

Assessment of the ecological and trophic status of Lake Bafa (Turkey) based on phytoplankton

Bafa Gölü'nün (Türkiye) ekolojik ve trofik durumunun fitoplankton bazlı değerlendirilmesi

Atakan Sukatar¹ • Alperen Ertaş^{2*} • Rıza Akgül³ • İnci TÜney Kızılkaya⁴

¹ Department of Biology, Faculty of Science, Ege University, 35100 Bornova, İzmir, Turkey

² Department of Biology, Faculty of Science, Ege University, 35100 Bornova, İzmir, Turkey

³ Department of Crop and Animal Production, Mehmet Akif Ersoy University, Burdur, Turkey

⁴ Department of Biology, Faculty of Science, Ege University, 35100 Bornova, İzmir, Turkey

 <https://orcid.org/0000-0002-1895-0165>

 <https://orcid.org/0000-0001-8510-6100>

 <https://orcid.org/0000-0002-0280-2897>

 <https://orcid.org/0000-0003-0293-6964>

*Corresponding author: alperenertas@hotmail.com

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Abstract: Phytoplankton groups are one of the major quality element to be used in the evaluation of the trophic and ecological state of freshwater ecosystems according to the EU Water Framework Directive. This research was made to assess the trophic and ecological status of Lake Bafa in Turkey, on the basis of phytoplankton communities. Büyük Menderes River is one of the most important factor that carries pollutants to Lake Bafa. The eight sampling station were assigned to evaluate the ecological and trophic state of the lake. Phytoplankton species were collected monthly for 2 years study period. Most commonly used phtoplankton indices Q index and Carlson's Trophic State Index (TSI), and different versions of diversity indices were used to estimate trophic and ecological state of the lake. Similarities between the sampling stations were clustered by using the unweighted pair group method using arithmetic average (UPGMA), based on phytoplankton communities. Correlations between the applied indices were determined by using Pearson Correlation. After the identification of collected phytoplanktons, total of 63 taxa which belong to classis of Cyanophyceae (11.2%), Bacillariophyceae (49.2%), Chlorophyceae (23.8%), Xanthophyceae (1.5%), Euglenophyceae (11.2%) and Dinophyceae (3.1%) were detected. The 1st and 2nd stations were the most similar stations to each other (88%) according to phytoplankton communities. Secchi disc depth (SD) and TP played an important role in the distribution of phytoplankton species in Lake Bafa. The highest significant positive correlation was determined between Q and TSI ($r = 0.987$, $p < 0.01$). Considering the TDI values in the phytoplankton composition of the lake, it can be said that although the productivity status of the studied lake is still "mesotrophic", it has a tendency towards "eutrophic" state. According to the Q values, the first five stations reflect the moderate ecological state, while the 6th, 7th and 8th stations represent the poor ecological state.

Keywords: Lake Bafa, phytoplankton, Q index, Trophic State Index, Water Framework Directive

Öz: Fitoplankton, AB Su Çerçeve Direktifi'ne göre tatlı su ekosistemlerinin trofik ve ekolojik durumunun değerlendirilmesinde kullanılan en önemli kalite unsurlarından biridir. Bu araştırma, Bafa Gölü'nün trofik ve ekolojik durumunu fitoplankton grupları temel alarak değerlendirmek için yapılmıştır. Büyük Menderes Nehri, kirlenici Bafa Gölü'ne taşıyan en önemli faktörlerden biridir. Gölün ekolojik ve trofik durumunu değerlendirmek için sekiz örnekleme istasyonu belirlenmiştir. Fitoplankton türleri 2 yıllık çalışma süresi boyunca aylık olarak toplanmıştır. Gölün trofik ve ekolojik durumunu tahmin etmek için en yaygın kullanılan fitoplankton indeksleri Q indeksi ve Carlson'un Trofik Durum İndeksi (TDI) ve çeşitlilik indekslerinin farklı versiyonları kullanılmıştır. Uygulanan indeksler arasındaki korelasyonlar Pearson Korelasyonu kullanılarak belirlenmiştir. Örnekleme istasyonları arasındaki benzerlikler, fitoplankton topluluklarına dayanan aritmetik ortalama ile ağırlıksız çift grup metodu (UPGMA) kümeleme yöntemiyle belirlenmiştir. Toplanan fitoplankton örneklerinin tanımlanmasından sonra, Cyanophyceae (11.2%), Bacillariophyceae (49.2%), Chlorophyceae (23.8%), Xanthophyceae (1.5%), Euglenophyceae (11.2%) ve Dinophyceae (3.1%) sınıflarına ait toplam 63 takson tespit edilmiştir. Fitoplankton topluluklarına göre 1. ve 2. istasyonlar (%88) birbirlerine en yakın istasyonlar olduğu görülmüştür. Secchi disk derinliği (SD) ve TP Bafa Gölünde fitoplankton türlerine dağılımında önemli rol oynamıştır. En yüksek anlamlı pozitif korelasyon Q ve TDI arasında belirlenmiştir ($r = 0.987$, $p < 0.01$). Gölün fitoplankton dağılımındaki TDI değerleri göz önüne alındığında, incelenen gölün verimlilik durumu halen "mezotrofik" olmakla birlikte, "ötrofik" duruma doğru bir eğilim gösterdiği söylenebilir. Q değerlerine göre, ilk beş istasyon orta ekolojik durumu yansıtırken, 6., 7. ve 8. istasyonlar kötü ekolojik durumu temsil etmektedir.

