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Phytoplankton functional groups provide a quality assessment method by the *Q* assemblage index in Lake Mogan (Turkey)

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Abstract: The aim of this research is to test the *Q* phytoplankton assemblage index based on phytoplankton functional groups in Lake Mogan and to provide a quality state estimation by data from 2006. Phytoplankton was sampled at 2 stations of the lake, paralleled with physical (water temperature, Secchi depth, pH, conductivity) and chemical (DO, chlorophyll-*a*, alkalinity, total hardness, soluble reactive phosphorus, total phosphorus, NO_2-N, NO_3-N, NH_3-N) analyses. The *Q* index was able to follow the main seasonal changes of the physical and chemical parameters and indicated a moderate ecological status for Lake Mogan. Phytoplankton biomass varied between 0.75 and 10.12 mg/L in the research period, and provided a similar ecological state by *Q* index, chlorophyll-*a*, total phosphorus, and Secchi depth. A total of 76 phytoplankton species were identified in the study period, belonging to 12 functional groups. The seasonal succession of dominant functional groups followed this sequence of coda: **X2** (*Chlamydomonas*), **Lo** (*Merismopedia*, *Peridinium*, *Chroococcus*), **F** (*Botryococcus*, *Sphaerocystis*, *Oocystis*, *Planktosphaeria*), **S1** (*Phormidium*, *Planktothrix*), **M** (*Microcystis*), and **F** (*Botryococcus*, *Oocystis*).

Key words: Lake Mogan, assemblage index, ecological status, quality assessment

1. Introduction

The monitoring and management of water resources according to the European Water Framework Directive (WFD, 2000) are very important to Turkey because of the harmonization processes. The WFD requires the monitoring of inland water bodies by biological groups (fish, macrophyte, macrozoobenthos, benthic diatoms, and phytoplankton) and the amelioration of water quality to a good ecological state by 2015. Each EU country has started to use approaches based on these indicator groups to determine the ecological status of their water bodies (Padisák et al., 2006; Gesheva et al., 2013). Functional groups of phytoplankton have been described to pool phytoplankton species together with similar tolerances and sensitivities to different combinations of biological, physical, and chemical properties of lakes (Reynolds et al., 2002; Padisák et al., 2003, 2009). These groups have been investigated by several authors in lakes (Nixdorf et al., 2003; Romo and Villena, 2005; Çelik and Ongun, 2008; Soylu and Gönülol, 2010), rivers (Devercelli and O'Farrell, 2013), and reservoirs (Albay and Akçaalan, 2003; Crossetti and Bicudo, 2005; Borges et al., 2008). While the functional classification of Reynolds et al. (2002) is not the only existing one, it has been already reconsidered for ecological qualification by the *Q* index (Padisák et al., 2006).

Some other indexes based on phytoplankton have also been developed to estimate the ecological state of water bodies according to the WFD. For example, 3 trophic indexes were proposed for deep subalpine lakes using algal orders, species order, and their ratios (Salmaso et al., 2006). The *Q* assemblage index was developed for Hungarian lakes by Padisák et al. (2006) and PSI was described for phytoplankton-based assessments in Germany (Mischke at al., 2008).

Before the requirements of the WFD, lakes were classified by their trophic state to develop management strategies, where trophic limits were determined by Secchi depth, primary production, chlorophyll-*a* (Chl-*a*), or total phosphorus (TP) (OECD, 1982). However, the WFD aims to determine ecological quality classes using biological data and requires a quality classification on a scale ranging between 0 and 5. These 5 ecological classes should reflect the 5 corresponding trophic states, namely oligotrophy (4–5, excellent), oligomesotrophy (3–4, good), mesotrophy (2–3, moderate), mesoeutrophy (1–2, tolerable) and eutrophy (0–1, bad).

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Lake Mogan is a shallow lake, dominated by submerged macrophytes during the vegetation period (Burnak and Beklioğlu, 2000). The lake is under increasing human pressure, such as population increase associated with decreasing water sources, destroyed reed belts, and organic pollution. Several restoration attempts have been done in Lake Mogan, like wastewater discharge collection and sediment removal from the shoreline (Fakıoğlu and Pulatsü, 2005). The human population of the area increased to 95,000 by 2010. Aquatic organisms are useful tools to assess and monitor human impact (Solak et al., 2012). Atici et al. (2010) reported that high concentrations of heavy metals were determined in the plankton; furthermore, Çok et al. (2011) pointed out that severe contamination of potential genotoxic pollutants has already occurred within the lake.

