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RESEARCH PAPER

Benthic Algae and Macroinvertebrates in Response to Habitat Conditions and Site-Specific Fish Dominance: A Case Study of Lake Qarun, Egypt

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Abstract

Benthic algae and macroinvertebrates play important role in global functioning of aquatic food web. Their spatial and temporal distributions in relation to environmental variables and fish composition were the aims of this study. Both benthic groups of organisms were studied at 10 sites covering the whole area of Lake Qarun. Total of 164 algae species belonging to phyla: Cyanobacteria, Bacillariophyta, Miozoa (previously Dinophyta), Chlorophyta, Cryptophyta, Ochrophyta and Euglenozoa (previously Euglenophyta) were recorded. Macroinvertebrates communities consisted of 16 species representing phyla: Arthropoda, Annelida and Mollusca. The highest densities of benthic algae and macroinvertebrates were recorded in the middle sub-region of the lake in line with the co-domination of tilapias, mullets, soles and anchovy, whereas their lowest density at site 1 in the eastern area. The sites primarily located in the western sub-region with higher density of benthic organisms and domination of *Mugil cephalus* were distinctly separated from the other sites. Similar trend was in distribution of chlorophyll *a* content, which strongly correlated with density of benthic algae. Temporal distribution indicated higher algae density in spring and summer, and higher macroinvertebrates density in spring and autumn. The fish community' composition was spatially and temporally different and environmental variables were more similarly distributed.

Introduction

Benthic algae include the group of photoautotrophic microorganisms inhabiting surface sediments of shallow aquatic ecosystems (Pinckney, Carman, Lumsden, & Hymel, 2003). They are mainly composed of diatoms and chlorophytes and play important role as primary producers in those sublittoral areas where the euphotic zone extends to the sediment–water interface (Cahoon, Nearhoof, & Tilton, 1999). In such environments microphytobenthic organisms are also substantial in the benthic trophic web, constituting a food source for sediment feeders (Nozais, Perissinotto, & Tita, 2005). All the live and dead phytoplankters contain photosynthetic pigments, especially chlorophyll *a* and its non-photosynthetic derivatives called pheopigments.

Benthic macro- and microinvertebrates include biota that spends a significant part of their lives on or in the bottom. Nile benthic macroinvertebrates (molluscs, worms and crustaceans) exhibit a marked variation in composition and density, reflecting a range of microhabitats but a comprehensive inventory of the existing taxa is still lacking. Macroinvertebrate species richness amounts to about 7–31 species at individual bank-side sites of the river and delta in Egypt. Benthic invertebrates, usually classified as macro- and meiobenthos, play an important role in the materia cycling and in energy flow. Benthic, especially microbenthic, production generally exceeds zooplankton production (Liang & Liu, 1995). It integrates change in physical, chemical and ecological characteristics of habitat over time and space (Milbrink, 1983) and it plays a key role in the accumulation in and transfer of contaminants to higher trophic levels (Amyot, Pinel-Alloul, & Campbell, 1994). Because of this, benthic communities are also useful for detecting the alterations in aquatic ecosystems (Dickman, Yang, & Brindle, 1990). Macrobenthic species offer advantages to water quality surveys because they inhabit almost all kinds of water types and they are sedentary, unable to avoid environmental disturbances. Macrobenthic group has a long life cycle compared with planktonic groups and its responses to different environmental conditions are known. Additionally, they play important role as the middle link in the aquatic food webs. Therefore, benthic macroinvertebrates as well as benthic algae are an important and very useful tool in ecological status assessment of water bodies (Miler *et al.*, 2013, Poikane, Kelly, & Cantonati, 2016, Ozbek, Tasdemir, Aydemir Cil, Somek, & Yildiz, 2018).

Historically, the lake fisheries' management of Lake Qarun in Egypt was characterized by significant stocks primarily of native fish: *Lates niloticus* (Linnaeus, 1758), *Clarias anguillaris* (Linnaeus, 1758), *Labeo niloticus* (Linnaeus, 1758), *Labeobarbus bynni* (Forsskål, 1775), *Anguilla anguilla* (Linnaeus, 1758), *Coptodon zillii* (Gervais, 1848) and *Oreachromis niloticus* (Linnaeus, 1758) (Gabr, 1998, El-Shabrawy & Fishar, 1999). The lake was also restocked with marine fish, i.e. *Mugil cephalus* Linnaeus 1758, *Chelon auratus* (Risso, 1810), *Chelon saliens* (Risso, 1810), *Chelon ramada* (Risso, 1827), *Atherina boyeri* Rissom 1810, *Solea aegyptiaca* Chabanaud, 1927, and also with marine prawns (Ishak, Abdel-Malek, & Shafik, 1982, El-Shabrawy & Fishar, 1999). Studies on food habitat of fishes inhabitnig Lake Qarun (Konsowa, 2006, El-Shabrawy & Fishar, 1999) shoved that most common tilapias consume primarily planktonic algal community. Benthopelagic mullets can alter their food preference, from planktonivorous or carnivorous feeding to benthic feeding, depending on their life stage. Soles have a special preference to feed on dinoflagellates and diatoms and they are well known as botttom feeders on especially benthic algae dominanted by diatoms.

Recently, the fish catches in Lake Qarun have been composed primarily of tilapias with dominant *C. zillii*, mullets with dominant *M. cephalus*, soles with dominant *Solea solea* (Linnaeus, 1758) and *S. aegyptiaca*, and anchovy with dominant *Engraulis encrasicolus* (Linnaeus, 1758) (Napiórkowska-Krzebietke, Hussian, Abd El-Monem, & El-Far, 2016). The other fish species, i.e. *Oreochromis aureus* (Steindachner, 1864), *O. niloticus, C. saliens*, *C. ramada*, *C. auratus* and *Sparus aurata* Linnaeus, 1758 were sporadic. High proportion in total catches had also shrimps (*Metapenaeus stebbingi* Nobili, 1904 and *Penaeus semisulcatus* De Haan, 1844).

The aim of this study was to determine the spatial and temporal distributions of benthic organisms, i.e. algae and macroinvertebrates, in relation to selected environmental variables and domination of fish species with various food preferences in the lake.

Materials and Methods

Study Area

Lake Qarun with surface area about 245 km^2 is the third largest lake in Egypt (Kotb, Ali, & El Semary, 2017). Its water level is approximately 43.7 m below sea level. The lake is situated at the northern edge of El-Fayoum Depression and it is considered as an ancient natural, reservoir (Figure 1). The length of the lake is 42 km, while the width varies between 5 km and 9.54 km. The depth of the water varies between 5 m in the East to 12 m in the West. Lake Qarun receives its water from two main drains, namely EL-Bats and El-Wadi drains besides several minor drains. The lake has a unique feature it is closed lake and has no outlet. The lake loses water by evaporation only which affects the water levels of the lake and its salinity. The salinity of the lake has been increasing for several decades. This has caused serious threat to the biodiversity and species populations of fish and birds. It has also threatened the socioeconomic systems.

Sampling Procedures

Sediment samples for benthic algae and macroinvertebrates were collected from 10 sites in Lake Qarun throughout the four successive seasons in 2017 (Table 1). Sites 1, 2 and 3 represent the East (eastern sub-region), while sites 4, 5, 6 and 7 represent the Middle (middle sub-region) and sites 8, 9 and 10 represent the West (western sub-region) of Lake Qarun (Figure 1). The sampling sites differ in depth. The depth of sites are as follows: site 1 – 2m, site 2 – 3m, site 3 – 4m, site 4 – 5m, site 5 – 5m, site 6 – 7.5m, site 7 – 2.5m, site 8 – 5.5m, site 9 – 4m and site 10 – 4m.

