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Trophic state assessment based on summer phytoplankton community structure and trophic indices: a small tectonic lake in Turkey

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ABSTRACT

Lake Gökgöl is a small lake with a tectonic origin located in Ordu, Turkey. Algal diversity and distribution as well as the trophic structure of the lake in the summer period were examined. It is a lake with poor acidic character, low dissolved oxygen content, high electrical conductivity, with very hard water characteristics, having nutritive elements particularly phosphorus, and high mineral concentration. In the phytoplankton, the highest diversity of species belongs to Bacillariophyta (33 taxa), followed by Cyanobacteria (6 taxa), Charophyta (5 taxa), Euglenozoa (3 taxa), Chlorophyta (3 taxa), Cryptophyta (1 taxa), and Miozoa (1 taxa), respectively. During the summer months, the biggest contribution to phytoplankton abundance is from Cyanobacteria (96%) and Bacillariophyta (4%). Of blue–green algae, *Chroococcus dispersus* and *Dolicospermum affine*, of the diatoms *Cyclotella radiosa*, *Achnanthidium exile*, *Ampohora ovalis*, of euglenoids *Euglena gracilis* are the taxa making a significant contribution to the phytoplankton abundance. The phytoplankton community was applied with various diversity, species richness, and evenness indices (Shannon, Pileou, Simpson, and Margaleff), and the environmental factors were applied with cluster analysis and correlation analysis. According to the correlation analysis results, the highest positive correlation is between NH_4–N, TP, and Cyanobacteria ($p < 0.01$). To determine the trophic level, phytoplankton compound quotient (PCQ), Palmer's algal genus pollution index, dominant genus scores, Carlson's trophic state index, and Burns's trophic level index were used. In conclusion, when evaluated according to the average of all parameters during the summer months, the Gökgöl Lake shows eutrophic character and clean to moderate water quality. Toxic Cyanobacteria bloom was not detected in the lake, which could pose a risk to human health. Gökgöl Lake, which does not carry the risk of eutrophication, can be evaluated for health tourism because it contains high mineral salts.

Keywords: Algal diversity; Ecological state of lake; Biological indicators; Phytoplankton; Trophic indices; Water quality

1. Introduction

The state of lake ecosystems and its changes can be assessed based on biotic and abiotic elements. Phytoplankton are the main producers in open waters, so they condition the structure and density of consumers as well as physical and chemical properties of water. Moreover, phytoplanktonic organisms are sensitive indicators, as phytoplankton structure and metabolism changes quickly in response to environmental changes. Growth rate and variability of phytoplankton are subject to cyclic changes: fluctuation and succession [1–3]. Species composition of the phytoplankton community is an efficient bioindicator for water quality [4]. Investigations of phytoplankton are an important aspect in studying water quality and eutrophication of lakes [5,6]. Phytoplankton community composition responds sensitively to changes in water quality, making phytoplankton a useful biological quality parameter for lake monitoring [7]. It would be better to analyze the basic information of the phytoplankton in order to improve water quality and prevent the occurrence of water bloom [8,9]. Although individual algal species can be rated primarily in terms of trophic preferences, they are also frequently adapted to other related ecological factors. Acidity, oligotrophic waters are frequently slightly acid with low calcium concentrations, and vice versa for eutrophic conditions. High-nutrient lakes, with established populations of blue–greens and dinoflagellates, often have these as dominant algae during the summer months [10].

Lake Gökgöl, located in the north of Turkey in Middle Black Sea Region is a small lake with a slight acidic character. The water of the lake, which is fed with underground water, has soda. Lake Gökgöl is a natural lake; however, arrangements were made around the lake which is in the center of Gölköy town and it is used as a recreation area (child and family park, an area of walk and rest, swimming area especially for children). The excess water of Lake Gökgöl, which is a closed lake, is removed from an artificially opened canal. Water quality of Lake Gökgöl, which is used by the local people for irrigation and as swimming water, is very important in terms of public health. In a previously conducted study [11], the water was reported to show extreme characteristics. No other limnological studies have been conducted on the lake which has poor acidic characteristic, high conductivity and hardness rate, and low dissolved oxygen content. Species diversity, abundance, and distribution of planktonic algae in the summer period play a significant role in determining the water quality and trophic status of the environment. Summer months are the season in which algae community, especially indicator and toxic species show the best development. However, no study has been conducted on the phytoplankton assemblage of Lake Gökgöl. Therefore, in this study, it was aimed to determine the effect of physico-chemical parameters on the phytoplankton composition and abundance of the lake ecosystem Gökgöl, which is prone to anthropogenic pressures in summer.

2. Materials and methods

2.1. Study area

Lake Gökgöl, which is in the north of Anatolia (Turkey), is located in the temperate zone, in the province of Ordu. The altitude of Lake Gökgöl is 840 m and it is positioned at 40°41′ N and 37°36′ E. The lake is one of the smallest lakes of the country and it is created in the section where the fault origin reaches the surface. Its origin is tectonic. Its area is 2,020 m^2, its perimeter is 168 m, and its diameter is 48 m. The average depth of the lake is 8.5 m, and its maximum depth is about 10 m. The lake is fed with the underground spring waters and rain waters have an exit from the surface with a canal. No fish lives in the lake (Fig. 1).