Padisák et al. (2009) reported 67 published articles closely related to the application of the functional groups that originated from Reynolds et al. (2002). However, only a few studies have been conducted to test the applicability of the *Q* index for lake quality monitoring (Crossetti and Bicudo, 2008; Pasztaleniec and Poniewozik, 2010). The trophic state estimation of shallow lakes may be biased when using Chl-*a*, Secchi depth, or TP data because of the large stir-up effect of wind, influencing chlorophyll content by dead macro- or epiphytes. Conversely, phytoplankton composition metrics like the *Q* index seem to respond quickly not only to the seasonal changes of environmental parameters but to anthropogenic disturbances as well. Therefore, the aims of the present study are to determine the dominant functional groups of phytoplankton and to test the applicability of the *Q* assemblage index for ecological state estimation in Lake Mogan.

2. Material and methods

2.1. Study site

Lake Mogan is an alluvial-set lake situated 20 km south of Ankara at 39°44′45″N to 39°47′45″N and 32°46′30″E to 32°49′30″E at 972 m above sea level. The lake has an area of 5.4 km^2, a volume of 13.3×10^6 m^3, a maximum depth of 4 m, and an average depth of 2.4 m. Underwater macrophytes are dominant in the whole lake (Obalı, 1984; Pulatsü et al., 1998; Burnak and Beklioğlu, 2000; Akbulut Emir and Akbulut, 2002). The lake has been polluted by industrial and municipal wastes from the increased human population around the lake. Restoration studies have been performed, such as rehabilitating the water resources feeding the lake and constructing wastewater collectors around the lake (Fakıoğlu and Pulatsü, 2005). As the water sources of the lake tend to provide less water, the water level shows a decreasing trend, while conductivity shows an increasing trend. In restoration work by the municipality in 2005, an important area of reeds was destroyed, and mud was removed from most of the shoreline. This work, rather than being beneficial, was actually damaging to the lake's ecosystem, as it did not allow the lake to clean itself; furthermore, walkways were constructed along a large portion of the lake's shoreline. Besides recreational use, Lake Mogan has been identified as an important water bird area and has had protected status since 1990. A study of phosphorus release from the littoral sediment showed that the external phosphorus load must be reduced to control the eutrophication (Pulatsü et al., 2009).

At the end of June 2006, a sudden change in water color (whitish) was observed, along with an unpleasant, strong smell and fish kill, lasting about 15 days. July sampling was only continued when visible effects disappeared. This unexplained situation was thought to be caused either by some unknown chemical substance released into the water or by calcite precipitation, known to occur in lakes (Salmaso and Decet, 1998; Ramisch et al., 1999). However, the whitening had never occurred before in Lake Mogan, and its cause has not yet been confirmed.

2.2. Methods

Sampling was carried out monthly from March to December 2006 at 2 stations (Figure 1). Lake Mogan was frozen

Figure 1. Sampling stations of Lake Mogan, 2006.

over during the months of January and February. Samples were collected from 2 depths at each sampling point, right below the surface and 2 m below the surface, using a Ruttner type sampler. Data obtained from the 2 depths and sampling points were averaged.

In situ measurements comprised water temperature, dissolved oxygen (DO; YSI 51 B), euphotic depth (by Secchi disks of 20 cm in diameter), pH (WTW 330), and conductivity (Jenway 4010). Chl-*a* concentration was determined by the acetone extraction method using a spectrophotometer (Shimadzu UV 1201V) (Strickland and Parsons, 1972). Hardness, alkalinity, nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N), soluble reactive phosphorus (SRP), and TP were determined by standard methods (APHA, 1995).

Phytoplankton was fixed by acetic Lugol solution. For taxa identification, the most common taxonomic literature was applied (Komarek and Fott, 1983; Krammer and Lange-Bertalot, 1986, 1988; Popovski and Pfiester, 1990; Cox, 1996; Komarek and Anagnostidis, 1999; John et al., 2002). Taxa and authors names were identified following standardized databases (Guiry and Guiry, 2007). Phytoplankton counts were carried out by the inverted microscope method (Utermöhl, 1958), using 400 units (Lund et al., 1958). Cell dimensions of algae were measured with a Leica DMIL microscope, with a digital camera and the Leica Application Suite. Total phytoplankton biovolume was estimated by the corresponding geometrical forms (Hillebrand et al., 1999; Sun and Liu, 2003) using the 1 mm^3/m^3 of algal volume to 1 mg wet weight/m^3 biomass calculation.

Phytoplankton species constituted more than 5% of total biomass were classified into functional groups according to Reynolds et al. (2002). The *Q* phytoplankton assemblage index was estimated following Padisák et al. (2006), and ranged from 0 to 5 on a scale according to the WFD requirements. Values between 0 and 1 were classified as bad, between 1 and 2 as tolerable, 2 and 3 as medium, 3 and 4 as good, and 4 and 5 as of excellent quality (Padisák et al., 2006). For Lake Mogan, the factor numbers described for the Hungarian lake type 2 were used (Padisák et al., 2006), because of the similarity in shallowness and in high conductivity.