The selected environmental variables were also measured at all sampling sites throughout the year. The electrical conductivity (EC, mS/cm) was measured using a conductivity meter (S.C.T.33 YSI). Water transparency was measured using a white/black Secchi disk (0.3 m in diameter) and water temperature (°C) by an ordinary thermometer. The pH values were measured in-situ using Hydrolab (Multi Set 430i WTW).

Surface sediment samples (about 1 cm depth) with known surface area were collected by plastic cubic from the Ekman grab samples. Samples were transferred into plastic bottle and fixed with 4% formalin. Benthic algae were identified and enumerated using inverted microscope ZEISS 1M4738, at 400X magnification and at

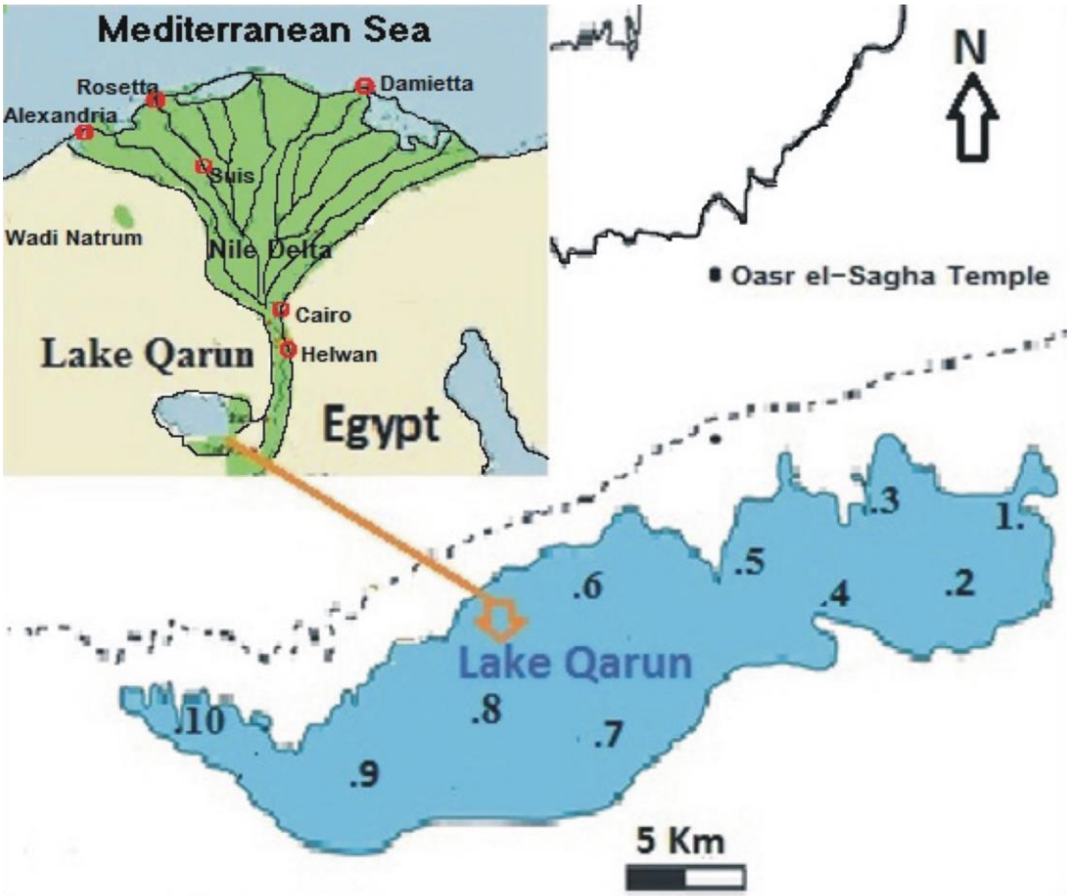

Figure 1. Map of sampling sites (1-10) in Lake Qarun.

Table 1. Biodiversity indices* of benthic algae and macroinvertebrates in Lake Qarun

Sites	Longitude	Latitude	Benthic algae			Benthic macroinvertebrates		
			Richness	S-WI	E	Richness	S-WI	E
1	30º 48.47′	29º 31.04′	31	2.084	0.607	2	0.673	0.971
2	30º 47.23′	29º 28.58′	67	2.942	0.700	7	0.698	0.358
3	30º 44.58′	29º 30.56′	59	2.785	0.683	12	1.959	0.788
4	30º 42.53′	29º 29.11′	70	2.646	0.623	10	1.356	0.589
5	30º 40.57′	29º 29.37′	79	3.378	0.773	9	1.439	0.655
6	30º 37.10′	29º 29.36′	52	2.131	0.539	13	1.160	0.452
7	30º 37.43′	29º 26.49′	86	3.265	0.733	10	1.278	0.555
8	30º 34.51′	29º 27.41′	84	2.754	0.622	7	1.620	0.833
9	30º 31.09′	29º 25.42′	83	3.232	0.731	10	2.001	0.869
10	30º 26.08′	29º 26.37′	73	3.131	0.730	8	1.798	0.865

*Richness – the numbers of species, S-WI – Shannon-Weaver Index, E – evenness

1,000X with immersion oil by the drop method application (APHA 1992). The algae density was expressed as numbers of cells per cm^2 (cell/cm^2). The benthic algae were identified to species level and the currently accepted taxonomical names were checked according to Guiry and Guiry (2018).

Using Ekman grab sampler, with an opening area of 225 cm^2, three samples were taken from the upper layer of the bottom sediments of each site. Each sample was immediately washed to remove any adhering sediments or mud and then sieved through net with a 500 µm mesh, stored in polyethylene jars and mixed with 10% neutral formaldehyde solution.

In laboratory, the samples were stained with Rose Bengal (l mg/dm^3) and were preserved in 4% formalin solution then washed and sieved again through the same net (500 µm mesh). Benthic animals were initially sorted to their genera or species level using a zoom stereo microscope. Each group was counted and kept in a glass bottle with 7% formalin for further identification. Three subsamples (1 cm^3 each) from each sample were examined separately under a dissecting microscope. Sorted animals were then identified to, as much as possible, species level. Individuals of each species were counted and the average total density was expressed as number of organisms per cm^2. The currently accepted taxonomical names of benthic macroinvertebrates species were checked according to Read and Fauchald (2018).

Samples of sediment for chlorophyll *a* analysis were transferred to 60-mL polyethylene tubes and then preserved in dark ice boxes. In laboratory, chlorophyll *a* was extracted by soaking of known weight (mg) in 5 ml acetone (90%) and preserved in dark at 20ºC overnight. Samples were shaken well and centrifuged for 5 minutes. The clear acetone extract was siphoned carefully and then samples were measured in dark at different wave lengths using NIKTON 930 spectrophotometer. Chlorophyll *a* concentration was determined according to the Trichromatic equation (APHA, 1992) and expressed as µg/g.