2.2. Phytoplankton analysis

Surface phytoplankton and water samples were collected from June to August of 2009. The samples for qualitative phytoplankton analysis were taken with the plankton net, with a mesh size of 55 μm. The samples for the quantitative analysis were taken directly to the plastic bottles with a volume of 1 L, from the depth of 0.5 m under water surface. Phytoplankton samples were preserved with 4% formaldehyde (identification of phytoplankton) and lugol's iodine solution (quantification of phytoplankton). A settling and siphoning procedure was followed to concentrate samples from 1,000 to 10 mL. For counting phytoplankton cells and identification of genera and species, 1 mL of concentrated samples were transferred into a Sedgewick–Rafter plankton counting chamber. All the 1,000 squares in the Sedgewick–Rafter were examined microscopically using 20×–40× objectives for the phytoplankton cells. Oil immersion 100× objective on a Leica DM500 microscope was also made use of for confirming the genera or species. Diatoms were identified on permanent slides. Taxonomic identifications were carried out according to Krammer and Lange-Bertalot [12–15], Cox [16], and John et al. [17]. Taxonomic identifications were carried out according to the *AlgaeBase*; and website database was also used to check the taxonomy of algae. For chlorophyll-*a*, 1,000 mL of water

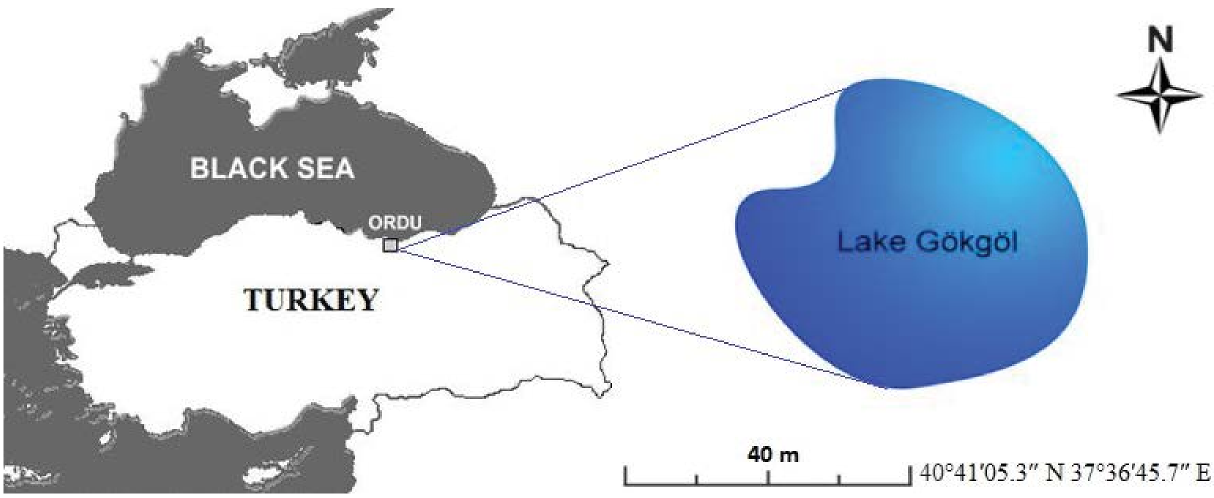

Fig. 1. Location of the study area.

samples was filtered immediately after collecting through glass fiber filter (Whatman GF/C). The materials left in the filters were extracted with acetone (90% v/v) in the dark for 24 h at 4°C. The extracting solution was measured photometrically (UV-vis 1800 spectrophotometer, SHIMADZU, Japan) and the concentration of chlorophyll-*a* was calculated by the standard method [18].

2.3. Data analysis

In order to determine the trophic level of the lake and the water quality phytoplankton compound quotient (PCQ) [19], Palmer's algal genus pollution index (API) [20], dominance genus score [21], Carlson's trophic state index (TSI) [22], and Burns's trophic level index (TLI) [23] were used. The diversity and species richness of community structure was determined according to Shannon diversity index (H'), Pielou's evenness index (J') Simpson diversity index (D), and Margalef's species richness index (R) using Biodiversity Pro. 2. We calculated species diversity of the phytoplankton community assemblages, identified through the cluster analysis. For the analysis of community composition, we used multivariate techniques. Species distribution patterns in relation to environmental factors, as well as the partition of lake groups, were analyzed using canonical correspondence analysis (CCA) within the CANOCO 4.5 software. To illuminate the relationships of phytoplankton abundance to trophic indicators, Pearson's correlation analysis was done using IBM SPSS Statistics 22.

3. Results

Lake Gökgöl is a lake with poor acidic character, low dissolved oxygen, very high conductivity, phosphorus, calcium, and hard water characteristic (Table 1). In the analyses made in the surface water, it was found that the water of Lake Gökgöl has a poor acidic character. Lake Gökgöl's average pH value is 6.31 in the surface water, and approximate pH is 6 in the depth of 5 m. Lake Gökgöl has an acidic character because of the lake's tectonic origin and the waters with carbon dioxide reaching from the depth to the surface. Dissolved oxygen content and oxygen saturation are very low (DO < 5 mg/L). pH and DO values are directly related to the lack of living thing diversity in the lake. Electrical conductivity (EC) of water is very high. EC was measured as 1,294.3 µS/cm on average on the surface and as 1,278.5 µS/cm at 5 m. DO was very low and NO_2–N was recorded high in the lake. Very high level of phosphorus recorded resulted from the geologic structure of the lake. Calcium ion which gives the water hardness was recorded very high. The reason for this was the lithologic structure of the research area. Total hardness (TH) value was included in the very hard water class (30–50 d°H).

When Lake Gökgöl's summer phytoplankton diversity was examined, a total number of 7 phyla and 52 taxa were identified in the phytoplankton community. The total number consisted of 33 species of Bacillariophyta, 6 species of Cyanobacteria, 5 species of Charophyta, 3 species of Chlorophyta, 3 species of Euglenozoa, 1 species of Cryptophyta, and 1 species of Miozoa (Table 2).