For comparison of all parameters between the 2 stations, a paired t-test was applied using SPSS 11.5. The phytoplankton biomass was log-transformed in order to better approximate the normal distribution. The relationships between the biomass of functional groups and the mentioned environmental parameters were determined by canonical correspondence analysis (CCA) using the CANOCO 4.5 software package. Significance of selected variables was tested by Monte Carlo permutations (499 iterations) (ter Braak and Smilauer, 2002).

3. Results

The variations of water temperature, DO, pH, Secchi depth, NO_3-N, NO_2-N, NH_3-N, SRP, and TP were insignificant, while Chl-*a* and biomass values between the 2 sampling stations were significant ($P < 0.05$). The mean, minimum, and maximum values of the measured parameters are given in Table 1.

Table 1. Main environmental parameters of Lake Mogan, 2006 (minimum, maximum, and mean ± standard deviation).

Variable	Min	Max	Mean ± SD
Temperature (°C)	8.0	28.0	18.1 ± 7.2
Secchi depth (m)	0.25	3.0	1.21 ± 0.70
Dissolved O_2 (mg/L)	4.6	10.9	8.61 ± 1.19
pH	8.0	8.98	8.65 ± 0.24
Conductivity (mS/cm)	2.12	4.64	3.37 ± 0.68
Alkalinity (mg $CaCO_3$/L)	240	360	307 ± 40
Hardness (mg $CaCO_3$/L)	240	720	462 ± 174
SRP (mg/L)	0.001	0.008	0.003 ± 0.002
TP (mg/L)	0.032	0.078	0.063 ± 0.040
NO_3-N (mg/L)	0.081	1.061	0.477 ± 0.267
NO_2-N (mg/L)	0.002	0.495	0.147 ± 0.013
NH_3-N (mg/L)	0.010	0.151	0.051 ± 0.038
Phytoplankton biomass (mg/L)	0.75	10.12	3.4 ± 2.0
Chl-*a* (mg/m^3)	1.12	28.95	8.87± 2.06

The mean values of water depth at Stations 1 and 2 were 4.0 ± 0.14 and 2.95 ± 0.12 m, respectively. In March, average water temperature was 9.8 °C, which then increased up to 28 °C (August) and decreased gradually to 8 °C (December). Secchi depth showed reduced values from March and was the lowest in June at Station 2 (0.25 m, Figure 2). The Secchi depth increased from July, fell in October, and rose again in November, reaching 3 m at Station 2 (December). The average Secchi depth for the research period was 1.21 ± 0.70 m.

The pH values showed slight seasonal changes and ranged between 8.0 and 8.98. Dissolved oxygen changed between 4.6 and 10.9 mg/L during the research period. Average alkalinity was measured as 307 ± 40 mg $CaCO_3$/L and average total hardness as 462 ± 174 mg/L. Average conductivity was relatively high during the whole study period (3.37 ± 0.68 mS/cm), while the mean TP concentration was 62.5 ± 39.6 µg/L.

The Chl-*a* concentration showed 2 seasonal peaks: first in April (16.8 mg/m^3) and then in July (28.9 mg/m^3; Figure 2). It dropped suddenly in August, providing an average of 8.87 ± 2.06 mg/m^3 for 2006.

A total of 76 phytoplankton taxa were identified (Table 2) from Bacillariophyta (26), Chlorophyta (24), Cryptophyta (4), Cyanobacteria (13), Dinophyta (4), and Euglenophyta (5). In March and April, the phytoplankton biomass was dominated by green algae (51%–66%), followed by blue-green dominance (63%; Figure 3) in May. In June, total biomass fell, and blue-green algal dominance occurred (50%). In July, the biomass proportion of green algae, centric diatoms, and euglenophytes increased, and then in August, colonial green algae reached 93% of the total biomass. From September, an increase in both Cyanobacteria and Cryptophyta was observed. In October the total biomass decreased, and the dominance of Chlorophyta and Cyanobacteria reversed. At the end of the year, only Chlorophyta taxa were dominant, forming 79% and 75% of total biomass.