Anahtar kelimeler: Bafa Gölü, fitoplankton, Q indeksi, Trofik Durum İndeksi, Su Çerçeve Direktifi

INTRODUCTION

Increasing human population cause big pressure on the aquatic ecosystems. The oceans, lakes, rivers and streams are being "squeezed" by human activities such as demotechnical and industrial improvements, agricultural activities and other human impact. Thus, ecological quality associated with water quality deteriorates (Vollenweider and Kerekes, 1982).

The European Union (EU) Water Framework Directive (WFD) 2000/60/EC commits EU member states and is adopted in 2000 takes a pioneering approach to protecting aquatic systems. The directive aime to achieve good qualitative and quantitative status of all surface water bodies and groundwaters (European Commission, 2000).

According to the WFD, phytoplankton groups occupies an important place and it has a vital role in the aquatic systems, therefore, phytoplankton is one of the biological quality indicators required for evaluation of ecological status of freshwaters in Europe. Amount of the nutrient load, has direct effect on the community of the phytoplankton. Therefore many researchers have preferred, the usage of phytoplankton for both water quality and eutrophication impact assessment (Paształeniec and Poniewozik, 2010). In some cases, the accumulation of extra phytoplankton can cause undesirable situations such as decreasing the photosynthesis of submerged vegetation due to shading, and develop of anoxic conditions in aquatic ecosystems (Paształeniec, 2016). As a result of this kind of situations, phytoplankton composition shows alterations, which influence aquatic food web and can pose the risk of the harmful algal blooms in the aquatic ecosystems.

Biomonitoring of aquatic ecosystems based on phytoplanktons is a routine method in European countries, on the other hand, using the biotic index is the important part of the water quality assessment. The using of biotic indices are shows the differences according to the country, climate and topography. In Turkey, using the biometric approaches for determining water quality based on phytoplankton (Çelekli and Öztürk, 2014; Toudjani et al., 2017; Çelekli and Lekesiz, 2020) was not a common method but nowadays these kind of studies become prominent.

Lake Bafa has been faced with pollution pressure due to human activities. The inflow of the Büyük Menderes River into Lake Bafa causes pollutant accumulation in the lake. Büyük Menderes River is born Dinar district of Afyon province and flows 584 km to the Aegean Sea. One arm of Büyük Menderes River, that separates from the river just before it goes into the Aegean Sea, and feeds the lake. Most of the industrial, agricultural and domestic wastes of the cities around lake, accumulates in the lake. In addition Büyük Menderes River, there are also many of olive oil facilities around the lake. Accidental leakage of black water from these factories reaches the lake and also overflowing of black water wells may happen after heavy rains. On the other hand, agricultural activities around the lake, using big amount of fertilizers, pesticides and chemicals are another pollution factors on the lake. All of this organic and inorganic pollutants increase salinity levels and caused the deterioration the biodiversity. Sarı et al. (1999) reported the fish fauna of the Lake Bafa changed mainly because of the increasing salinity levels. Balık and Ustaoglu (1989) also reported that one of the third endemic species in the basin, *Acanthobrama mirabilis* is extinct in Lake Bafa. Previous studies (Mermer, 1989; Balık et al., 1992; Balık, 1995) reported that *Cyprinus carpio*, *Cyprinus nasus*, *Barilius pectoralis*, *Silurus glanis* were also extinct in the lake due to increased salinity levels and decreased water quality.

