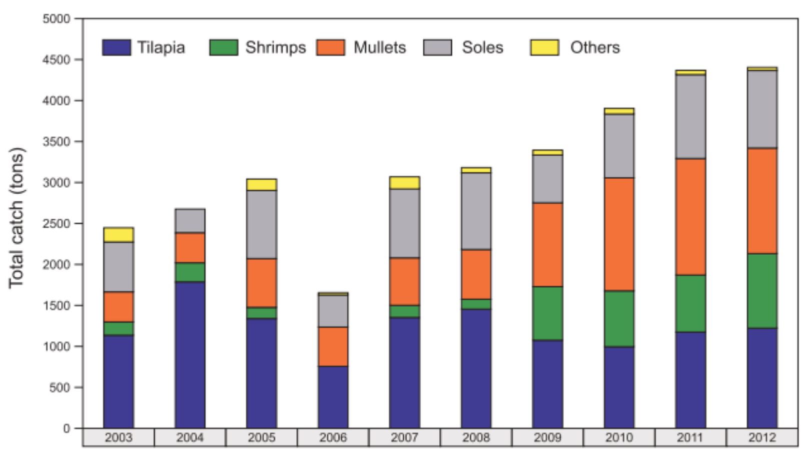

Figure 6

Fish and seafood catches from Lake Qarun and their composition during the period of 2003-2012 according to GAFRD (2013)