Data Analyses

The relationship between benthic algae, benthic macroinvertebrates and environmental variables was tested using the Spearman's coefficient and principal component analysis (PCA) with a correlation matrix (StatSoft, Inc.). Significant changes of the benthic organisms' density in Lake Qarun were tested with the Kruskal-Wallis test. As assumed, these relations were statistically significant with a 0.05 significance level. The similarity of algae and macroinvertebrates taxa was determined based on a cluster analysis (Multi-Variate Statistical Package, Kov. Comp. Serv. 1985-2009). The map with the distribution of the total density of both benthic algae and macroinvertebrates and their composition was presented with Arc GIS v. 10.5

Results and Discussion

Environment Variables

Throughout the study period water temperature ranged from 14.3°C to 27.4°C at all sampling sites. Electrical conductivity, reaching approximately 21 mS/cm, was the lowest at 1 site, and at the other sites it was about twofold higher (Figure 2). Analogues, pH of

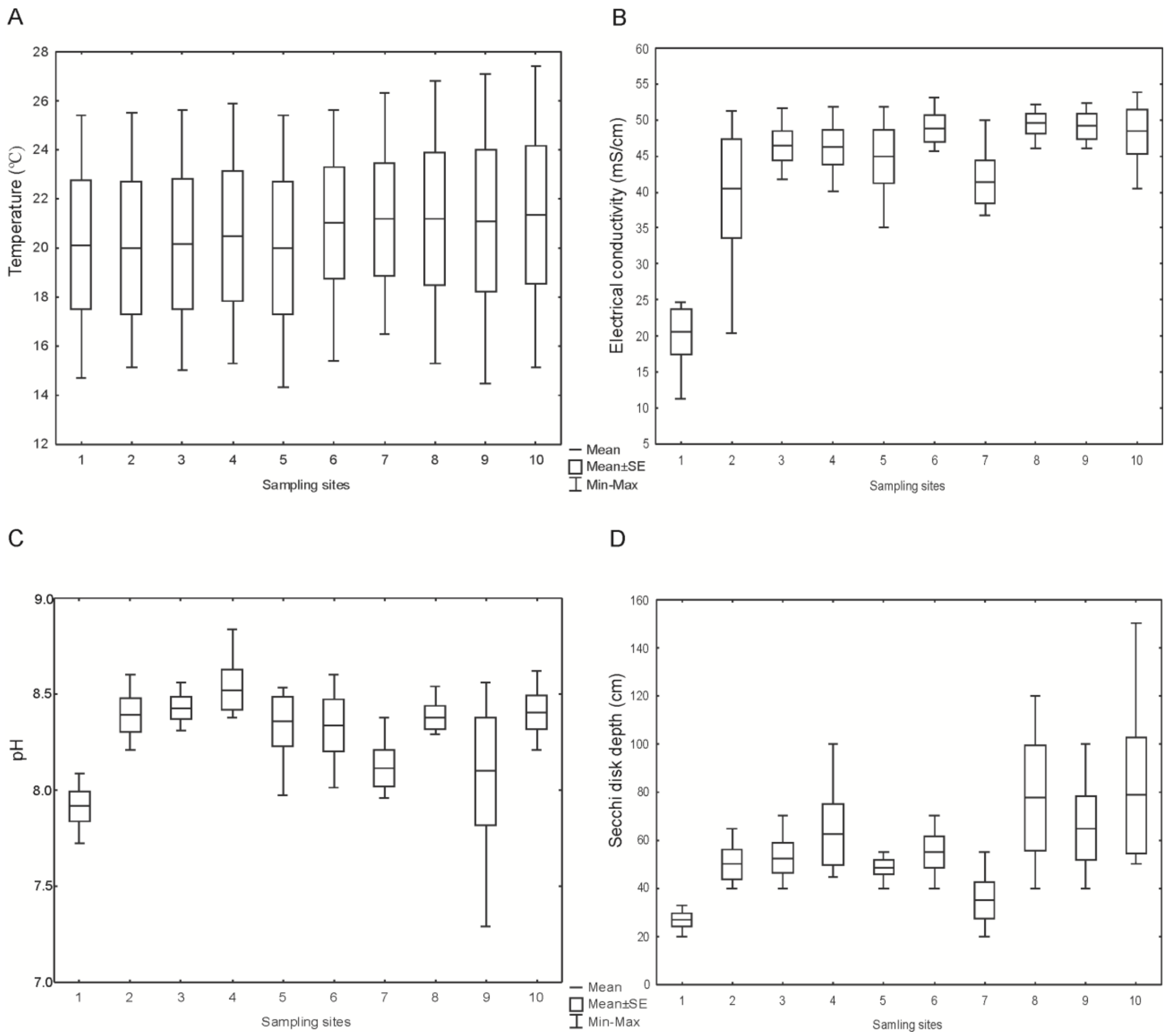

Figure 2. Annual changes in environmental parameters concerning water temperature (A), electrical conductivity (B), pH (C), water transparency (D).

water at site 1 (7.9, on average) was usually lower than at sites 2-10 (8.3, on average), except for site 9 with the lowest value of 7.3 in winter. The Secchi disk depth ranged, then, from 20 cm to 150 cm. The lowest water transparency throughout the year was usually recorded at sites 1 (20-33 cm) and 7 (20-55 cm), i.e. at the shallowest and the most exposed to pollution sites (El-Shabrawy, Anufriieva, Germoush, Goher, & Shadrin, 2015), respectively. The highest water transparency of 150 cm, in turn, was at site 10 in spring. It was consistent with the studies conducted in 2004-2005 and in 2012 (Hussein, Amer, Gaballah, Refaat, & Abdel-Wahad, 2008; Napiórkowska-Krzebietke *et al.*, 2016), when usually higher content of phytoplanktonic chlorophyll *a* was recorded in the eastern sub-region (sites 1-3) of Lake Qarun, with a clear tendency to decrease towards the western sub-region. Furthermore, high concentration of nutrients indicated hypereutrophic waters in the eastern and western sub-regions of Lake Qarun.

Fish Community

The annual composition of fish catches in Lake Qarun is spatially and temporally differentiated, but it was characterized by relative stability in the recent period. Based on data from 2012, the highest share in the annual total catch in the eastern sub-region of this lake had tilapias, primarily benthopelagic *C. zillii* (57%) (Figure 3). This fish species consume primarily