With this study, it is aimed to reveal the phytoplankton composition and environmental condition of Lake Bafa. The trophic and ecological status of Lake Bafa was evaluated by

using of Q index and TSI index based on phytoplankton and environmental data obtained monthly for two years.

MATERIAL AND METHODS

Study area

Lake Bafa, the largest lake in the Aegean Region, is located at 2 m a.s.l. in the inner parts of the Menteşe Mountains in the southeastern part of the Büyük Menderes basin. It is a brackish water lake with a deepest point of 21 m and a surface area of 65 km². This lake is part of the Aegean Sea in its initial formation, remains inside the coast for miles due to the alluviums carried by the Büyük Menderes River. Lake Bafa is an example of alluvial-set lakes in terms of formation.

Sampling method

The sampling was monthly carried out for 2 years in 8 sampling stations of Lake Bafa (Figure 1).

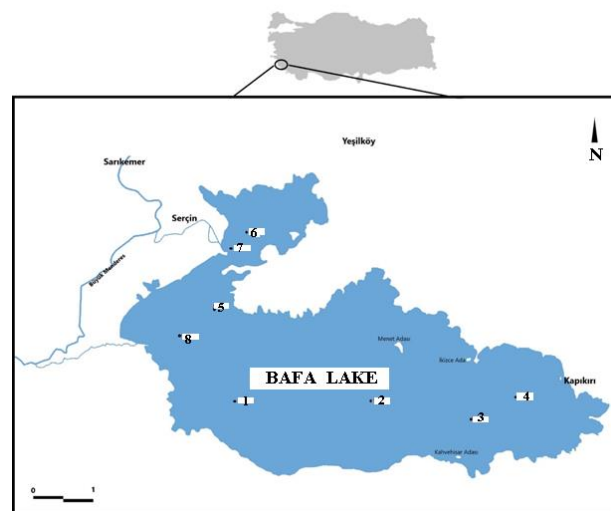


Figure 1. Sampling stations of Lake Bafa

Phytoplankton samples were collected monthly between July 2015 and June 2017 using plankton net (50 µm mesh size). Secchi disk visibility and chlorophyll a were measured in situ. Total phosphorus (TP) amount of stations were measured spectrophotometrically by using Merck Phosphate Cell Test Kit. Chlorophyll a was measured by using the BBE Moldaenke AlgaeTorch. In Lake Bafa, the water samples for quantitative analyses were fixed with lugol solution.

The quantification of microalgal cells, colonies and filaments were evaluated under inverted microscope according to the Utermohl method (Utermohl, 1958). Counting and identification of algae were applied using a Palmer-Maloney counting cell (volume: 0.1 mL) and an inverted microscope equipped with water immersion lenses and a phase-contrast attachment (400× magnification). The final abundance of each algal species was considered to be the average from two replicates. Algal species were identified according to the most

updated literature. Taxonomy of algae was checked according to (Guiry and Guiry, 2020). Diatom identifications were performed after having prepared permanent slides following European standard NF EN 13946 (Feret et al., 2017). Diatom frustules were counted per slide at $\times 1,000$ magnification, and diatoms were identified to the lowest taxonomic level possible using taxonomic literature from central Europe (Krammer and Lange-Bertalot, 1986; Sala et al., 1993; Round and Bukhtiyarova, 1996; Krammer, 1997; Compère, 2001; Bukhtiyarova, 2006; Potapova, 2006).

Statistical analysis

The diversity scores were obtained as by using PAST3 software program.

In order to determine the trophic and ecological status of Lake Bafa, we utilized the phytoplankton assemblage index (Q) (Padisak et al., 2006) and the Carlson Trophic State Index (TSI) (Carlson, 1977). According to Reynolds et al. (2002), on the centre of the phytoplankton functional group concept, Padisak et al. (2006) improved the Q index. In order to determine ecological classes, Q index grouped the lakes into five classes (Padisak et al., 2006). Q index based on the factor F weights assigned to each functional group, lake type 2 (alkaline, average depth 1–3 m, and persistent) in Padisak et al. (2006) was selected because the characteristics of this type are similar to the Lake Bafa. According to Pasztaleniec and Poniewozik (2010), the Q index emphasized that relative shares (p_i , where $p_i = n_i/N$) of functional groups (n_i number of the i -th functional group; N : total number) in the total phytoplankton numbers, and a factor number (F) assessed for each functional group in each type of water body at the same time (Padisak et al., 2006).

$$Q = \sum_{i=1}^n p_i \cdot F$$

The ranges of the Q index is between the 0-5, and can be expressed into five degree classification procedure: 0-1 grade indicate bad ecological status, 1-2 grade indicate tolerable (poor) ecological status, 2-3 grade indicate medium (moderate) ecological status, 3-4 grade indicate good ecological status, 4-5 grade indicate high ecological status.