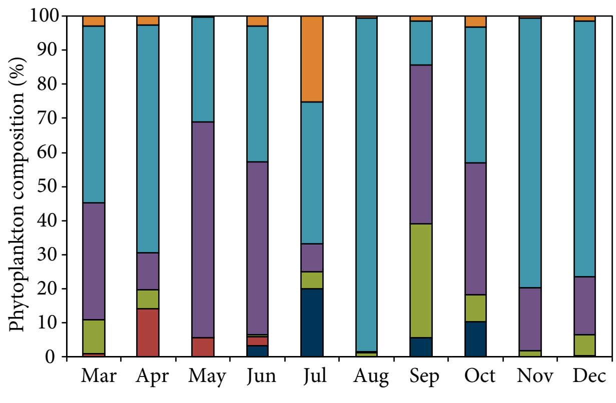

Figure 3. Seasonal succession of phytoplankton biomass in Lake Mogan, 2006.

In Lake Mogan, the dominant phytoplankton functional groups of the study period were **X2**, **H1**, **Y**, $\mathbf{L_M}$, **F**, **Lo**, **M**, **W1**, **C**, **P**, **X1**, and **S1** (Figure 4). When functional groups were examined on a month-by-month scale, dominant functional groups were found to be **X2** (*Chlamydomonas*) in March and April, **Lo** (*Merismopedia*, *Chroococcus*) in May and June, **F** (*Botryococcus*, *Sphaerocystis*, *Planktosphaeria*, *Oocystis*) in July and August, **S1** (*Phormidium*, *Planktothrix*) in September, **M** (*Microcystis*) and **F** (*Botryococcus*, *Oocystis*) in October, and **F** (*Botryococcus*) in November and December (Table 3). In March, functional group **H1** (*Dolichospermum*), in July functional group **W1** (*Euglena*), and in September functional group **Y** (*Cryptomonas*) showed subdominant characteristics.

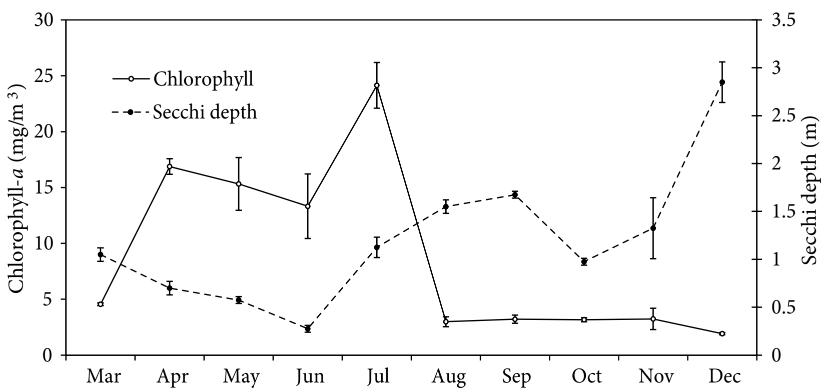

Figure 2. Seasonal change of Chl-*a* concentration and Secchi depth provided as averaged values of the 2 sampling stations (mean ± standard deviation) in Lake Mogan, 2006.

Table 2. Phytoplankton taxa identified in Lake Mogan, 2006.

Cyanobacteria
Aphanocapsa incerta (Lemm.) Cronberg & Komarek
Chrooccocus turgidus (Kütz.) Naeg.
Dolichospermum spiroides (Kleb.) Wacklin, L.Hoffm. & Komarek
Gomphosphaeria aponina Kütz.
Komvophoron constrictum (Szafer) Anagnostidis & Komarek
Merismopedia tenuissima Lemm.
M. glauca (Ehr.) Naeg.
Microcystis aeruginosa Kütz.
M. flos-aquae (Wittrock) Kirchner
Phormidium limosum (Dillwyn) P.C.Silva
Planktothrix agardhii (Gomont) Anagnostidis & Komarek
Spirulina major Kütz.
Trichormus catenula (Kützing ex Bornet & Flahault) Komarek & Anagnostidis

Cryptophyta
Cryptomonas erosa Ehr.
C. marsonnii Skuja
C. ovata Ehr.
Rhodomonas minuta Skuja

Pyrrophyta
Ceratium hirundinella (O.F.Müll.) Dujardin
Peridinium aciculiferum Lemm.
P. cinctum (O.F.Müll.) Ehr.
P. inconspicuum Lemm.

Euglenophyta
Euglena acus Ehr.
E. oxyuris Schmarda
Phacus longicauda (Ehr.) Dujardin
Trachelomonas hispida (Perty) F.Stein
T. volvocina Ehr.