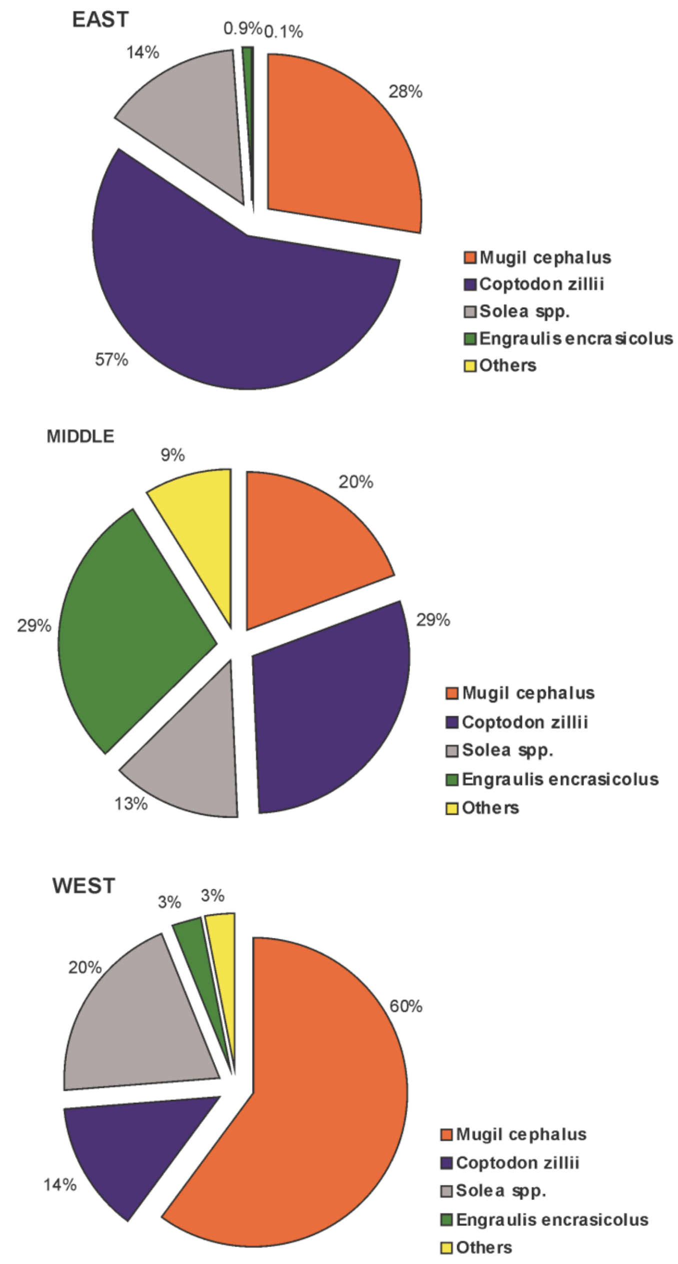

Figure 3. Fish community structure based on fish catches in three sub-regions (East, Middle and West) of Lake Qarun in 2012 (according to Napiórkowska-Krzebietke et al. 2016, modified).

planktonic diatoms and dinoflagellates (Konsowa, 2006), and its prominent dominantion corresponded well with the highest phytoplankton density in this sub-region (Napiórkowska-Krzebietke *et al.*, 2016). The share of 28% had one of the representative mullets, i.e. benthopelagic *M. cephalus* and 14% had representatives of soles, i.e. demersal *Solea* spp. In the middle sub-region, *C. zillii* and pelagic-neritic *E. encrasicolus* (anchovy) constituted for approximately 29% in the annual total catch, whereas *M. cephalus* and *Solea* spp. formed 20% and 13%, respectively. In the west sub-region, which was characterized by the highest total catch compared to other sub-regions (Napiórkowska-Krzebietke *et al.*, 2016), *M. cephalus* dominated the fish community (60%). High share had also *Solea* spp. (20%) and *C. zillii* (14%). The general composition of fish catches have been more or less stable for many years, and according to GAFRD (2013) mullets, tilapias, and soles have co-dominated the fish community since 2009 up to date. In 2003-2012, a progressive increase was in the fish and seafood catches, however, the overall fish production in Lake Qarun was relatively poor compared with the other Egyptian lakes (El-Serafy, El-Haweet, El-Ganiny, & El-Far, 2014). Concerning temporal changes, the fish catches were generally higher in the summer period, except for the middle sub-region, where they were significantly lower than in the winter period (Napiórkowska-Krzebietke *et al.*, 2016).

General Overview of Benthic Algae and Macroinvertebrates

Benthic algae (including also cyanobacteria) were represented by seven phyla: Cyanobacteria, Bacillariophyta, Miozoa (previously Dinophyta), Chlorophyta, Cryptophyta, Ochrophyta and Euglenozoa (previously Euglenophyta). Total of 164 benthic algae species were identified in Lake Qarun. While a total of 92 microphytobenthic species representing six phyla were previously identified by Hussian, Morsi, and Goher (2014). Comparing the phytoplankton studies, in turn, more than 130 species belonging to similar phyla were recorded in this lake (Napiórkowska-Krzebietke *et al.*, 2016).

In present study, Bacillariophyta as the most dominant phylum formed 87% of the total density, on average. It was represented by 100 species. The dominant diatoms were *Pleurosira laevis* (Ehrenberg) Compère, *Cyclotella meneghiniana* Kützing, *Pantocsekiella ocellata* (Pantocsek) K.T. Kiss et E. Ács, *Aulacoseira granulata* (Ehrenberg) Simonsen, *Melosira varians* C. Agardh, *Melosira* sp., *Cosmioneis lundstroemii* (Cleve) D.G. Mann, *Stephanodiscus astraea* (Kützing) Grunow. Phylum Chlorophyta with 41 species occupied the second position and it constituted 9% of the total density. The dominant chlorophytes were *Monoraphidium griffithii* (Berkeley) Komárková-Legnerová, *Hariotina reticulate* P.A. Dangeard, *Coelastrum cambricum* W. Archer, *Mucidosphaerium pulchellum* (H.C. Wood) C. Bock, Proschold et Krienitz, *Parapediastrum biradiatum* (Meyen) E.Hegewald and *Scenedesmus quadricauda* (Turpin) Brébisson. The average contribution of Cyanobacteria in the total density was 3%. It was represented by 27 species, primarily *Aphanocapsa delicatissima* West et G.S. West, *Planktolyngbya limnetica* (Lemmermann) Komárková-Legnerová and Cronberg, *Merismopedia glauca* (Ehrenberg) Kützing, *Merismopedia elegans* A. Braun ex Kützing, *Pseudanabaena papillaterminata* (Kiselev) Kukk and *Rivularia rufescens* Nägeli ex Bornet et Flahault. Representatives of the other algae phyla occurred much less often. Similar results were also observed in many lakes in the East Black Sea region of Turkey (Şahin, 2008, Şahin & Akar, 2005). Round (1984) and Hussian *et al.* (2014) pointed out that diatoms are usually the most common elements of microphytobenthic communities as well as of phytoplankton assemblages in Lake Qarun (Napiórkowska-Krzebietke *et al.*, 2016). It is also well known that the representatives of Bacillariophyta are sensitive to a wide range of limnological and environmental variables, and their community structure may quickly respond to changes in physical, chemical and biological conditions of the environment (Mooser, Macdonald, & Smol, 1996). An increase of diatoms can be considered as an ecological benefit supplying energy for the planktonic food web (Gorczyca & London, 2003, Napiórkowska-Krzebietke, 2017).

The benthic macroinvertebrate community comprised from three phyla Arthropoda, Annelida and Mollusca throughout the whole study period. Sixteen macroinvertebrate species were identified in total. Arthropoda ranked the highest percentage share, i.e. 74% of the total macroinvertebrate density. Seven species of this phylum were recorded, i.e. *Monocorophium acherusicum* (Costa, 1853), *Cyprideis torosa* (Jones, 1850), *Chironomus* larvae, *Fistulobalanus pallidus* (Darwin, 1854), *Lekanesphaera hookeri* (Leach, 1814), *Palaemon elegans* Rathke, 1837, and *Gammarus* sp. They contributed about 40.1%, 29.8%, 16.8%, 10.5%, 1.7%, 0.6% and 0.5% to the total density of Arthropoda, respectively. Annelida was considered as the second dominant macrobenthic group contributing approximately 21% of the total macroinvertebrate density. This phylum was represented by five species including *Hediste diversicolor* (O.F. Müller, 1776), *Ficopomatus enigmaticus* (Fauvel, 1923), *Polydora cornuta* Bosc, 1802, *Limnodrilus* sp. and one species of *Tubificidae* family. Their contributions were about 33%, 32%, 15%, 10% and 10% to the total density of Annelida, respectively. Mollusca constituted the third macrobenthic group with contribution of 5% into the total macroinvertebrate density. This phylum included four species *Heleobia* sp. (previously *Semisalsa* sp.), *Cerastoderma glaucum* (Bruguière, 1789), *Nassarius kraussianus* (Dunker, 1846) and *Polititapes aureus* (Gmelin, 1791) which contributed about 65%, 28%, 4% and 3% to the total density, respectively.