Table 2

Dominant species in phytoplankton assemblages in Lake Qarun in 2012

Species*	Sampling sites**									
	1	2	3	4	5	6	7	8	9	10
Spring										
Aphanocapsa elachista var. *conferta* West & G. S. West	+	+	+	-	+	+	-	-	-	+
Aulacoseira granulata (Ehr.) Sim.	-	-	-	-	-	+	+	+	+	+
Chroococcus dispersus (Keiss.) Lemm.	-	-	-	-	-	+	-	+	+	-
Coscinodiscus lacustris Grun.	+	+	+	-	+	+	+	+	+	+
Cosmarium nitidulum De Notaris	-	-	-	+	+	-	+	-	-	+
Crucigenia tetrapedia (Kirch.) Kuntze	+	-	+	+	+	-	-	+	+	-
Cyclotella glomerata Bach.	+	+	+	+	-	+	-	+	+	+
Cyclotella operculata (C. Agardh) Bréb.	-	-	-	-	-	-	+	+	+	+
Desmodesmus protuberans (F. E. Fritsch & M. F. Rich) E. Heg.	-	+	+	-	+	+	+	-	-	-
Gomphonema truncatum Ehr.	+	+	+	+	+	+	-	+	+	+
Lindavia kuetzingiana (Thwait.) T. Nakov et al.	+	+	+	-	+	-	+	-	-	-
Lindavia ocellata (Pant.) T. Nakov et al.	+	-	-	-	-	+	-	-	-	-
Mallomonas ploesslii Perty	-	+	-	-	-	+	-	+	-	+
Mallomonas sp.	+	-	+	+	+	-	-	-	-	-
Navicula dicephala Ehr.	-	-	-	+	+	-	+	-	-	+
Nitzschia acicularis (Kütz.) W. Smith	+	-	+	+	+	+	+	-	-	+
Ulnaria ulna (Nitzsch) P. Comp.	+	+	+	+	+	+	-	+	+	+
Summer										
Cosmarium sp.	-	-	+	+	-	-	-	-	+	+
Cyclotella glomerata Bach.	-	-	-	-	-	-	-	+	+	+
Lindavia ocellata (Pant.) T. Nakov et al.	-	-	+	+	+	+	+	+	-	+
Mallomonas helvetica Pasch.	+	+	+	+	-	-	-	-	-	-
Mallomonas sp.	-	-	-	-	+	-	-	-	-	+
Nusuttodinium aeruginosum (F. Stein) Y. Tak. & T. Hor.	+	+	+	+	+	+	-	+	+	+
Parvodinium pusillum (Penard) S. Carty	+	+	+	+	+	-	-	-	-	+
Parvodinium umbonatum (Stein) S. Carty	+	+	+	+	+	+	-	+	-	+
Prorocentrum micans Ehr.	+	+	+	+	+	+	+	+	+	+
Rhabdoderma lineare Schmid. & Laut.	-	-	-	-	-	-	-	-	+	-
Schroederia nitzschioides (G. S. West) Korsch.	-	+	+	+	+	+	+	-	-	-
Ulnaria ulna (Nitzsch) P. Comp.	+	+	+	-	+	+	+	-	-	+
Autumn										
Achnanthidium minutissimum (Kütz.) Czarn.	-	-	-	+	-	+	-	-	-	+
Amphora ovalis (Kützing) Kützing	-	-	-	+	-	-	-	-	-	-
Aphanocapsa elachista var. *conferta* West & G. S. West	+	+	+	-	+	-	+	+	+	-
Aulacoseira granulata (Ehr.) Sim.	+	-	-	+	-	-	+	-	+	+
Chlamydomonas globosa J. W. Snow	-	+	+	+	+	+	-	-	+	+
Chroococcus dispersus (Keiss.) Lemm.	+	-	-	-	-	-	+	+	-	-
Cosmarium nitidulum De Notaris	-	-	+	-	-	-	-	+	-	+
Cyclotella glomerata Bach.	-	-	+	+	-	+	-	-	-	-
Lindavia ocellata (Pant.) T. Nakov et al.	+	+	+	-	-	+	+	+	+	-
Mallomonas ploesslii Perty	-	-	-	-	+	-	+	-	-	-
Prorocentrum micans Ehr.	+	+	+	+	+	+	+	+	+	+
Prorocentrum scutellum Schröd.	-	+	+	-	+	-	+	-	-	+
Scenedesmus quadricauda (Turp.) Bréb.	+	-	-	-	-	-	-	+	-	-
Thalassiosira leptopus (Grun. ex Van Heurck) Hasle & G. Fryx.	-	-	-	-	+	-	+	+	+	-
Trachelomonas dubia Svir. [Swir.]	-	+	+	-	-	-	-	-	-	-
Ulnaria ulna (Nitzsch) P. Comp.	+	-	+	+	+	+	-	+	+	+
Winter										
Conticribra guillardii (Has.) K. Stach.-Such. & D. M. Will.	-	-	-	+	+	+	+	+	+	+
Cosmarium nitidulum De Notaris	-	-	-	-	-	+	+	+	-	+
Cyclotella glomerata Bach.	+	+	+	+	+	-	+	-	+	+
Cyclotella meneghiniana Kütz.	+	+	+	+	+	+	+	+	-	+
Cyclotella operculata (C. Agardh) Bréb.	+	+	+	+	+	+	+	-	+	+
Cyclotella schroeteri Lemm.	-	-	-	+	+	+	-	-	-	+
Gymnodinium colymbeticum T. M. Harris	+	+	+	+	+	+	+	+	+	+
Lindavia ocellata (Pant.) T. Nakov et al.	-	+	+	+	+	-	+	+	-	-
Prorocentrum micans Ehr.	+	+	+	+	+	+	+	+	+	+
Prorocentrum scutellum Schröd.	+	+	+	+	+	+	+	+	-	-
Staurastrum paradoxum Mey. ex Ralfs	-	-	-	-	-	+	+	+	+	-
Ulnaria ulna (Nitzsch) P. Comp.	+	+	+	+	+	+	+	+	+	+

* the currently accepted taxonomical names of species according to Guiry & Guiry (2016), ** the codes of 10 sampling sites were given in Fig. 1, + present, - absent.