Bacillariophyta
Aulacoseira granulata (Ehr.) Simonsen
Caloneis amphisbaena (Bory) Cleve
Cocconeis placentula Ehr.
Craticula cuspidata (Kütz.) D.G.Mann
Cyclotella meneghiniana Kütz.
C. ocellata Pantocsek
Cymatopleura solea (Breb.) W.Smith
Cymbella affinis Kütz.
C. crassistigmata Krammer
Diatoma vulgaris Bory de Saint-Vincent

Bacillariophyta
Encyonema ventricosum (C.Agardh) Grunow
Epithemia sorex Kütz.
E. turgida (Ehr.) Kütz.
Fragilaria construens (Ehr.) Grunow
Gomphonema olivaceum (Hornemann) Kütz.
Gyrosigma acuminatum (Kütz.) Rabenhorst
Melosira varians C.Agardh
Navicula cryptocephala Kütz.
Nitzschia amphibia Grun.
N. sigmoidea (Ehr.) W.Smith
Rhoicosphaenia curvata (Kütz.) Grun.
Rhopalodia gibba (Ehr.) O. F.Müler
Surirella ovalis Breb.
Ulnaria ulna (Nitzsch) P.Compere
Ulnaria acus (Kütz.) M.Aboal

Chlorophyta
Ankistrodesmus falcatus (Corda) Ralfs
Botryococcus braunii Kütz.
Chlamydomonas sp.
Closterium venus Kütz. ex Ralfs
Coelastrum microporum Naeg.
Cosmarium humile (F.Gay) Nordstedt in De Toni
Crucigenia tetrapedia (Kirchner) West & G.S.West
Korshikoviella michailovskoensis (Elenkin) P.C.Silva
Monoraphidium griffithii (Berkeley) Komarkova-Legnerova
*M. irregulare (*G.M.Smith) Komarkova-Legnerova
M. minitum (Naeg.) Komarkova-Legnerova
M. tortile (West & G.S.West) Komarkova-Legnerova
Oocystis borgei Snow
O. lacustris Chodat
O. parva W.West & G.S.West

Chlorophyta
Pediastrum boryanum (Turpin) Meneghini
P. duplex Meyen
Planktosphaeria gelatinosa G.M.Smith
Scenedesmus arcuatus Lemm.
S. communis E.H.Hegewald
Schroederia setigera (Schröder) Lemm.
Sphaerocystis schroeteri Chodat
Staurastrum cingulum (West & G.S.West) G.M.Smith
Tetraedron minimum (A. Br.) Hansg.

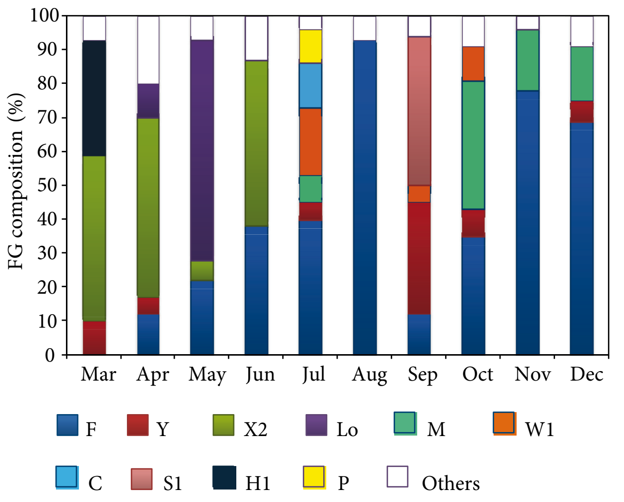

Figure 4. Seasonal succession of phytoplankton functional groups (FGs) in Lake Mogan, 2006. "Others" mean phytoplankton species that constituted less than 5% of the total biomass.

The CCA of environmental parameters versus functional groups had an eigenvalue of 0.17 explaining 29% of variance on the first axis and of 0.13 explaining 52% of variance on the second (Table 4). The first axis was associated with Secchi depth and Chl-*a*, while the second axis was related to water temperature, NO_3-N, NH_3-N, SRP, DO, TP, NO_2-N, and pH (Figure 5). The functional groups **X1**, **F**, **C**, **Lo**, and **Y** were positioned near the center of the ordination diagram. Codon **W1** was positioned on the positive side of the second axis, while coda **X2**, **Y**, and **H1** were positioned near each other and on the negative side of the first axis. Coda **S1** and **P** occurred far from the axis. September samples containing codon **S1** had a direct relationship with Secchi depth. Codon **P** accounted for 11% of the total biomass in July and its species occurred only once during the study period.

The phytoplankton biomass of Lake Mogan varied between 0.75 and 10.12 mg/L (Figure 6). The lowest biomass was recorded in March, which then increased from April

Table 3. Functional groups (FGs) and their monthly participation in the total phytoplankton biomass (%) in Lake Mogan, 2006.