Spatial and Temporal Distributions of Benthic Algae and Macroinvertebrates

The highest average annual density of benthic algae (nearly 8,000 cells/cm^2) was recorded at the one of shallowest site 7 in the middle sub-region of the lake (Figure 4). The eastern and similarly shallow site 1 was characterized by the lowest average annual density of benthic algae. Similarly, the content of chlorophyll *a* in benthic algae was the highest at site 7 and considerable lower at sites 2-3, 5-6 and 10 (Figure 5). The distributions of benthic algae are usually patchy, and mostly controlled by the depth gradient, substratum as well as food resources (Cantonati & Lowe, 2014).

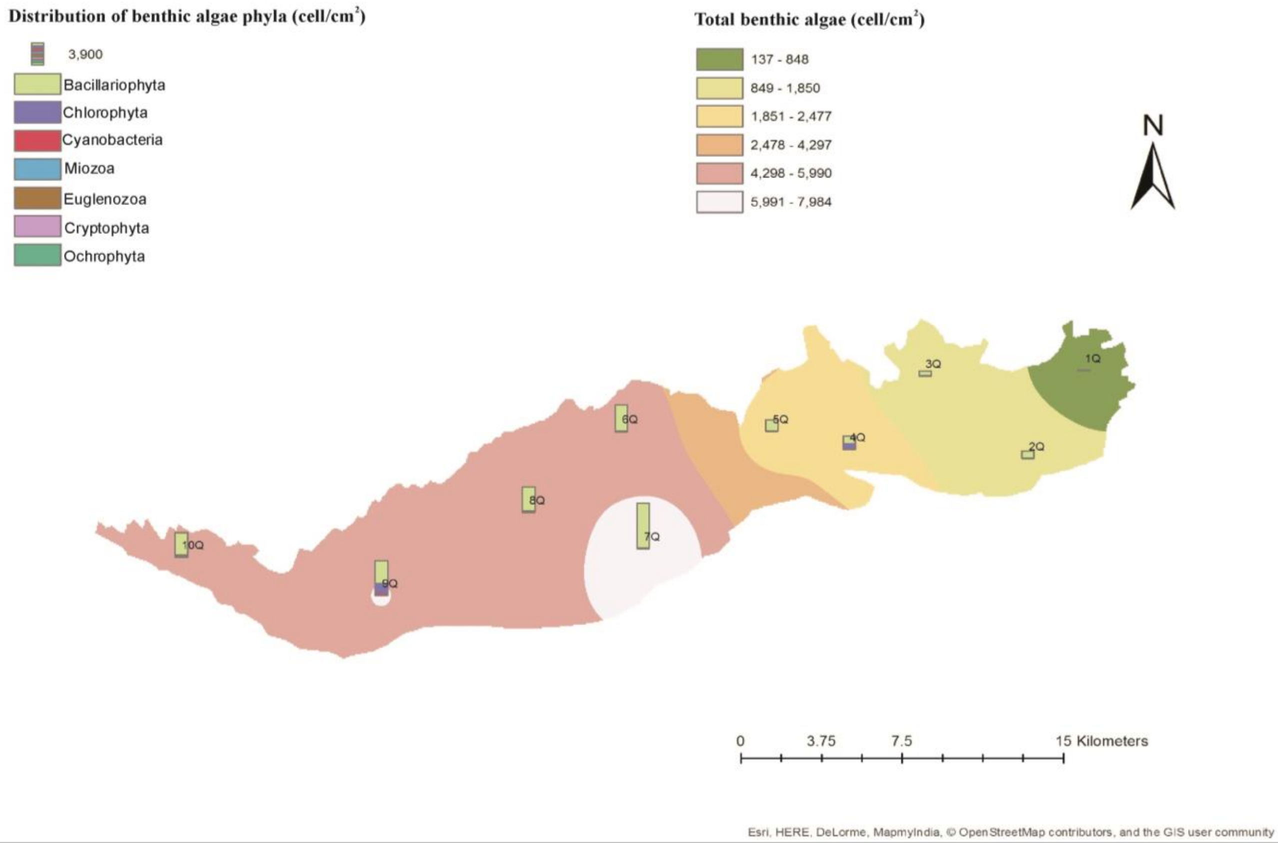

Figure 4. Spatial distribution of benthic algae in Lake Qarun based on an average annual density, the codes of 1Q –10Q refer to sampling sites 1-10 and name of the lake.

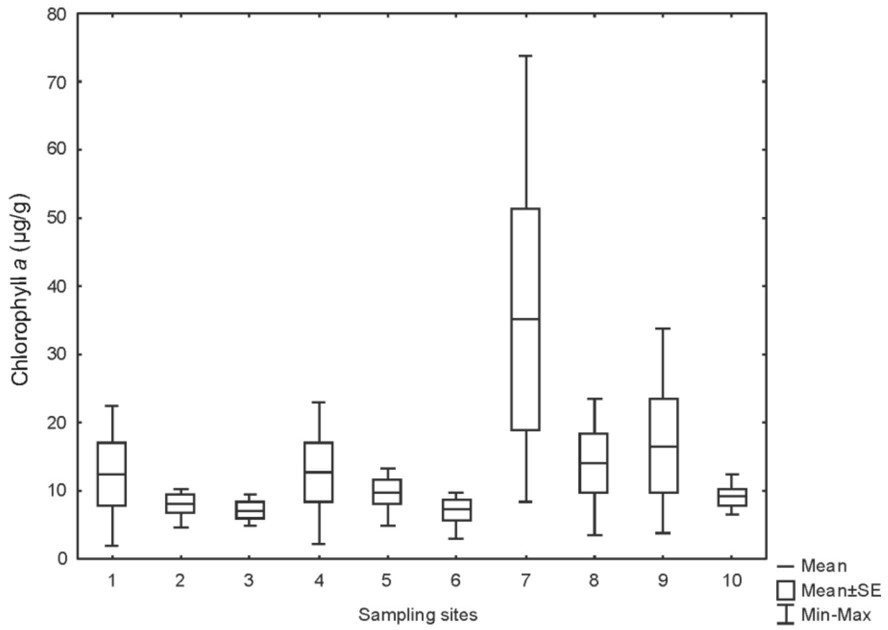

Figure 5. Spatial distribution of chlorophyll *a* content in benthic algae of Lake Qarun.

Bacillariophyta was dominant group at all sites, but a relatively high share of Chlorophyta was noted at sites 4 and 9. The species richness ranged from 31 to 86 species, Shannon-Weaver index from 2.084 to 3.378, and evenness from 0.539 to 0.773 (Table 1). Generally, the sites 6-10 were more abundant and richer in algae species than the other sites. A clear tendency to increase in algae density was also from eastern towards western sub-regions of the lake.