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was also recorded in Egypt (Samy-Kamal 2015). According to El-Serafy et al. (2014), the fish production level in Lake Qarun is rather low compared to other Egyptian lakes. During the 2012 fishing season, the total catch in Lake Qarun was estimated at 4410 tons according to GAFRD (2013). In winter, the catch was 1731 tons (ca. 39.35%), and 2679 tons (ca. 60.7%) in summer. The catch in the lake was composed mainly of tilapias (dominant *T. zillii* while *Oreochromis aureus, O. niloticus* and *Sorthedon galileous* were sporadic), mullets (*M. cephalus*, *L. saliens*, *L. ramada* and *L. aurata*), soles (*Solea solea* and *S. aegyptiaca*), sea-bream (*Sparus auratus*), sea-bass (*Decintrarachus labracus*), anchovy (*Engraulis encrasicolus*) and shrimps (*Metapenaeus stebbingi* and *Penaeus semisulcatus*). The species composition in the whole lake was seasonally recorded as follows: in winter, the dominant species were tilapias (mainly *T. zillii*), soles (*S. solea* and *S. aegyptiaca*), mullets (*M. cephalus*, *L. saleins, L. aurata* and *L. ramada*) and shrimps (*M. stabbingii* and *P. semisulcatus*), which contributed about 32.1%, 25.0%, 24.6% and 17.2% of the lake catch, respectively. The sea-bass, eels (*Anguilla anguilla*) and others (*E. encrasicolus* and *Gubius niger*) each contributed below 1%. In summer, the catch composition showed a higher species diversity and included mullets (32.0%), tilapias (25.0%), shrimps (22.9%), soles (19.2%), *D. labracus* (0.3%), eels (0.1%), *Siganus luridus* (0.1%), *S. auratus* (0.1%) and other species (0.3%). Similar fish and shrimp taxa were also frequently recorded in the national catch composition in Egypt (Samy-Kamal 2015).

The fish and seafood catches in Lake Qarun according to subareas are presented in Table 3. The production of the east subarea was about 27.2% (1199 tons) of the annual lake catch (11.3% in winter and 15.9% in summer). The middle subarea produced about 35.7% (1573.7 tons), most of which (26.0%) was caught in winter and the rest in summer. The catch of the west subarea accounted for about 37.1% (1637.3 tons) of the lake catch (about 30.0% in summer and about 7.1% in winter).

The fish species structure was differentiated in subsequent subareas. In the east subarea, *T. zillii* (67.2%), *Solea* spp. (17.2%) and *M. cephalus* (13.9%) accounted for over 98% of the total catch in winter, similar to the summer catch (*T. zillii* – 49.7%, *M. cephalus* – 37.3% and *Solea* spp. – 12.4%) (Fig. 7). In the middle subarea, the dominant species were mainly *E. encrasicolus* (39.1%), *M. cephalus* (26.1%) and *T. zillii* (9.0%) in winter, while *T. zillii* (65.7%), *Solea* spp. (25.3%)

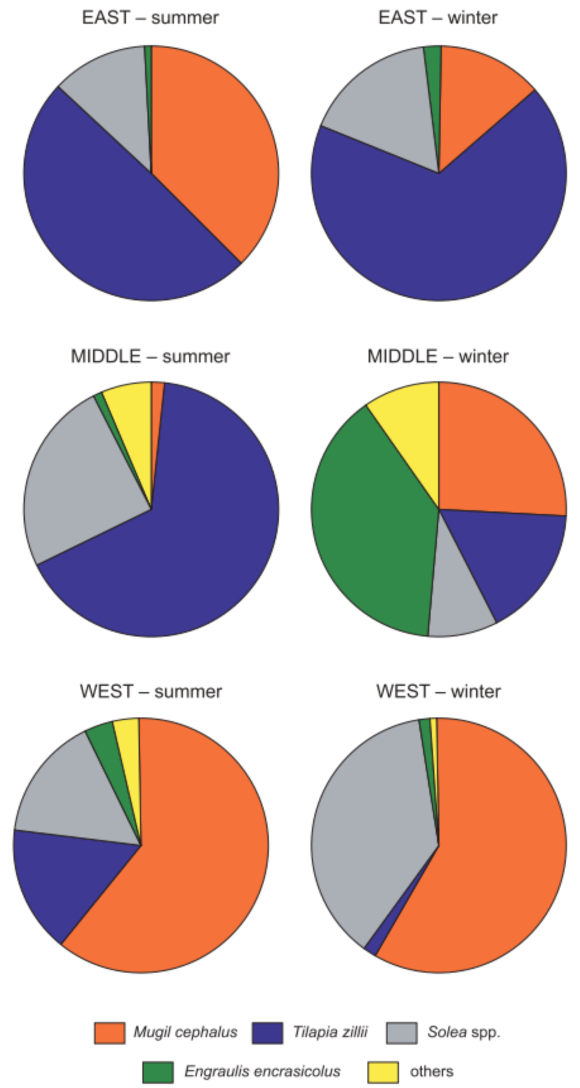

Figure 7

Seasonal variation of catch composition in the east, middle and west subarea of Lake Qarun during the fishing season of 2012 according to GAFRD (2013)