Diatoms were the most important group in terms of species number (63%), followed by Cyanobacteria (11%), Charophyta (10%), Chlorophyta (6%), Euglenozoa (6%), and by the others 2%. During the summer months *Achnanthidium minutissimum*, *Amphora ovalis*, *Chroococcus dispersus*, *Cymbella affinis*, *Euglena gracilis*, *Geitlerinema amphibium* (*Oscillatoria amphibia*), *Mougeotia parvula*, *Pediastrum duplex*, *Lacunastrum gracillimum* (*P. duplex* var. *gracillimum*), *Pinnularia viridis* var. *fallax*, *Pseudoanabaena limnetica*, and *Klebsormidium subtilissimum* (*Ulothrix subtilissima*) were recorded in each

Table 1
Some features of Lake Gökgöl's surface water [11]

Parameters	Minimum–Maximum	Average	Standard deviation
pH	6.22–6.40	6.31	0.09
Water temperature (T) (°C)	19.3–26.8	23.20	3.76
Dissolved oxygen (DO) (mg/L)	3.62–5.63	4.45	1.05
Conductivity (EC) (µS/cm)	1,269–1,320	1,294.33	25.50
Total dissolved solvent (TDS) (mg/L)	635–663	649	14.00
Suspended solids (SS) (mg/L)	0.2–2.0	1.20	0.92
NH_4–N (mg/L)	0.22–1.20	0.707	0.49
NO_2–N (mg/L)	0.022–0.045	0.032	0.01
NO_3–N (mg/L)	0.20–3.90	2.40	1.95
SO_4 (mg/L)	82.0–88.0	85.33	3.05
PO_4–P (mg/L)	0.336–0.421	0.385	0.04
Total phosphorus (TP) (mg/L)	1.03–1.42	1.223	0.19
Ca (mg/L)	256.52–306.21	288.77	27.96
Mg (mg/L)	23.56–51.52	33.613	15.5
Total hardness (TH) (mg/L)	853.3–892.56	870.27	20.16
Chlorophyll-*a* (chl-*a*) (µg/L)	0.654–1.842	1.256	0.59
Secchi depth (SD) (m)	1.72–2.26	1.967	0.27

Table 2
Taxonomic composition of the planktonic algae in Lake Gökgöl

Phylum	Class	Order	Family	Genus	Species
		Chroococcales	Chroococcaceae	*Chroococcus*	*C. dispersus* (Keissler) Lemmermann
					C. minimus (Keissler) Lemmermann
		Nostocales	Nostocaceae	*Dolichospermum*	*D. affine* (Lemmermann) P. Wacklin, L. Hoffmann & J. Komárek
Cyanobacteria	Cyanophyceae	Pseudanabaenales	Pseudanabaenaceae	*Geitlerinema*	*G. amphibium* (C. Agardh ex Gomont) Anagnostidis
				Pseudanabaena	*P. catenata* Lauterborn
					P. limnetica (Lemmermann) Komárek
		Achnanthales	Achnanthidiaceae	*Achnanthidium*	*A. exile* (Kützing) Heiberg
					A. biasolettianum (Grunow) Round & Bukhtiyarova
					A. minutissimum (Kützing) Czarnecki
			Cocconeidaceae	*Cocconeis*	*C. diversa* J.R.Carter
		Bacillariales	Bacillariaceae	*Hantzschia*	*H. amphioxys* (Ehrenberg) Grunow
				Nitzschia	*N. palea* (Kützing) W. Smith
		Cymbellales	Cymbellaceae	*Cymbella*	*C. affinis* Kützing
					C. cymbiformis var. *nonpunctata* Fontell
				Brebissonia	*B. lanceolata* (C. Agardh) Mahoney & Reimer
				Encyonopsis	*E. microcephala* (Grunow) Krammer
			Gomphonemataceae	*Gomphonema*	*G. apicatum* Ehrenberg
					G. olivaceum (Hornemann) Brébisson
					G. truncatum Ehrenberg
		Fragilariales	Fragilariaceae	*Fragilaria*	*F. crotonensis* Kitton
				Ulnaria	*U. ulna* (Nitzsch) P. Compère
		Naviculales	Cavinulaceae	*Cavinula*	*C. scutiformis* (Grunow ex A. Schmidt) D.G. Mann & A.J. Stickle
Bacillariophyta	Bacillariophyceae		Diploneidaceae	*Diploneis*	*D. elliptica* (Kützing) Cleve
			Naviculaceae	*Caloneis*	*C. amphisbaena* (Bory de Saint Vincent) Cleve
				Navicula	*N. cincta* (Ehrenberg) Ralfs
					N. cryptocephala Kützing

					N. lanceolata Ehrenberg
					N. tripunctata (O.F. Müller) Bory de Saint-Vincent
					N. sp.
			Pinnulariaceae	*Pinnularia*	*P. acutobrebissonii* Kulikovskiy, Lange-Bertalot & Metzeltin
					P. intermedia (Lagerstedt) Cleve
					P. rupestris Hantzsch
					P. viridis (Nitzsch) Ehrenberg
					P. viridis var. *fallax* Cleve
					P. sp.
		Surirellales	Surirellaceae	*Surirella*	*S.* sp.
		Thalassiophysales	Catenulaceae	*Amphora*	*A. ovalis* (Kützing) Kützing
		Thalassiosirales	Stephanodiscaceae	*Cyclotella*	*C. radiosa* (Grunow) Lemmermann
				Pantocsekiella	*P. kuetzingiana* (Thwaites) K.T. Kiss & E. Ács
Cryptophyta	Cryptophyceae	Cryptomonadales	Cryptomonadaceae	*Cryptomonas*	*C. erosa* Ehrenberg
Miozoa	Dinophyceae	Gonyaulacales	Ceratiaceae	*Ceratium*	*C. hirundinella* (O.F. Müller) Dujardin
		Euglenales	Euglenaceae	*Euglena*	*E. gracilis* Klebs
Euglenozoa	Euglenophyceae			*Trachelomonas*	*T. ovata* Roll
					T. volvocina (Ehrenberg) Ehrenberg
		Sphaeropleales	Hydrodictyaceae	*Pediastrum*	*P. duplex* Meyen
Chlorophyta	Chlorophyceae			*Lacunastrum*	*L. gracillimum* (West & G.S. West) H. McManus
			Selenastraceae	*Monoraphidium*	*M. minutum* (Nägeli) Komárková-Legnerová
		Desmidiales	Closteriaceae	*Closterium*	*C. closterioides* (Ralfs) A. Louis & F. Peeters
	Conjugatophyceae	Zygnematales	Zygnemataceae	*Mougeotia*	*M. parvula* Hassall
Charophyta				*Spirogyra*	*S. mirabilis* (Hassall) Kützing
					S. parva (Hassall) Kützing
	Klebsormidiophyceae	Klebsormidiales	Klebsormidiaceae	*Klebsormidium*	*K. subtilissimum* (Rabenhorst) P.C. Silva, K.R. Mattox & W.H. Blackwell