Month	FGs	Representative	%
March	**X2**	*Chlamydomonas*	49
	H1	*Dolichospermum*	34
	Y	*Cryptomonas*	10
April	**X2**	*Chlamydomonas*	53
	L_M	*Ceratium*	14
	F	*Planktosphaeria, Oocystis*	12
	Lo	*Merismopedia, Chroococcus*	10
	Y	*Cryptomonas*	5
May	**Lo**	*Merismopedia, Peridinium, Chroococcus*	65
	F	*Botryococcus*	22
	X2	*Chlamydomonas*	6
June	**Lo**	*Merismopedia, Peridinium*	49
	F	*Botryococcus, Sphaerocystis, Planktosphaeria, Oocystis*	38
	M	*Microcystis*	5
July	**F**	*Botryococcus, Sphaerocystis, Oocystis, Planktosphaeria*	40
	W1	*Euglena*	20
	C	*Cyclotella*	13
	P	*Aulacoseira*	11
	M	*Microcystis*	8
	Y	*Cryptomonas*	5
August	**F**	*Botryococcus, Oocystis, Sphaerocystis, Planktosphaeria*	93
	X1	*Monoraphidium, Korshikoviella*	5
September	**S1**	*Phormidium, Planktothrix*	44
	Y	*Cryptomonas*	33
	F	*Oocystis, Sphaerocystis*	12
	W1	*Euglena*	5
October	**M**	*Microcystis*	38
	F	*Oocystis, Sphaerocystis*	35
	W1	*Euglena*	10
	Y	*Cryptomonas*	8
	X1	*Monoraphidium*	5
November	**F**	*Botryococcus, Oocystis*	78
	M	*Microcystis*	18
December	**F**	*Botryococcus*	69
	M	*Microcystis*	16
	Y	*Cryptomonas*	6
	X1	*Monoraphidium*	5

Table 4. Summary of the CCA analysis of functional groups and environmental parameters in Lake Mogan, 2006.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.172	0.135	0.122	0.070	0.727
Species–environment correlations	0.968	0.932	0.863	0.940	
Cumulative percentage variance of species data	23.6	42.1	58.9	68.5	
Cumulative percentage variance of species–environment relation	29.3	52.4	73.2	85.2	
Sum of all eigenvalues					0.727
Sum of all canonical eigenvalues					0.585

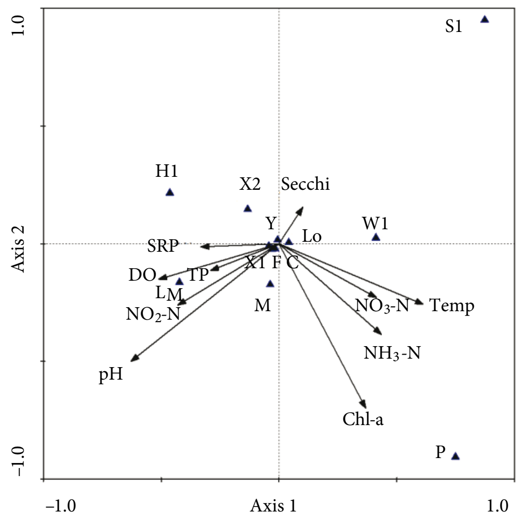

Figure 5. CCA of functional groups and environmental parameters in Lake Mogan. **X2**, **H1**, **Y**, **L_M**, **F**, **Lo**, **M**, **W1**, **C**, **P**, **X1**, and **S1** are functional groups. Temp: temperature, Secchi: Secchi depth, DO: dissolved oxygen, SRP: soluble reactive phosphorus, TP: total phosphorus, NO_2-N: nitrite-nitrogen, NO_3-N: nitrate-nitrogen, NH_3-N ammonia-nitrogen.

and reached its peak in May. Phytoplankton biomass fell to 6.7 mg/L in June, with further continuous decrease until July, and did not increase after that.

The *Q* quality index based on functional groups varied between 0.94 and 3.99 (Figure 6). On a temporal scale, *Q* index fluctuated between values 2 (tolerable) and 3 (medium) during spring (March and April), and it showed tolerable values in May and bad values in June (*Q* = 0.94). In July and August, the *Q* index values indicated medium to good ecological states. In September, *Q* showed tolerable status (1.37), which then rose to medium in October. At the end of the growing season (November and December), the *Q* index indicated good ecological conditions (3–4).