Table 3

Seasonal variation in fish and seafood catches in subareas of Lake Qarun in 2012

Subarea	East		Middle		West		Total
Season	winter	summer	winter	summer	winter	summer	
Catch, ton	500.0	699.0	1146.7	427.0	314.7	1322.6	4410.0
Catch, %	11.34	15.85	26.00	9.68	7.14	29.99	100.0
Subarea, %	27.19		35.68		37.13		

and *L. saliens* (6.1%) in summer. In the west subarea, *M. cephalus* (58.0%) and *Solea* spp. (38.7%) co-dominated in winter, and *M. cephalus* (60.7%), *T. zillii* (16.4%) and *Solea* spp. (16.0%) co-dominated in summer.

Physicochemical and biological relationships

The highest phytoplankton density and chlorophyll *a* concentrations were recorded in the east subarea (Fig. 8A). The highest water transparency was recorded in the middle (site 6) and in the west part (site 8), whereas the lowest transparency was determined in the east subarea (site 1). The maximum nutrient concentrations were recorded at site 1 (mineral nitrogen and orthophosphates) and site 7 (total phosphorus), characterized by the strongest exposure to pollutants (El-Shabrawy et al. 2015). The largest total catch of fish and seafood, with *M. cephalus* as a dominant fish, came from the west subarea in summer (Fig. 8B), along with the lowest phytoplankton. Similar results were found for some Polish lakes, where conditions with less abundant phytoplankton and high oxygen concentrations were suitable for some coregonids (Napiórkowska-Krzebietke et al. 2016). Furthermore, the peak of phytoplankton density was accompanied by a decline in the fish catch in the east subarea.

The correlations between the physicochemical and biological variables in Lake Qarun were tested with Spearman's rank correlation coefficient and are presented in Table 4. The large catch of *M. cephalus* was significantly correlated with the total catch in Lake Qarun (R=0.829). The second dominant fish, i.e. *T. zillii* was significantly positively correlated with Dinophyceae, concentrations of TP and ammonium, TLI and pH. Statistically significant negative correlations were found between *Solea* spp. and the total phytoplankton density, Dinophyceae density and the concentrations of chlorophyll *a*, nitrite and nitrate. Salinity and electrical conductivity were significantly positively correlated with *Solea* spp. In addition, the relationship between other fish species and orthophosphates was statistically significant, but negative.

In Lake Qarun, four major groups: mullets, soles, tilapias and shrimps (with different diet preferences and direct/indirect pressure on phytoplankton) have been recorded in the total catch for many years. Mullets can be detritivorous (Porter et al. 1996), benthivorous (Cardona & Castelló 1989)

Table 4

Statistical relationships (R-Spearman correlation coefficient) between physicochemical and biological variables in Lake Qarun

Variables	Total catch	*Mugil cephalus*	*Tilapia zillii*	*Solea* spp.	*Engraulis encrasicolus*	Others
Total catch	-	0.829	n.s.	n.s.	n.s.	n.s.
Mugil cephalus	0.829	-	n.s.	n.s.	n.s.	n.s.
Tilapia zillii	n.s.	n.s.	-	n.s.	n.s.	n.s.
Solea spp.	n.s.	n.s.	n.s.	-	n.s.	n.s.
Engraulis encrasicolus	n.s.	n.s.	n.s.	n.s.	-	n.s.
Other fish species	n.s.	n.s.	n.s.	n.s.	n.s.	-
Phytoplankton density	n.s.	n.s.	n.s.	-0.943	n.s.	n.s.
Bacillariophyceae	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Dinophyceae	n.s.	n.s.	0.943	-0.829	n.s.	n.s.
Chlorophyll *a*	n.s.	n.s.	n.s.	-0.943	n.s.	n.s.
Total nitrogen	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Total phosphorus	n.s.	n.s.	0.943	n.s.	n.s.	n.s.
Secchi disk depth	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Trophic Level Index	n.s.	n.s.	0.943	n.s.	n.s.	n.s.
Ammonium	n.s.	n.s.	0.829	n.s.	n.s.	n.s.
Nitrite	n.s.	n.s.	n.s.	-0.829	n.s.	n.s.
Nitrate	n.s.	n.s.	n.s.	-0.812	n.s.	n.s.
Orthophosphate	n.s.	n.s.	n.s.	n.s.	n.s.	-0.943
Temperature	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Salinity	n.s.	n.s.	n.s.	0.829	n.s.	n.s.
pH	n.s.	n.s.	0.829	n.s.	n.s.	n.s.
Electrical conductivity	n.s.	n.s.	n.s.	0.829	n.s.	n.s.