sample of the Lake Gökgöl phytoplankton. An increase in the blue–green algae was recorded in the lake depending on the increase of temperature and nutrients. Particularly the species of *C. disperses*, which was the coccoidal species, provided a significant contribution to the summer phytoplankton. In terms of phytoplankton intensity, Cyanophyceae was the most important group (96%), subdominant group Bacillariophyceae (4%), and the other groups have been recorded in significant numbers. Total organism numbers were recorded as 1,216; 2,367; and 3,426 cells/mL during the summer months. For this reason, it can be said that the lake has eutrophic waters due to the presence of blue–green algae. These are abundant in summer months as 1,170; 2,197; and 3,249 cells/mL, respectively. *C. dispersus* included in this alga group increased extremely in summer months and were counted as 1,000; 2,120; and 2,970 cells/mL. It was recorded that abundance of *Dolicospermum affine* has 46–272 cells/mL in summer months. The contribution of diatoms was less to phytoplankton abundance (42, 170, and 78 cells/mL). *Cyclotella radiosa* from centric diatoms was recorded as 113 cells/mL in July, pennat diatoms *Cocconeis diversa* was recorded as 20 cells/mL in June and *Achnanthidium exile* was recorded as 67 cells/mL in August. *E. gracilis* from euglenoids was recorded as 98 cells/mL in August when the temperature rises. The contribution of other taxa to the phytoplankton intensity were not to be much significant.

This is an important aspect indicating the distribution of phytoplankton and their relation to pollution. In Lake Gökgöl, Shannon H' index is 0.655, 0.522, 0.544 bit/ind., respectively, during the summer months, and evenness J' index were calculated as 0.223, 0.167, and 0.196 (Table 3). According to these results, species diversity of the lake was very low (Shannon H', 0.0–1.0) and its pollution level was very high. The values under 1.0 indicate that there is pollution and degradation of habitat structure. Simpson's diversity index (D) is 0.695, 0.805, and 0.759, respectively, in the summer months. In terms of these results, phytoplankton diversity has the highest possible equal number of different species (D, 0.5–1).

In terms of the trophic status of the lake according to the PCQ, Lake Gökgöl is hypereutrophic (PCQ > 7) according to PCQ = 14. The lake was assessed according to phytoplankton dominant genus scores. Accordingly, the genera of *Anabaena*, *Chroococcus*, *Cyclotella*, and *Euglena* in the lake were recorded as dominant species. According to the score results [(8 + 6 + 2 + 10)/4 = 6.5], the lake's trophic status is meso-eutrophic (5.6–7.5). The species that are tolerant to organic pollution in Lake Gökgöl are as follows: *A. minutissimum*, *Cryptomonas erosa*, *E. gracilis*, *Ulnaria ulna*, *Fragilaria crotonensis*, *Hantzschia amphioxys*, *Navicula cryptocephala*, *Nitzschia palea*, *P. duplex*. Considering the species recorded in the counting results as more than 50 cells/mL, pollution indices of the species of *Cyclotella* and *Euglena* located in Palmer's API were calculated (API = 3).

In Lake Gökgöl, TSI_{Chl-a} value was found as 26.43–36.59, TSI_{SD} was determined as 48.25–52.19, TSI_{TP} was recorded as 88.03–91.28 (Fig. 2). In the summer months TSI_{mean} was evaluated as 57.42, with the highest value in August (TSI = 60), and the lowest value in June (TSI = 54). TLI values in Lake Gökgöl were found as 4.45 (eutrophic; TLI 4–5), 5.45 (supertrophic; TLI 5–6), and 5.69 (supertrophic; TLI 4–5) in summer months, respectively (Table 3).

Algae are related with physicochemical variables and each other. The Pearson correlation coefficients between

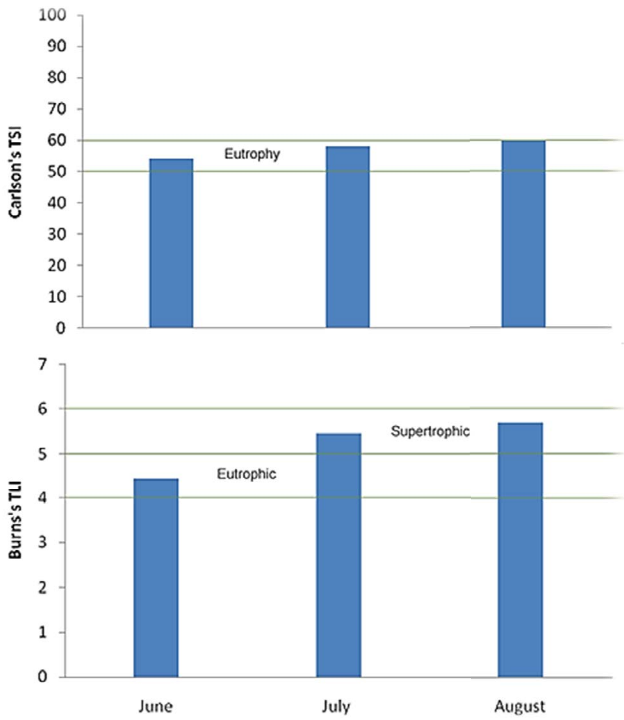

Fig. 2. TSI and TLI changes of Lake Gökgöl in summer months.