4. Discussion

The list of phytoplankton species identified in this study was compared to earlier lists provided by phytoplankton researchers (Obalı, 1978; Aykulu et al., 1983; Atay and Bakan, 1990; Akbulut Emir and Akbulut, 2002; Atici et al., 2010; Yerli et al., 2012). Pennate diatoms were found in the phytoplankton, albeit in small numbers. Lake Mogan has shallow characteristics and thus retains high conductivity, as well as the dominance of submerged aquatic plants. For

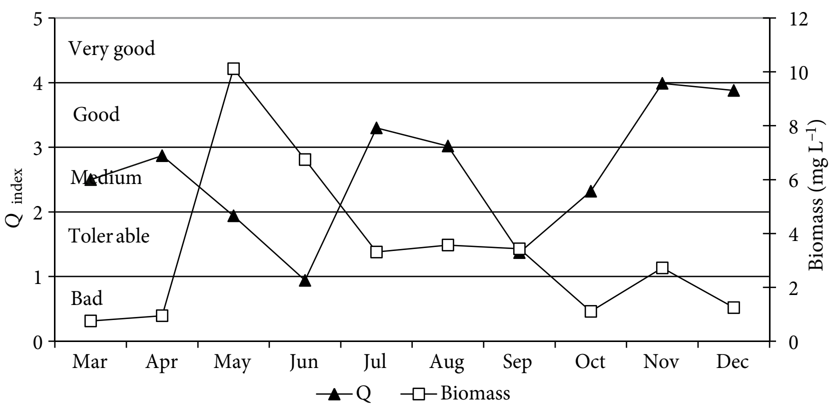

Figure 6. Seasonal changes of the phytoplankton biomass and the *Q* assemblage index in Lake Mogan, 2006 (left-side scale shows the ecological quality classes according to the *Q* index, Padisák et al., 2006).

this reason, diatoms belonging to codon **MP**, such as *Cocconeis*, *Gomphonema*, *Navicula*, and *Epithemia*, were frequently found in the lake. As the same finding has been reported from various shallow lakes, codon **MP** was created to reflect this functional trait (Padisák et al., 2006). In the present study, codon **MP** was recorded with proportion rates of only around 1%–2%, providing an insignificant proportion of the total biomass during 2006.

In a study performed from 1988 to 1989 in Lake Mogan, Chlorophyta dominance was found in the phytoplankton composition, followed by diatoms. The average Secchi depth was 1.35 ± 0.08 m, with an average Chl-*a* concentration of around 7.21 ± 0.37 mg/m^3. In that study, the lowest Chl-*a* occurred in February (1.52 mg/m^3), whereas the highest was in November (15.96 mg/m^3; Atay and Bakan, 1990). Chl-*a* concentrations were also observed to be higher than in earlier studies by Yerli et al. (2012). In the present study, lower average Secchi depth was found (1.21 ± 0.70 m), and the average and maximum concentration of Chl-*a* (8.87 ± 2.06 mg/m^3 and 28.95 mg/m^3) remained higher. These results may show advanced eutrophication of the lake compared to its state in 1988–1989.

As for the recent states of Lake Mogan, mean values of Chl-*a* and TP pointed toward eutrophic conditions according to the OECD (1982), while the average Secchi depth indicates hypertrophy. Low Secchi depth might also be influenced by the shallowness of the lake, providing evidence for wind-mediated mixing. Furthermore, as the OECD's classification has been developed for transparent lakes (Koponen et al., 2002), its classifications might be not suitable for Lake Mogan. When the lake is evaluated according to the proposition of Sondergaard et al. (2005) based on Secchi depth, Chl-*a*, algal biomass, and TP, the lake shows moderate ecological status. During the color change of Lake Mogan observed in June, a large depletion of dissolved oxygen was also observed below the depth of 1 m. The authors agree with the opinion that perhaps some chemical substances had been released into the lake, or that natural changes due to calcite precipitation had occurred. At the same time, the decay of water plants was observed, with observable fish kill. Fish kill has been periodically observed in Lake Mogan, but generally in autumnal mornings, when hypertrophy-induced severe oxygen depletion occurs, creating anoxic conditions. However, the fish kill observed in our study occurred at the beginning of summer and coincided with an unexpected drop of phytoplankton biomass. These findings may provide evidence that the fish kill of 2006 was not related to algae blooms but rather seemed to be an abnormal situation in Lake Mogan. The seasonal succession of phytoplankton showed some similarities to other temperate shallow lakes, where blooms of blue-green algae dominate in late summer. Despite a decrease in the phytoplankton biomass after June, the proportion of blue-green algae rose again in September. The lack of considerable blue-green algae dominance in Lake Mogan (2006) may also be related to the sudden condition change of the lake, which induced the dominance of colonial green algae (codon **F**) at a high proportion (93%). Colonial green algae are thought to be resistant to grazing, because of their large size and mucilaginous cover (Boyd and Tucker, 1998), and to indicate good underwater light conditions (Reynolds et al., 2002). This latter condition seemed to be proven by deep transparency in this period of the study. In September, the general seasonal pattern of eutrophic lakes occurred again; planktonic Cyanobacteria such as *Phormidium* and *Planktothrix* dominated, and their filaments created large flocks floating on the surface of the water. In October, *Microcystis aeruginosa* indicated more stable conditions of the water column, which then returned to green algae dominance.