*statistically significant correlation, $p<0.05$, $n = 40$, n.s. – not significant

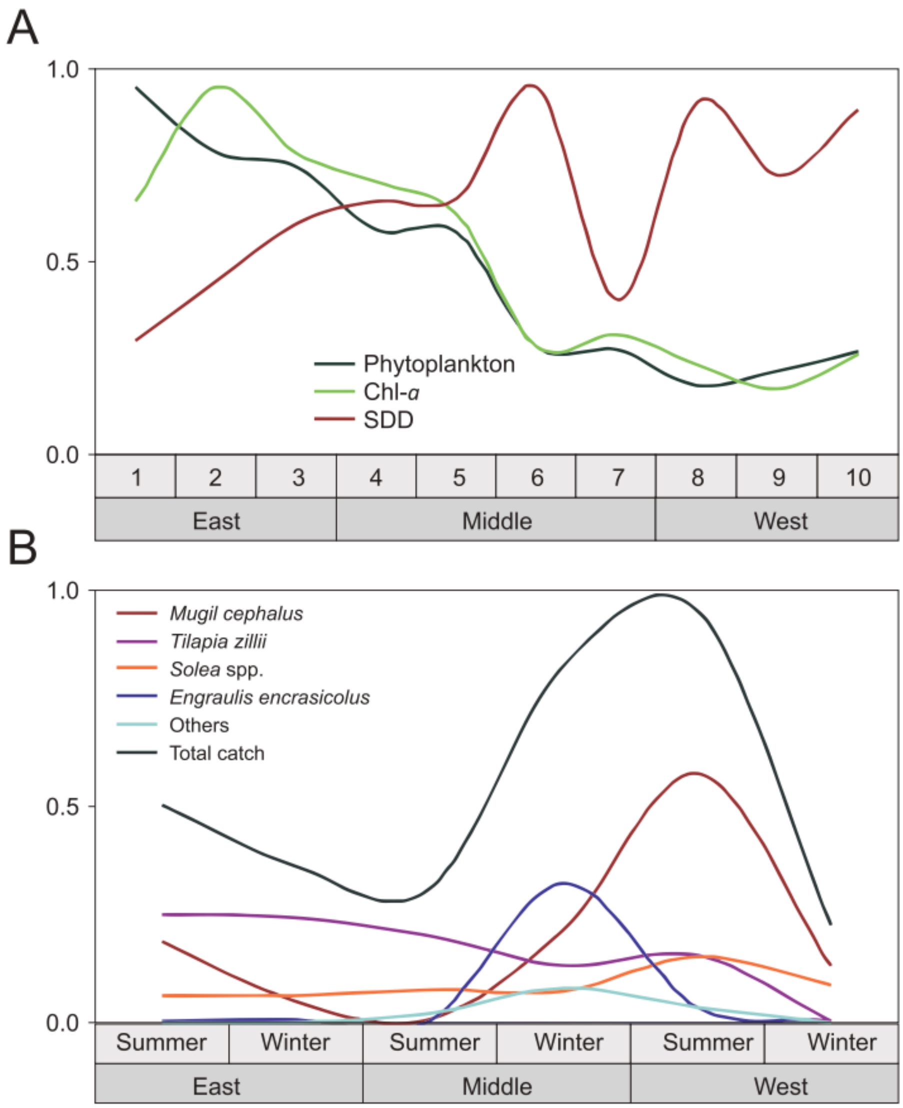

Figure 8

Models (optimal trend lines) of changes in phytoplankton, chlorophyll *a* and Secchi disk depth at the study sites (A) and the total catch with dominant fish in summer and winter (B) in three subareas of Lake Qarun