Table 3
Results of biotic and trophic indices in Lake Gökgöl

Index	June	July	August	Mean
Biodiversity index				
Shannon H'	0.655	0.522	0.544	0.574
Shannon H'_{max}	2.944	3.135	2.773	2.951
Pielou evenness J'	0.223	0.167	0.196	0.195
Simpson D	0.695	0.805	0.759	0.753
Simpson evenness $E_{1/D}$	1.439	1.242	1.318	1.333
Margalef R	9.078	8.304	7.97	8.451
Trophic status index				
TSI_{Chl-a}	26.43	32.96	36.59	31.99
TSI_{SD}	48.25	50.59	52.19	50.34
TSI_{TP}	88.03	90.47	91.28	89.93
TSI_{mean}	54.24	58.01	60.02	57.42
Trophic level index				
TLc (Chl-*a*)	1.75	2.49	2.89	2.38
TLs (SD)	4.11	4.31	4.44	4.29
TLp (TP)	7.59	7.81	7.88	7.76
TLn (TN)	4.35	7.17	7.56	6.36
TLI_{mean}	4.45	5.45	5.69	5.2

various physicochemical parameters, algal groups, and chl-*a*, based on data from 3 months, are listed in Table 4. Whether the correlation coefficient as a result of Pearson's correlation analysis applied is statistically significant was assessed within a certain degree of significance ($p < 0.01$ and 0.05). A significant positive correlation was found between TDS and EC ($r = 1.000$, $p < 0.01$). SO_4 and NO_2–N have negative correlation ($r = -1.000$, $p < 0.05$). PO_4–P has positive correlation with the NO_3–N ($r = 0.998$, $p < 0.05$). TP and NH_4–N have positive correlation ($r = 1.000$, $p < 0.01$). Mg has negative correlation with the Ca ($r = -1.000$, $p < 0.05$). TH is positively correlated with NO_2–N ($r = 0.998$, $p < 0.05$); however, it is negatively correlated with SO_4 ($r = -0.999$, $p < 0.05$).

Cyanobacteria showed a significant positive correlation with NH_4–N and TP ($r = 1.000$, $p < 0.01$), and water temperature ($r = 0.997$, $p < 0.05$). We found a significant positive correlation between green algae (Chlorophyta–Charophyta) abundance and euglenoids ($r = 1.000$, $p < 0.01$). Cryptophyta was positively correlated with Mg ($r = 0.997$, $p < 0.05$). However, it was negatively correlated with Ca ($r = -0.999$, $p < 0.05$). Total phytoplankton and chl-*a* values showed a positive correlation with water temperature ($r = 0.999$, $p < 0.05$), NH_4–N ($r = 0.999$, $p < 0.05$), TP ($r = 0.999$, $p < 0.05$), and Cyanobacteria ($r = 1.000$, $p < 0.05$), respectively. There are a strong positively correlation between chlorophyll-*a* concentration and total phytoplankton abundance in the lake during the summer months ($r = 1.000$, $p < 0.01$).

The relationship between the phytoplankton communities and 17 environmental variables were researched using a CCA (Fig. 3). Two components comprised the analysis of results. The eigenvalues for CCA axes 1 and 2 are 0.024 and 0.004, and the algal groups-environment correlations for CCA axes 1 (0.776) and 2 (0.998) are high. NO_3–N, PO_4–P, Mg, Ca, SD, Cryptophyta, temperature, chl-*a*, Cyanobacteria, NH_4–N, TP, NO_2–N, SO_4, TH, DO, and pH are in the first component and explain 74.80% of the total variation. TSS, TDS, EC, Bacillariophyta, Euglenozoa, and Chlorophyta–Charophyta are found in the second component. They also describe the 25.22% of the total variation. In order to determine the relation of algal groups, Bray–Curtis cluster analysis is widely used. In terms of cluster analysis, the highest similarities are seen between June–July (84%) (Cyanobacteria; 1,170 and 2,197 cells/mL). There are similarities between July and August (79%) (Cyanobacteria; 2,197 and 3,249 cells/mL), June–August (75%).

4. Discussion

Summer period is a good time for water quality assessment and trophic state depicts on the subject of biological productivity in lakes. Nutrient effects on the abundance of phytoplankton are commonly used to indicate trophic status. In this study, which was carried out on Lake Gökgöl in summer period, planktonic algae, and trophic status were researched. According to Turkish Management of Surface Water Quality Regulation [24], the quality of lake water is; pH, water temperature is first class in terms of NO_3–N and SO_4, second class in terms of NH_4–N and TSS, third class in terms of DO and NO_2–N and fourth class in terms of NH_4–N, PO_4–P [11]. TH is very high according to the classification made by Klee [25]. It is even very close to hard water class anomalously (48.73 d°H). The earth structure of the lake supported by underground waters is of tectonic origin and has a hard water character due to tectonic–calcareous structure.