The highest total macroinvertebrate density (11,837 ind./cm^2, on average) was noted at site 6 in the middle sub-region of Lake Qarun (Figure 6), i.e. similarly as benthic algae. This result was primarily attributed to the predominance of Arthropoda with *M. acherusicum* dominated in spring. The dominance of Arthropoda was also noted at the other three sites (i.e. 4, 5 and 7) of the middle sub-region and at site 2. A sharp decline in benthic macroinvertebrate community, only 50 and 75

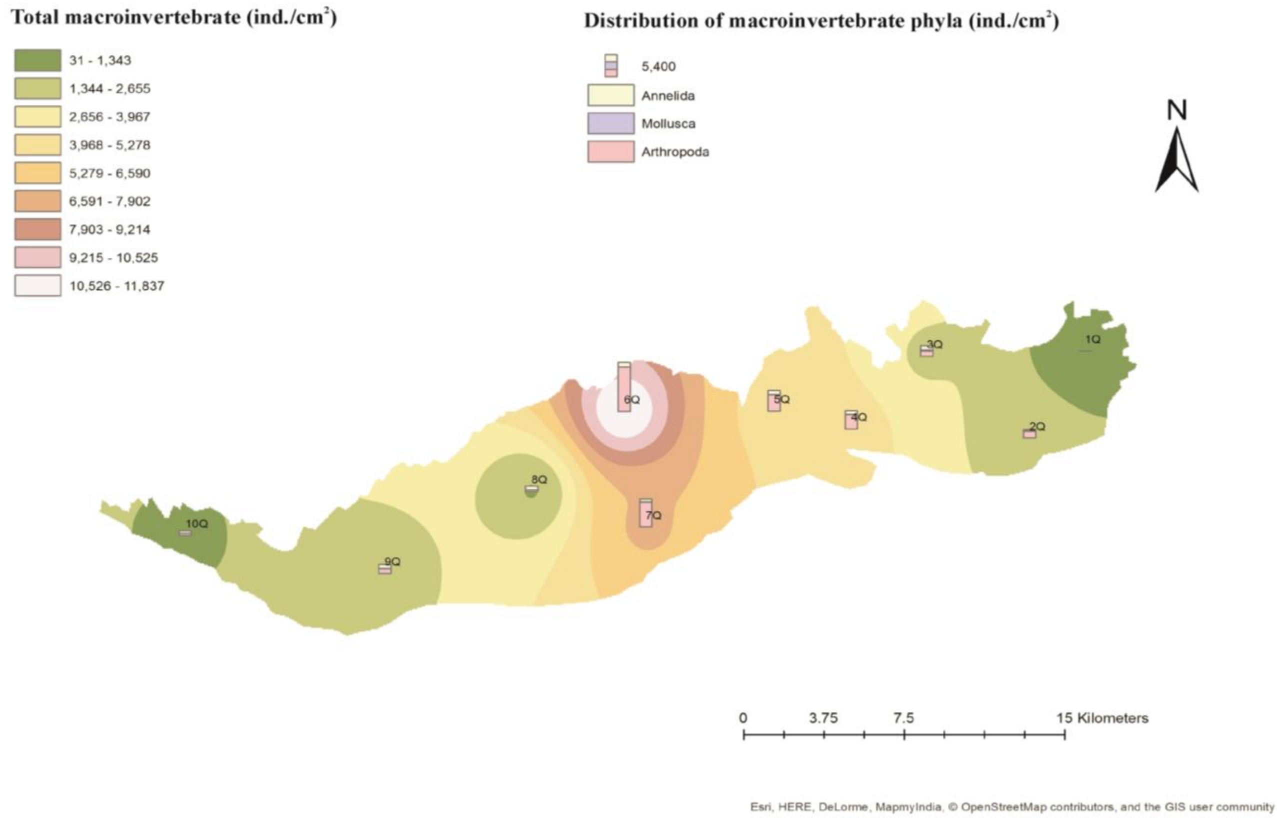

Figure 6. Spatial distribution of macroinvertebrates in Lake Qarun based on an average annual density; the codes of 1Q –10Q refer to sampling sites 1-10 and name of the lake.

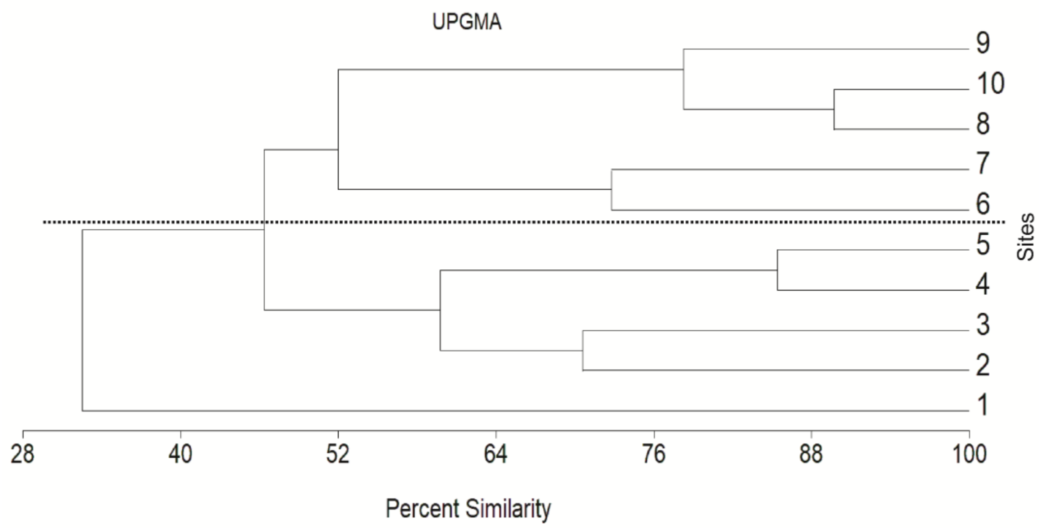

Figure 7. Hierarchical cluster analysis based on similarity percent of benthic algae and macroinvertebrates density at sampling sites in Lake Qarun.

individuals per m^2 in spring and winter, respectively were noticed at site 1 located near the discharge of agricultural drainage waters from the El-Bats Drain. Such situation was connected with the worst water transparency, lowest values of EC and pH, and generally the highest nutrient enrichment and heavy metal pollution compared to other sites in the lake (Hussein *et al.*, 2008, El-Shabrawy *et al.*, 2015, Shadrin, EL-Shabrawy, Anufriieva, Goher, & Ragab, 2016). The community formed there only arthropods of the genus *Gammarus* in spring and molluscs of the genus *Heleobia* (previously *Semisalsa*) in winter whereas annelids were absent. The highest density of Annelida was recorded at site 6 with an average value of 1,056 ind./cm^2, while the lowest density was recorded at site 2 with an average value of 44 ind./cm^2. Annelida dominated macroinvertebrate community at site 8 (approximately 70%) where Mollusca was absent, whereas at sites 3, 9, 10 Annelida co-dominated with Arthropoda. The highest density of Mollusca, with an average value of 350 ind./cm^2, was recorded at site 2.

It was more or less consistent with the lowest and relatively high total density of benthic algae at sites 1 and 6, respectively. However, general tendency in the occurrence of macroinvertebrates was different. The middle sub-region of the lake including sites 4-7 was richer in macrobenthic organisms (approximately 4.5 fold higher density) and species (9-13 species, S-WI 1.160-1.439, E 0.452-0.655; Table 1) than the other sub-regions. The middle sub-region of Lake Qarun was also characterized by a strong exposure to pollutants of agriculture origin (high content of nutrients and heavy metals) inflowing directly to the lake with the El-Wadi Drain (Hussein *et al.*, 2008, El-Shabrawy *et al.*, 2015, Shadrin *et al.*, 2016). According to Pan, Wang, Liang, and Wang (2012) the river connectivity is a key factor that affects the macroinvertebrate assemblages in the lake.