The TSI developed by Carlson (1977) is used to determine the productivity of lentic habitats in many limnological studies conducted today (Katip et al., 2015; Cigagna et al., 2016). According to Carlson (1977), Walker (1979), Swanson (1998) and Xu (2008), TSI proposed in order to determine the biochemical pattern of eutrophication and to powerful remove pollution related with the oligotrophic, mesotrophic and eutrophic trophic states. The ranges of the TSI is between the 0-100, and can be expressed into four degree classification procedure. If TSI values are <30 or 30-40, oligotroph, if 40-50 is mesotroph, 50-70 is eutroph, and 70-80 or >80 is hyperutroph (Carlson and Simpson, 1996). (Table 1).

Table 1. Eutrophication state of Carlson Trophic State index

Trophic state	SD (m)	Chl a ($\mu\text{g/L}$)	TP ($\mu\text{g/L}$)	TSI
Oligotrophic	>40	<2.6	<12	<40
Mesotrophic	20-40	2.6-7.2	12-24	40-50
Eutrophic	0.5-20	7.22-55.5	24-96	50-70
Hypertrophic	<0.5	>55.5	>96	>70

Secchi disk (SD), chlorophyll a (Chl a), and total phosphorus (TP) are used in the formulas for calculating the TSI (Saghi et al., 2014). The TSI index expressed by;

$$TSI = 60 - 14.43 \ln(SD)$$

$$TSI = 3056 + 9.81 \ln(Chl a)$$

$$TSI = 4.14 + 14.43 \ln(TP)$$

The floral similarity between the stations were evaluated by using Bray- Curtis similarity index (Sommerfield, 2008; Yoshioka, 2008). UPGMA method was used to indicate existent clustering relationships based on phytoplanktons by using PAST3 software program.

Analysis of variance (One-Way ANOVA) was applied to data for determining the statistical differences in phytoplankton species and classis, physical parameters, Q index, TSI index and all diversity indices among the sampling stations of the Lake Bafa using SPSS 20.0. Pearson correlations between the physical parameters and the Q index, TSI index and all diversity indices were also determined using SPSS 20.0. Canonical Correspondance Analysis (CCA) was carried out using PAST3 software programme (Ter Braak and Šmilauer, 2002) to determine the relationships between the functional groups and physical variables. CCA was carried out on the log-normal transformed abundance data. Statistical significance of the all predictor variables was assessed by Kaiser-Meyer-Olkin (KMO) Sample Proficiency Test.

RESULTS

The physical variables and coordinate of the stations indicated in Table 2. The Chl a values varied between 6.00-82.8 $\mu\text{g/L}$, the TP values varied between 1.04-1.92 mg/L and the SD values varied between 0.50-3.60 m at the stations in the lake. SD depth is much lower in the 5th and 7th stations compared to other stations. Especially in the 5th stations, the turbidity is visibly more than the other stations. Although Chl a values are higher in 6th and 7th stations, there is no significant difference between Chl a values in other stations. There is no significant difference in TP values at all stations.

As a result, a total of 63 taxa were determined from the eight sampling stations in the lake. In this study, 7 taxa belong to Cyanophyceae, 31 taxa belong to Bacillariophyceae, 15 taxa belong to Chlorophyceae, 1 taxon belong to Xanthophyceae, 7 taxa belong to Euglenophyceae and 2 taxa belong to Dinophyceae.