Phytoplankton compositions are affected by different environmental factors such as pH, light, and temperature [26]. Besides, due to their importance as the primary producers in food webs and ensuring ecological balance, species of phytoplankton can be used as indicators of water quality [27,28]. Each group of the planktonic algae may be found as dominant depending on the quality of water, nutrition quality, and seasons. Blue–green algae compose the dominant group particularly in waters rich for nutrition elements in summer months. If the nutrition elements increase extremely, certain algae are reproduced extremely, and water bloom may arise. The cyanophytes found in Lake Gökgöl were small, spherical or ovoid cells of chrococcal species. Coccal blue–green algae can only be found at pH > 4.5 [29]. Blue–green algae at high cells number have often been considered as characteristic of eutrophic environments. These algae, however, are not exclusive to productive environments. Generally, the eutrophic lakes are year round dominated by blue–green algae, which occupy an advantageous position (such as pollution resistibility) in extreme environmental conditions [30]. *C. dispersus* being euplankter finds in many lakes of both hard and soft water [31]. This species has important contribution to the summer phytoplankton of the lake. It is a plankton of less nutrient-rich lakes and ponds [17] and present in clear ponds and lakes; oligotrophic or mesotrophic reservoir, rarely in slightly brackish waters. Also, the general distributions of this species are temperate zones, all over Eurasia, Asia, and North America [32]. In the lake, diatoms members are the richest group in terms of species diversity in the phytoplankton assemblage. It is known that diatoms are generally a dominant group in calcareous regions. In environments

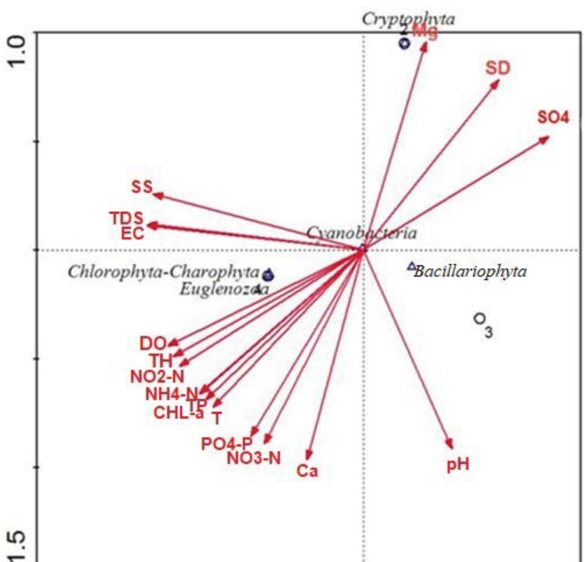

Fig. 3. CCA graph of phytoplankton groups and environmental variables.

Table 4
Correlation analysis for the environmental variables and phytoplankton of Lake Gökgöl, during the summer season

	pH	*T*	DO	EC	TDS	TSS	SD	NH_4–N	NO_2–N	NO_3–N	SO_4	PO_4–P	TP	Ca	Mg	TH	Cya	Bac	Eug	Cry	Chl	Tphy	Chl-*a*
pH	1																						
T	0.611	1																					
DO	0.290	0.935	1																				
EC	–0.433	0.449	0.736	1																			
TDS	–0.444	0.439	0.729	1,000**	1																		
TSS	–0.605	0.261	0.586	0.980	0.982	1																	
SD	–0.672	–0.997	–0.904	–0.377	–0.366	–0.184	1																
NH_4–N	0.545	0.997	0.961	0.520	0.510	0.338	–0.987	1															
NO_2–N	0.402	0.971	0.993	0.651	0.642	0.486	–0.948	0.987	1														
NO_3–N	0.786	0.970	0.820	0.217	0.205	0.017	–0.986	0.947	0.882	1													
SO_4	–0.387	–0.967	–0.995	–0.663	–0.655	–0.500	0.943	–0.984	–1,000*	–0.874	1												
PO_4–P	0.749	0.982	0.852	0.272	0.262	0.074	–0.994	0.964	0.908	0.998*	–0.901	1											
TP	0.542	0.996	0.962	0.522	0.513	0.341	–0.987	1,000**	0.987	0.946	–0.985	0.963	1										
Ca	0.874	0.918	0.718	0.058	0.047	–0.143	–0.947	0.883	0.796	0.987	–0.786	0.976	0.882	1									
Mg	–0.863	–0.927	–0.735	–0.082	–0.071	0.119	0.954	–0.894	–0.810	–0.991	0.800	–0.981	–0.893	–1,000*	1								
TH	0.350	0.956	0.998*	0.693	0.684	0.534	–0.929	0.976	0.998*	0.854	–0.999*	0.883	0.977	0.760	–0.776	1							
Cya	0.549	0.997*	0.959	0.516	0.506	0.334	–0.988	1,000**	0.986	0.948	–0.983	0.965	1,000**	0.885	–0.896	0.975	1						
Bac	0.952	0.339	–0.017	–0.689	–0.697	–0.820	–0.412	0.261	0.102	0.559	–0.086	0.510	0.258	0.684	–0.666	0.046	0.266	1					
Eug	0.055	0.824	0.971	0.876	0.870	0.762	–0.777	0.867	0.936	0.661	–0.942	0.703	0.869	0.533	–0.553	0.955	0.865	–0.254	1				
Cry	–0.896	–0.899	–0.685	–0.011	1,000	0.189	0.931	–0.860	–0.766	–0.979	0.756	–0.965	–0.859	–0.999*	0.997*	–0.729	–0.863	–0.717	–0.492	1			
Chl	0.064	0.829	0.974	0.872	0.866	0.756	–0.782	0.872	0.939	0.667	–0.945	0.709	0.873	0.540	–0.560	0.957	0.869	–0.245	1,000**	–0.500	1		
Tphy	0.574	0.999*	0.950	0.489	0.479	0.305	–0.992	0.999*	0.980	0.957	–0.977	0.973	0.999*	0.899	–0.909	0.968	1,000*	0.296	0.849	–0.878	0.854	1	
Chl-*a*	0.574	0.999*	0.950	0.489	0.479	0.304	–0.992	0.999*	0.980	0.958	–0.977	0.973	0.999*	0.899	–0.910	0.968	1,000*	0.296	0.849	–0.878	0.854	1,000**	1

**Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed).
Cya, Cyanobacteria; Bac, Bacillariophyta; Eug, Euglenozoa; Cry, Cryptophyta; Chl, Chlorophyta-Charophyta; Tphy, total phytoplankton; Chl-*a*, chlorophyll-*a*.

with high conductivity, diatoms are abundant as well [33]. *Achnanthidium* and *Cymbella*, which can tolerate such extreme conditions, are known as calciphiles or calcium loving organisms. *Achnanthidium* is widely spread and very common and found in a wide range of water qualities. They are sensitive to wastewater and β-α-mesosaprobic conditions [16], pH difference [34]. *C. affinis* is widespread in littoral, common epilithic or epiphytic, in standing or flowing waters [16]. Blue–green algae occur in a wide range of environments, they tend to be more abundant in summer. For instance, picoplankton species are important in the summer phytoplankton [17]. In the water basins with eutrophic characteristic, blue–green algae were reported to make blooms in the Black Sea Region in summer months [35–37]. *Euglena* are common and abundant in ponds and shallow waters. Some species are found in acid waters [10]. *E. gracilis* are cosmopolitan, planktonic and benthic in small water bodies, peat bogs, puddles, lakes, springs, village ponds, field, and fishponds; often forms water blooms [32]. *E. gracilis* are known as common species from unpolluted to heavily polluted water in Europe, Asia, and North America [17]. These algae have an important role in the productivity of Lake Gökgöl.

Diversity has two basic components: richness, or number of species in a given area, and evenness, or how relative abundance or biomass is distributed among species [38]. Diversity index proves to be an important tool in determining the trophic status of lakes. Shannon–Weaver and Simpson from diversity indices were performed to explain the diversity of phytoplankton [39]. Such indices are important for large-scale monitoring and assessment efforts, such as the European Water Framework Directive (WFD) [40]. Once water quality classification criteria of WFD are considered, Lake Gökgöl is "bad" category according to diversity indices in terms of average values of summer months ($H' < 1.56$–0.90; $J' < 0.50$–0.27; $D > 0.36$–0.64). Margalef's richness index (R) is another criterion to evaluate the phytoplankton diversity, which depends on the species. In Lake Gökgöl the highest R was recorded in June (9.078). In July and August, it was 8.304 and 7.970, respectively. To determine community ecology, use with a lot of indices has stimulated researchers [41–43]. The biological index of H' gives a good description of the community structural and biotic aspects. However, only if used in combination with the species richness, the evenness index, and maybe the floristic data, highlighting the dominance of opportunistic species gives a safe description of the community structure and composition. Low species diversity refers to the presence of relatively few successful species in the habitat, and a quite stressful environment due to relatively few ecological niches. Since very few organisms would be well adapted to the environment and as a result of simple food webs, environmental changes would lead to serious effects. Extreme conditions such as high mountain lakes [44,45] or harsh conditions such as soda lake [46] and salty lake [47] cause a great pressure on biodiversity. The living beings in these ecosystems survive if they adapt well to environmental conditions or if they have large ecological tolerance. Certain species may have increased resistance against changes in environmental factors. However, if the value of the environmental factor becomes lower than the lower limit or higher than the upper limit for a certain species, this species cannot adapt quickly to such changing environmental conditions. In this case, its place in the ecosystem is occupied by another species. In the Lake Gökgöl, in summer months, particularly *C. dispersus* (Cyanobacteria) made excessive reproduction. In addition to this, certain taxa that provide contribution to the phytoplankton density are: of blue–green algae *D. affine*, of diatoms *C. radiosa*, *A. exile*, *A. ovalis*, of euglenoids *E. gracilis*. In Lake Gökgöl, the index values were recorded as low because of environmental stress and negative effects. The diversity of species and relative abundance is affected by physical changes arising from physico-chemical properties of lake water, organic enrichment, foods, sediment loads, and surface waters. The lake has acidic character, due to the fact that its dissolved oxygen content is low, and the water is too hard [11], phytoplankton diversity is very low. Similar results were reported in some Danish lakes [48].

A classification for each lake is given based on its current trophic state. Trophic state is classified by using water characteristic and dominant phytoplankton [4,19,49,50]. Lake Gökgöl is hypereutrophic according to PCQ. According to dominant genus scores (6.5), the lake has general water quality including moderately dirty (meso-eutrophic). According to API result, Lake Gökgöl has low organic pollution. The trophic state of a lake can be determined from phytoplankton productivity or total biomass. Chlorophyll-*a* concentration (chl-*a*), total phosphorus (TP), and Secchi depth (SD) are the most significant measures of the lake's trophic status [22,51,52]. TSI is a significant index used for determining the trophic status of a lake. Lake Gökgöl is oligotrophic according to average $TSI_{Chl\text{-}a}$ value, meso-eutrophic according to TSI_{SD} value, and hypertrophic according to TSI_{TP} value. TSI_{mean} value indicates that Lake Gökgöl is eutrophic (TSI = 50–70). In the Gaga Lake found in the same region, trophic level is oligotrophic (<40) according to $TSI_{Chl\text{-}a}$ and TSI_{SD} values, mesotrophic according to TSI_{TP} value (40–50) [53] (Table 5). Besides, TLI is used to determine water quality and trophic level of lakes [23]. It is seen that average TLI value (5.19) is supertrophic [23] in the Gökgöl Lake ($5.0 < TLI < 6.0$). According to the OECD [52] report, when the trophic structure of the lake is assessed it is, it is oligotrophic according to the chl-*a* value (1–2.5 μg/L), meso-eutrophic according to the SD value (3–1.5 m), and hyper-eutrophic according to the TP value (TP > 100, 385 μg/L). These values show similarity with Carlson's TSI.