and planktivorous (Cardona et al. 1996; Torras et al. 2000; El-Shabrawy & Khalifa 2007). Abdel-Malek (1980) found that the lake mullet (*Mugil cephalus*, *Liza saliens, L. aurata* and *L. ramada*) can feed on benthic animals and plants in a different ratio, i.e. *L. saliens* and *M. cephalus* feed mainly on benthic algae and detritus, and *L. ramada* prefers benthic algae (El-Shabrawy & Khalifa 2007). However, Cardona (2001) found that the spring diet of mullets in a coastal lagoon based on algae was a response to detritus reduction, but in autumn it shifted to detritus and diatoms. *Solea aegyptica* feeds mainly on the lake macrobenthos (El-Shabrawy & Khalifa 2007). *Tilapia zillii* is an omnivorous species, feeding mainly on phytoplankton: Bacillariophyceae (26.8%), Rhodophyceae (24.2%) and Cyanophyceae (12.4%), while polychaetes, crustaceans, mollusks contributed only 9.4% (Abdel-Malek 1980). Macrobenthos and zooplankton constitute the main food (27% and 6.6%, respectively), while phytoplankton account for only 18.3% (El-Shabrawy & Khalifa 2007). Regarding shrimps, *Prawn kerathurus* is predominantly carnivorous, but sometimes also omnivorous (Ishak et al. 1980). The euglenoids (*Euglena* sp. and *Phacus* sp.) were the most important food items in the gut of *Metapenaeus stebbingi* (dominant in shrimp catch) during the summer of 1993 (El-Shabrawy & Khalifa 2007).

Strong or slight physicochemistry-phytoplankton--fish correlations were previously mentioned e.g. by Reid et al. (2000) or James et al. (2003) in seawaters and by Hansen & Carey (2015) in temperate waters, where fishery (through top-down control) can be an important contributor to environmental changes. However, some reckless actions (e.g. overstocking or excessive feeding of fish in aquaculture systems) can lead to enhanced water degradation (Legaspi et al. 2015). In Lake Qarun, the complexity of biological and chemical interactions (e.g. food availability, competition, predation) and the additional input of pollutants (e.g. heavy metals, pesticides) affect the abundance and structure of aquatic organisms (e.g. Abou El-Geit et al. 2013; El-Shabrawy et al. 2015). The earliest response to the variability of this lake ecosystem is shown by phytoplankton, especially its spatial heterogeneity.

Conclusions

More than 130 species belonging to Bacillariophyceae, Chlorophyceae, Chrysophyceae, Cryptophyceae, Cyanophyceae, Dinophyceae and Euglenophyceae were recorded in phytoplankton assemblages of Lake Qarun. The highest annual phytoplankton density was recorded in the east subarea, and its decreasing tendency was recorded along the sampling sites, i.e. toward the west subarea. Bacillariophyceae and Dinophyceae co-dominated the phytoplankton, with a similar decreasing tendency in their density toward the west. The concentration of chlorophyll *a* also decreased in a similar way, whereas the Secchi disk depth significantly increased. The concentrations of nutrients were usually high, with the maxima recorded in the east subarea. The trophic level index TLI indicated the hypereutrophic waters at almost all sampling sites. The largest total catch with the dominant fish *M. cephalus* was recorded in the west subarea along with the lowest phytoplankton density and concentrations of mineral nitrogen and phosphorus.

The results of this study suggest that short-term relationships between the water quality indices and the fish structure in Lake Qarun were reflected and, to a large extent, determined by some significant correlations, e.g. between the dominant species: *T. zillii* or *Solea* spp. and the total phytoplankton density, Dinophyceae density, concentrations of TP, chlorophyll *a*, ammonium, nitrite and nitrate. However, despite the correlations between these physicochemical and biological variables, long-term studies are still urgently needed for a better description of the impact of water quality indices on fish structure and *vice versa*. A more detailed understanding of physicochemistry-phytoplankton-fish relationships will be useful for enhancing the sustainable fish production.

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