Table 2. Mean and standart deviation values of the SD, TP, Chl-a and latitude and longitude at the stations

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Latitude	37°29' N	37°29' N	37°29' N	37°29' N	37°31' N	37°32' N	37°32' N	37°30' N
Longitude	27°24' E	27°27' E	27°29' E	27°31' E	27°24' E	27°23' E	27°24' E	27°22' E
SD (m)	3.60±0.30	3.40±0.50	3.30±0.20	3.00±0.15	0.50±0.01	2.00±0.15	1.50±0.01	2.50±0.19
TP (mg/L)	1.46±0.44	1.92±0.67	1.14±0.32	1.74±0.52	1.62±0.26	1.04±0.11	1.32±0.16	1.13±0.09
Chl a (µg/L)	12.4±2.33	15.4±2.47	14.5±1.95	19.1±3.66	6.50±0.43	82.8±9.56	69.0±7.98	6.00±0.38

Bacillariophyceae was the dominant group in the phytoplankton composition. As a result of diagnosed phytoplankton between the stations, the maximum amount of cells were counted at 7th station (871.778 cell/mL) while the minimum amount of the cells were counted at 8th station (20.833 cell/mL).

Percentage distribution of phytoplankton groups according to seasons is shown in Figure 2. As a result of the

phytoplankton counting the dominant group is Bacillariophyceae (35%) in summer in Lake Bafa. The second dominant group is Dinophyceae (31%) while the third dominant group is Euglenophyceae (20%) in the summer. As a result of the phytoplankton counting, the dominant group is also Bacillariophyceae (95%) in the autumn, Dinophyceae (87%) in the winter, and Xanthophyceae (81%) in the winter in Lake Bafa. In Lake Bafa, distributions and relative occurrence (%) of the diagnosed phytoplanktons were given at Table 3.