Considering both groups of benthic organisms (algae and macroinvertebrates), the cluster analysis confirmed a strong similarity between samples from sites 8 and 10 (90%) which created the coherent group with site 9 of the western sub-region of the lake (Figure 7). The most similar to this group were samples collected at sites 6 and 7 with internal similarity of 73%. The second coherent group was formed by samples from sites 4 and 5 (85%) of the middle sub-region and

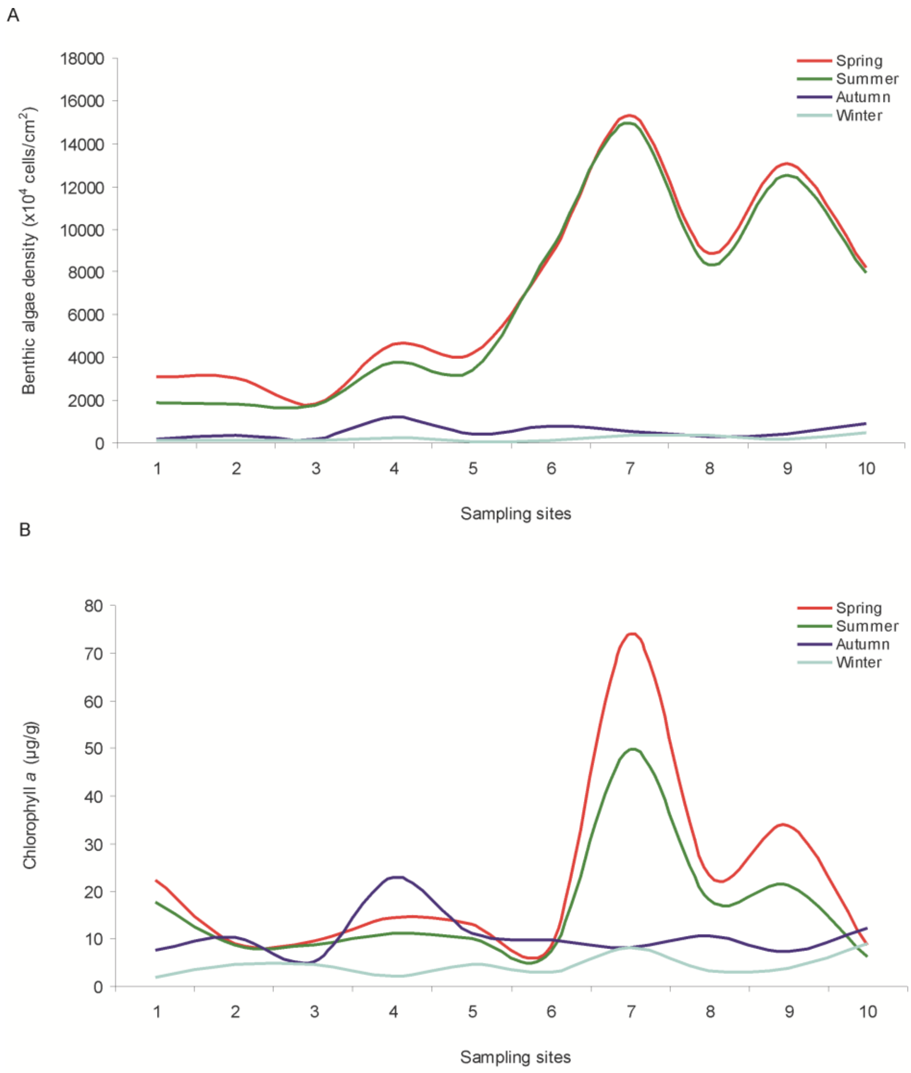

Figure 8. Temporal distribution of benthic algae (A) and chlorophyll *a* (B) at sampling sites.

the most similar to this group were samples from sites 2 and 3 (71%) of the eastern sub-region. The samples collected at site 1 were the least similar to these two groups.

Considering temporal distribution, the highest density of benthic algae was recorded in spring followed by summer with their maxima at site 7 (Figure 8A). However, the second spring and summer peaks were recorded at site 9. In winter, the total density was the lowest. In analogy, the algae density in autumn was generally similar to that noted in winter. Algae densities at sites 4, 5 and 6 were significantly (5-fold and 7-fold) higher in autumn than in winter. Chlorophyll *a* (Chl *a*), which can be included as a common indicator of algal biomass despite some discrepancy (Atici & Alaş, 2012, Baulch, Turner, Findlay, Vinebrooke, & Donahue, 2009), varied in a similar pattern as the benthic algae density. The highest Chl *a* content was also recorded in spring at site 7, while the lowest content was found in winter at site 1 (Figure 8B). These results coincide with findings of Underwood and Paterson (1993), Santos, Pastel, and Souza-Santos (1997) and Sin, Ryu, and Song (2009) who reported that epipelic biomass represented by Chl *a* often shows the seasonal patterns of increase during the summer months or throughout the year, even in winter. The highest density of macroinvertebrates (approximately 30,000 ind./cm^2), in turn, was recorded in spring at site 6 (Figure 9). However, their average density was the highest in autumn. In summer density with around 50 ind./cm^2 at site 10 and none organisms at site 1 was recognized as the lowest.

Algae-Macroinvertebrates-Fish-Environment Relationships

Concerning benthic organisms, a positive significant correlation was only found between Miozoa and Mollusca (Table 2). The negative correlations were between Chlorophyta, Bacillariophyta, Cyanobacteria and Mollusca. However, an increase in benthic algae was in line with an increase of benthic macroinvertebrates (Figures 8 and 9).

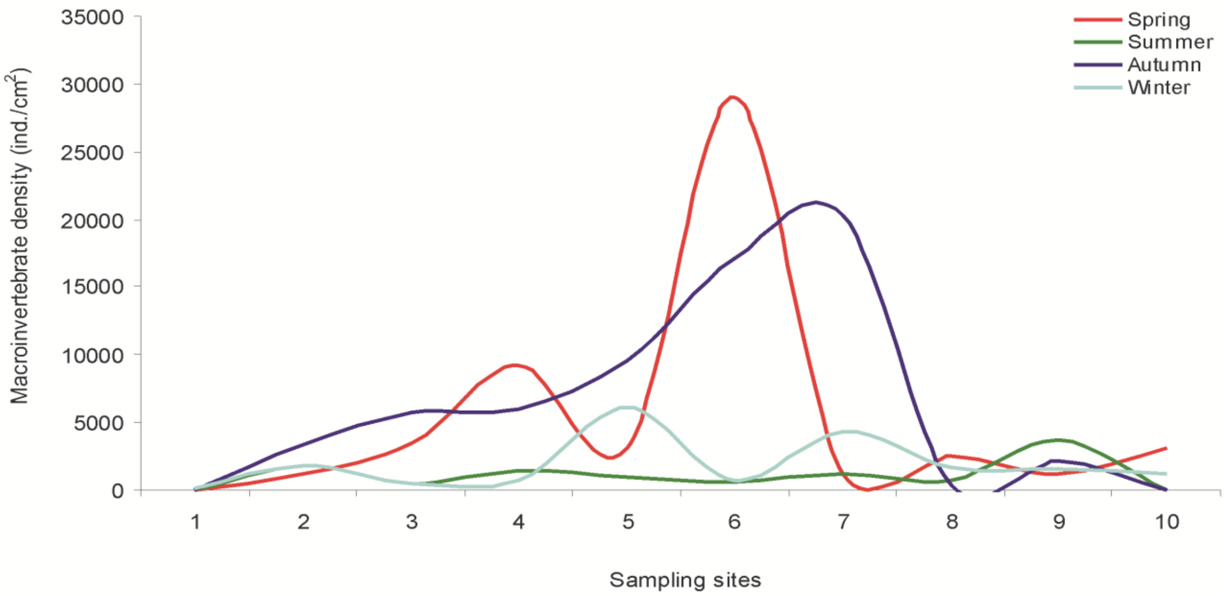

Figure 9. Temporal distribution of benthic macroinvertebrates at sampling sites.