In recent years, trophic status of lakes have been tried to be determined by using Carlson's TSI, OECD criteria, water quality, and plankton diversity. Lake Mogan (Ankara) according to Carlson's TSI has eutrophic characters [54]. Trophic level of Sarımsaklı Dam Lake (Kayseri) is eutrophic in terms of water quality parameters and zooplankton species [55]. Trophic status of lakes Acı, Meke, and Suğla (Konya) were determined according to Turkish WPCR and TSI. As a result of these researches, it was determined that Acı Lake is oligotrophic, Meke and Suğla lakes are eutrophic [56]. Water quality and TSI values, based on TP, SD and chl-*a*, indicated that Lake Uluabat was an eutrophic system [57]. Afşar Dam Lake (Manisa) was eutrophic according to TSI and OECD [58]. When the Gaga Lake (Ordu) trophic state is compared with OECD criteria, the lake is oligotrophic according to chl-*a* and SD. It has also mesotrophic character

Table 5
Trophic category of two lakes in the same region

Trophic model/ index	Lake Gökgöl (present study)		Lake Gaga (summer period) [53]	
	Mean (Range)	Trophic category	Mean (Range)	Trophic category
PCQ [19]	14 (>7)	Hypertrophic	3.78 (2–5)	Mesotrophic
DGS [21]	6.5 (5.6–7.5)	(Meso-eutrophic)	4.43 (3.6–5.5)	Mesotrophic
TSI_{mean} [22]	57.42 (50–70)	Eutrophic	38.74 (30–40)	Oligotrophic
$TSI_{Chl\text{-}a}$ [22]	31.99 (30–40)	Oligotrophic	30.21 (30–40)	Oligotrophic
TSI_{TP} [22]	89.93 (70–100+)	Hypertrophic	47.35 (40–50)	Mesotrophic
TSI_{SD} [22]	50.34 (50–70)	Eutrophic	38.65 (30–40)	Oligotrophic
TLI_{mean} [23]	5.2 (5.0–6.0)	Supertrophic	–	–

DGS: dominance genus score

concerning TP values. The results of TSI show a variation from oligotrophy to mesotrophy in the Gaga Lake [53]. Trophic status of lakes Karagöl and Mogan (Ankara) has eutrophic characteristics according to OECD, water parameters, and zooplankton [59]. The trophic states of five lakes in Haveri district (India) were determined using Calson's TSI. The study showed that Akkamahadevi, Neharuhalankere, and Heggere lakes are moderately eutrophic followed by Dundibasaweshwar and Mullankere lakes, which are highly eutrophic [60]. Trophic status of Lake Shkodra (Albania) has oligotrophic waters according to Carlson's TSI [61]. The average TSI value is 57 in the Sıddıklı Reservoir (Turkey). According to this data, the trophic state of the lake is eutrophic [62]. Also, characteristic assemblages of phytoplankton species are found in water with different trophic states. It has been reported that the phytoplankton community structure of Sazlıdere and Büyükçekmece dams show mesotrophic characteristics [63,64].

Since Lake Gökgöl is fed with groundwater, the quality of groundwater has been quite effective on the lake ecology. This is because it has been reported that groundwater with different hydrochemical properties changes the environmental parameters of the lake and that this situation sometimes causes the lake to gain the characteristics of polluted water [46]. Since the surrounding of Lake Gökgöl has been completely concreted with landscaping, its natural ecosystem feature has been lost. Surface polluted water and precipitation coming from settlements other than groundwater are not sufficient for a water change in the lake. However, a water change is an important factor affecting the water quality of the lake and it is especially important for public health because in summer months, children swim in the lake, and the water removed from the lake artificially with a canal is used in irrigation by the locals.

5. Conclusions

To determine the trophic state of a lake, phytoplankton assemblage structure and abundance during the summer period and chl-*a* values and nutrients contents are good indicators. When the phytoplankton-based summer season trophic status of Lake Gökgöl is evaluated; algal abundance, diversity indices, and trophic indices are eutrophic according to their mean values. According to both OECD criteria and Carlson's TSI values, the Gökgöl Lake is oligotrophic according to chl-*a* parameter, hypertrophic according to TP parameter, and eutrophic according to SD parameter. When evaluated according to the average of the summer months of all parameters, the lake shows eutrophic character ($51 < TSI < 70$).

Due to tectonic origin, the Gökgöl Lake has low pH and dissolved oxygen, high EC, and hardness. For this reason, blue–green algae, and diatoms that are resistant to environmental conditions are dominant in Lake Gökgöl. However, in the Gökgöl Lake, the concentration of chl-*a*, one of the best indicators of lake productivity, is low, as the abundance of phytoplanton is not high in the summer months when algae are best developed and small coccoid blue–green algae are dominant. In terms of this parameter (chl-*a*), Lake Gökgöl showed oligotrophic character. This result was influenced by the fact that the lake is fed with groundwater, it is a closed lake and the contaminated surface waters are collected in the lake since it is located in the city. Although high phosphorus originating from wastewater, rock, and/or groundwater showed the trophic structure of the lake at hypereutrophic level, extreme conditions of the lake (e.g., low dissolved oxygen concentration, circum neutral pH, high degree of hardness, and conductivity) limited algae biodiversity and algae intensity and created an environment for species who have a large tolerance to extreme environments such as Cyanobacteria. The fact that Lake Gökgöl, which does not contain toxic species and risk of eutrophication, contains high mineral salts can be a potential for health tourism. Both this lake and the spring water called "Çermik Lake" located at the downstream of the lake are used by local people for the purposes of healing on special days. Studies examining the mineral content of lake waters as a complex (Gökgöl-Çermik Lakes) and their effects on human health should be examined comprehensively.

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