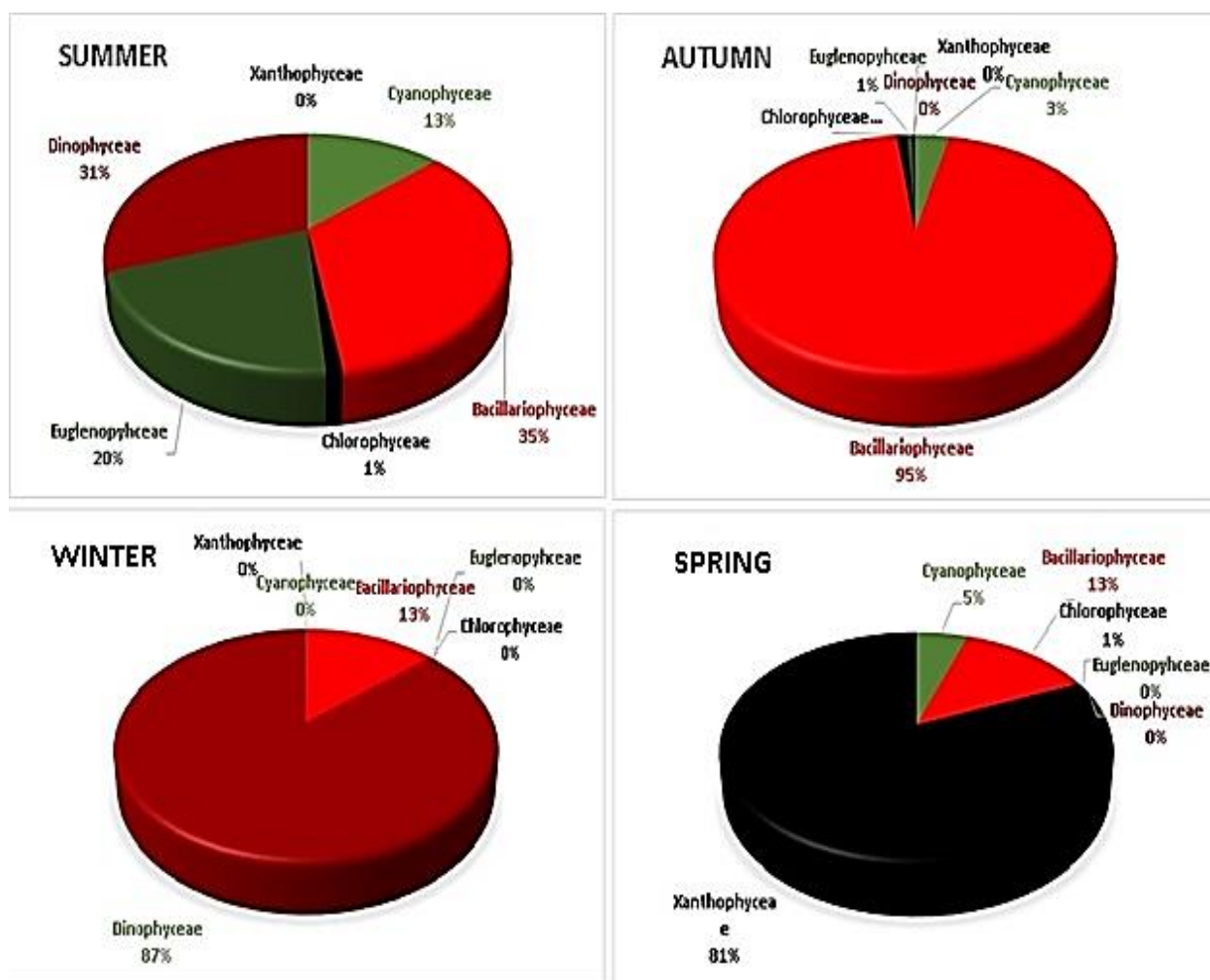


Figure 2. Proportional (%) distributions of phytoplankton groups in abundance basis according to seasons

Table 3. Distributions and relative occurrence (%) of phytoplankton species at the stations

Code		Station	Station	Station	Station	Station	Station	Station	
		1	2	3	4	5	6	7	8
Cyanophyceae									
1	<i>Komvophoron</i> sp.	-	-	-	-	-	0.01	-	-
2	<i>Cylindrospermopsis raciborskii</i> (Woloszynska) Seenayya & Subba Raju	-	-	-	-	-	0.68	-	-
3	<i>Lyngbya</i> sp.	-	-	0.46	-	-	-	-	-
4	<i>Nodularia spumigena</i> Mertens ex Bornet and Flahault	0.03	-	0.03	3.87	0.52	1.97	5.94	-
5	<i>Oscillatoria</i> spp.	0.07	0.19	0.37	-	2.92	0.12	0.14	2.18
6	<i>Oscillatoria limosa</i> C.Agardh ex Gomont	-	-	-	-	0.14	0.13	0.08	-
7	<i>Phormidium</i> spp.	-	-	-	0.07	1.78	0.10	-	2.08
Bacillariophyceae									
8	<i>Asterionella</i> sp.	-	-	-	-	-	0.39	0.10	-
9	<i>Biddulphia</i> sp.	-	-	0.07	0.74	-	0.01	0.03	-
10	<i>Caloneis amphibia</i> (Bory) Cleve	-	-	-	0.11	-	-	0.01	-
11	<i>Campylodiscus hibernicus</i> Ehrenberg	0.03	0.01	-	0.03	0.36	-	0.05	3.24
12	<i>Chaetoceros muelleri</i> Lemmermann,	17.9	13.7	5.32	2.61	0.76	-	0.48	9.06
13	<i>Cocconeis placentula</i> var. <i>euglypta</i> (Ehrenberg) Grunow	-	-	-	-	1.69	-	0.12	-
14	<i>Coscinodiscus granii</i> L.F.Gough	36.2	40.6	27.8	18.0	1.95	0.08	0.01	41.8
15	<i>Craticula cuspidata</i> (Kützing) D.G.Mann	-	-	-	-	-	-	0.01	-
16	<i>Cyclotella</i> sp.	-	-	0.16	0.06	-	-	-	-
17	<i>Cyclotella meneghiniana</i> Kützing,	-	-	-	-	-	0.34	-	-
18	<i>Cymatopleura solea</i> (Brébisson) W.Smith	-	-	-	-	-	0.01	-	-
19	<i>Entomoneis paludosa</i> (W.Smith) Reimer in R.M.Patrick & Reimer	-	-	-	-	-	0.03	-	-
20	<i>Fragilariforma virescens</i> var. <i>exigua</i> (Grunow) M.Poulin in Hamilton & al.	-	-	-	-	-	1.44	-	-
21	<i>Gyrosigma acuminatum</i> (Kützing) Rabenhorst	-	-	-	-	0.34	0.05	0.01	-
22	<i>Gyrosigma attenuatum</i> (Kützing) Rabenhorst	0.06	-	0.04	2.59	1.18	0.14	0.16	0.47
23	<i>Licmophora</i> sp.	0.07	-	0.27	4.20	12.1	-	-	-
24	<i>Melosira nummuloides</i> C.Agardh	0.17	0.01	0.11	10.0	2.20	0.05	0.37	-
25	<i>Melosira varians</i> C.Agardh	0.08	-	0.10	0.05	0.27	0.07	0.66	0.39
26	<i>Navicula</i> sp.	-	-	-	0.04	-	-	-	-
27	<i>Nitzschia</i> spp.	12.1	16.5	32.7	8.09	9.13	2.79	1.27	0.17
28	<i>Nitzschia acicularis</i> var. <i>typica</i> A.Cleve	-	-	-	-	4.92	0.72	2.09	-
29	<i>Nitzschia closterium</i> (Ehrenberg) W.Smith	-	-	-	-	-	0.20	-	-
30	<i>Nitzschia incerta</i> (Grunow) M.Peragallo	-	-	-	-	-	0.03	-	-
31	<i>Nitzschia intermedia</i> Hantzsch	-	-	-	-	-	-	0.11	-
32	<i>Nitzschia lorenziana</i> Grunow in Cleve & Möller	-	0.02	0.04	-	4.11	0.16	0.29	-
33	<i>Nitzschia sigmoidea</i> (Nitzsch) W.Smith	-	-	-	-	-	0.08	0.12	-
34	<i>Surirella ovalis</i> Brébisson	-	0.01	-	0.06	0.19	0.01	0.37	0.65
35	<i>Stephanodiscus</i> spp.	0.29	-	0.29	0.47	4.34	2.82	0.49	1.66
36	<i>Ulnaria ulna</i> (Nitzsch) Compère	0.55	0.31	0.27	15.7	36.0	5.04	3.42	5.65
37	<i>Ulnaria capitata</i> (Ehrenberg) Compère	-	-	-	-	-	-	0.02	-
38	<i>Tryblionella littoralis</i> (Grunow) D.G.Mann	-	-	-	-	-	-	0.05	0.09
Chlorophyceae									
39	<i>Chlamydomonas</i> sp.	-	0.54	-	-	-	-	-	-
40	<i>Cladophora glomerata</i> (Linnaeus) Kützing	0.02	-	0.12	-	-	-	-	-
41	<i>Desmodesmus communis</i> Hegewald	-	-	-	0.01	-	-	-	-
42	<i>Eudorina cylindrica</i> Korshikov	-	-	-	-	-	0.13	-	-
43	<i>Oedogonium</i> sp.	-	-	-	-	-	0.03	-	-
44	<i>Pandorina morum</i> (O.F.Müller) Bory	-	-	-	-	-	0.08	0.01	-
45	<i>Pseudopediastrum boryanum</i> (Turpin) E.Hegewald	-	-	-	-	-	0.24	0.18	-
46	<i>Pediastrum duplex</i> Meyen	-	-	-	-	0.02	0.06	0.06	-