Table 2. The Spearman's rank correlation coefficient (r_s) between benthic algae and macroinvertebrates

Benthic algae	Annelida	Mollusca	Arthropoda
Cyanobacteria	n.s.	-0.388	n.s.
Bacillariophyta	n.s.	-0.484	n.s.
Chlorophyta	n.s.	-0.450	n.s.
Cryptophyta	n.s.	n.s.	n.s.
Euglenozoa	n.s.	n.s.	n.s.
Miozoa	n.s.	0.444	n.s.
Ochrophyta	n.s.	n.s.	n.s.
Total algae density	n.s.	-0.465	n.s.

n.s. – not significant

The total density of benthic algae strongly and positively correlated with chlorophyll *a* content (r=0.711) (Table 3). Such close relations were also found in some temperate oligotrophic lakes only over a short-time scale but in a long-time scale they were divergent (Baulch *et al.*, 2009). It was due to the factors affecting the content of chlorophyll *a* in algal cells, which included e.g. algal composition, algal cell size, light, temperature, nutrient availability and grazing. Positive relations were also found with water temperature, electrical conductivity and pH (Table 3). Benthic algae density negatively correlated with water transparency. The similar positive relations were also between environmental variables and Chlorophyta, Bacillariophyta and Cyanobacteria, whereas negative relations with Miozoa. Among macroinvertebrates, Mollusca were significantly and negatively correlated with temperature and electrical conductivity. Such close relationships were confirmed by PCA analysis (Figure 10) where both PC (PC1 and PC2) axes explained 64% of total variability.

The middle sub-region of the lake was generally

Table 3. The Spearman's rank correlation coefficient (r_s) between benthic organisms and environmental variables*

Benthic organisms	Chl-*a*	Tw	SDD	EC	pH
Cyanobacteria	0.458	0.613	n.s.	0.729	0.327
Bacillariophyta	0.659	0.841	-0.362	0.619	0.377
Chlorophyta	0.423	0.512	n.s.	0.567	0.350
Cryptophyta	-0.410	-0.380	n.s.	n.s.	n.s.
Euglenozoa	n.s.	-0.493	n.s.	-0.428	n.s.
Miozoa	-0.435	-0.798	0.357	-0.571	-0.335
Ochrophyta	n.s.	-0.329	0.380	n.s.	n.s.
Total algae density	0.711	0.847	-0.354	0.636	0.396
Annelida	n.s.	n.s.	n.s.	n.s.	n.s.
Mollusca	n.s.	-0.494	n.s.	-0.484	n.s.
Arthropoda	n.s.	n.s.	n.s.	n.s.	n.s.

*Chl-*a* - Chlorophyll *a*, Tw – water temperature, SDD – Secchi disk depth, EC – electrical conductivity; n.s. – not significant

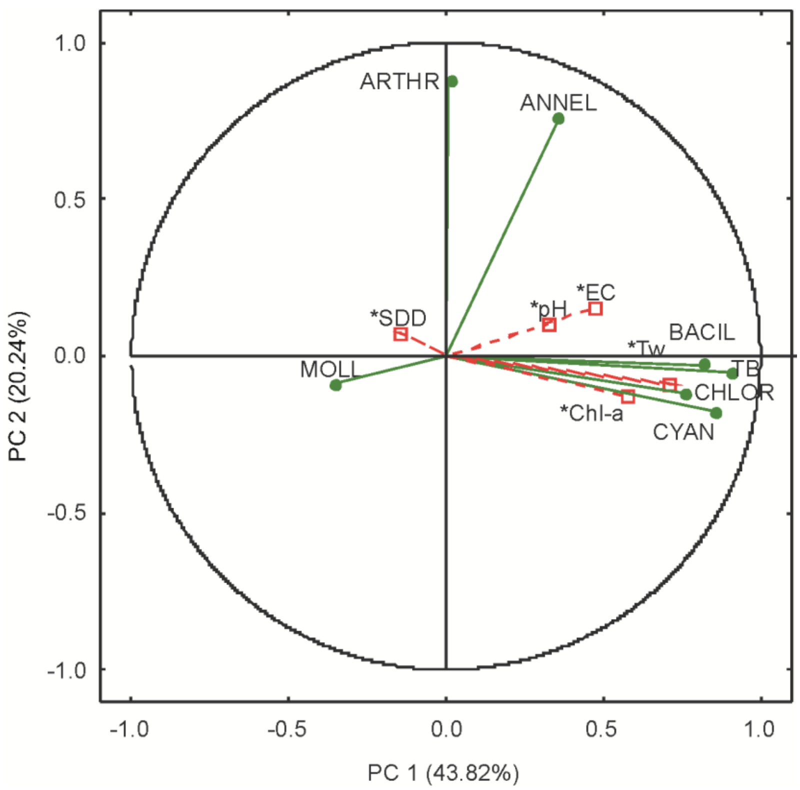

Figure 10. PCA ordination diagram showing the relationships between selected benthic organisms and environmental variables, TB – total algae density, BACIL – Bacillariophyta, CHLOR – Chlorophyta, CYAN – Cyanobacteria, ANNEL – Annelida, ARTHR – Arthropoda, MOLL – Mollusca, the explanation of environmental parameters was given in Table 3.

characterized by the highest density of benthic algae and macroinvertebrates, higher species richness than the other sub-regions. It was in line with a long tendency to co-dominate of fish species with different food preferences. Algae and macroinvertebrates communities in Lake Qarun were generally dependent on the fish pressure. *C. zillii* consumed primarily phytoplanktonic dinoflagellates and diatoms (Konsowa, 2006), while crustaceans, polychaetes and molluscs contributed much less (Abdel-Malek, 1980). Mullets, primarily with dominant *M. cephalus*, in an early life-stage start with feeding on phytoplankton and then on zooplankton (El-Shabrawy & Fishar, 1999). Finally, they become the benthic feeders on benthic algae, animal and detritus (Abdel-Malek, 1980). Soles (e.g. *S. aegyptica*) feed primarily on macrobenthos (El-Shabrawy & Khalifa, 2007), but they also show some food preference towards diatoms and dinoflagellates which also constite the benthic community (Konsowa, 2006). Enchovy *E. encrasicolus* feeds primarily on zooplankton but also on phytoplankton (Plounevez & Champalbert, 2000). The fish catches had a tendency to be generally higher in summer compared to winter season in both eastern and western sub-regions of Lake Qarun (Napiórkowska-Krzebietke *et al.*, 2016), suggesting, thus, possibly higher pressure on algae and macroinvertebrate communities.

Conclusions

Both benthic algae and benthic macroinvertebrates are very important in maintaining a proper functioning of ecosystem including the successful energy transfer to a higher tropic level. They are also set as very useful tool in a comprehensive assessment of the water quality. The highest density of benthic algae and strongly correlated content of chlorophyll *a* were also in line with the density of macroinvertebrates recorded in the middle sub-region of Lake Qarun. It was related with a worse water quality manifesting in low water transparency. The fish community in this sub-region was co-dominated by benthopelagic tilapias and mullets, demersal soles and pelagic anchovy. The lowest density of benthic organisms was recorded in the eastern sub-region, primarily at the shallowest sampling site, where *C. zillii* and *M. cephalus* were most often caught. Generally, the sampling sites from 6 to 10 were richer in benthic algae than the others sites, with a clear tendency to their increase from eastern towards western sub-regions of the lake. During spring and summer they grew most abundantly. The dominant group at all sites was Bacillariophyta which is considered as an ecologically beneficial contributor to the energy flow through the planktonic food web. However, a high share of Chlorophyta was noted at sites 4 and 9. Benthic macroinvertebrates also preferred the middle sub-region of the lake, primarily both deeper site 6 and shallower site 7 in spring and autumn.

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