Dominant functional groups in Lake Mogan varied according to the seasonal succession of **X2→Lo→F→S1→M→F** during the study period. Groups **X2** and **H1** were found in spring and were closely related in the CCA diagram. It was reported that codon **X2** is found in the mixing layers of mesoeutrophic shallow, clean lakes and is sensitive to lake mixing and/or filter-feeding of zooplankton (Reynolds et al., 2002). In Lake Mogan, codon **X2** showed a decrease in May, which might be a result of grazing pressure. In May and June, *Merismopedia tenuissima* and *Peridinium* spp. of codon **Lo** were dominant. The group **Lo** has been defined as a typical functional group of the summer epilimnion of mesotrophic lakes (Reynolds et al., 2002). Group **F** (*Botryococcus*, *Sphaerocystis*, *Planktosphaeria*, and *Oocystis*) showed a proportional increase in the total biomass during the summer months. This group contains large, colonial mucilaginous species; it is thought to prefer the clear epilimnia of mesoeutrophic lakes and have a tolerance for low nutrient levels and high turbidity (Reynolds et al., 2002). However, summer dominance of this codon has not yet been described from eu-hypertrophic lakes. These findings call attention to the ecological effects that might also be related to the unexpected coloration of the lake. Codon **F** was reported from Hungarian shallow lakes, occurring in the case of low phytoplankton biomass as well (Padisák et al., 2003). It is also known that chlorococcalean greens contain a large number of species and generally form only a small part (<20%) of the total biomass in shallow lakes (Padisák et al., 2003). In September the biomass proportion of codon **S1** increased with taxa *Phormidium* and *Planktothrix*. The preferred habitat of this group is turbid, mixed environments with a significant deficiency of light conditions (Reynolds et al., 2002). It was also reported in shallow Lake Balaton that enhanced eutrophication and restoration processes could produce alterations among taxa belonging to codon **S1**, as well as change between N_2-fixing and nonfixing taxa by different N/P ratios (Padisák and Reynolds, 1998). Additionally, the coloration event of Lake Mogan could normally facilitate the dominance of species of codon **S1**, rather than any other functional group of blue-green algae.

Reynolds et al. (2002) reported that species of codon **M**, which increased in October in Lake Mogan, are generally found in small eutrophic lakes with daily mixing. *Microcystis* spp. of this codon increased in September. This group is also considered to be subdominant at a medium level of biomass (approximately 4 mg/L) in shallow lakes (Padisák et al., 2003). Codon **X2** is found in mesoeutrophic lakes and **X1** in eutrophic-hypertrophic lakes (Reynolds et al., 2002). It is reported that Lake Fertő, which is similar to Lake Mogan in its shallowness, turbidity, and high conductivity, often contains colonial blue-green algae (*Aphanocapsa*, *Aphanothece*; codon **K**), green algae with good float regulation by mucilaginous envelop (*Oocystis* spp., *Planktosphaeria gelatinosa*, *Coenochloris* sp., *Labocystis planktonica*; codon **F**), and some Chlorococcales species with a long, thin structure (*Monoraphidium*, codon **X1**; *Koliella* spp., codon **X3**) (Padisák et al., 2006). Lake Mogan shows characteristics of shallow lakes, with the dominance of groups **X1** and **F**, which showed similar environmental response in the CCA. Group **X1** showed some increases in the lake with *Monoraphidium*. Its appearance was negatively correlated with Secchi depth and positively correlated with SRP and TP; this phenomenon might be explained by their tolerance for low light availability (Reynolds et al., 2002), while the cooccurrence of these algae with group **M** indicates eutrophic conditions.

With the **S1** and **M** groups in September and October, the *Q* index fell to tolerable and medium levels. In November, quality states rose once more to a good ecological level. The average *Q* index for Lake Mogan was found to be 2.6, which reflects an overall medium water quality for the lake. This value approximately represents mesotrophic (3 – medium) to mesoeutrophic conditions (2 – tolerable).

The use of the *Q* index requires a deep knowledge of taxonomy, besides further ecological information on different phytoplankton taxa. However, as an advantage, the method may provide a solution for ecological state monitoring when several lakes are compared based on late summer conditions, when phytoplankton biomass generally reaches its peak, and when the steady-state composition of phytoplankton prevails (Naselli-Flores et al., 2003)

Here, it is concluded that the *Q* assemblage index of phytoplankton was able to follow the main seasonal changes of physical and chemical conditions in Lake Mogan, 2006. Thus, the examination of the functional groups of phytoplankton communities seemed to be a useful method for ecological state estimation and may provide evidence for further examinations between the *Q* quality index and the ecological condition of other Turkish lakes.

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