Table 3. (Continued)

Code		Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
47	<i>Monactinus simplex</i> (Meyen) Corda	-	-	-	-	-	0.10	0.05	-
48	<i>Scenedesmus</i> spp.	-	-	-	-	-	0.14	0.03	-
49	<i>Tetradesmus obliquus</i> (Turpin) M.J.Wynne	-	-	-	-	-	0.08	-	-
50	<i>Tetradesmus lagerheimii</i> M.J.Wynne & Guiry	-	0.58	0.47	-	-	-	-	-
51	<i>Desmodesmus protuberans</i> (F.E.Fritsch & M.F.Rich) E.Hegewald	-	-	-	-	-	0.34	0.05	-
52	<i>Spirogyra</i> spp.	-	-	-	-	0.13	0.02	-	-
53	<i>Stauridium tetras</i> (Ehrenberg) E.Hegewald	-	-	-	-	-	0.01	-	-
Xanthophyceae									
54	<i>Tribonema</i> sp.	-	-	-	-	0.09	0.09	-	-
Euglenophyceae									
55	<i>Lepocinclis acus</i> (O.F.Müller) B.Marin & Melkonian	-	-	-	-	-	3.85	0.09	-
56	<i>Euglena hemichromata</i> Skuja	-	-	-	-	-	0.40	0.11	0.04
57	<i>Lepocinclis oxyuris</i> (Schmarda) B.Marin & Melkonian	-	-	-	-	-	2.80	-	-
58	<i>Euglena texta</i> (Dujardin) Hübner	-	-	-	-	-	0.05	0.11	-
59	<i>Lepocinclis fusiformis</i> (H.J.Carter) Lemmermann	-	-	-	-	-	3.02	-	-
60	<i>Lepocinclis ovum</i> (Ehrenberg) Lemmermann	-	-	-	-	-	0.86	-	-
61	<i>Phacus acuminatus</i> A.Stokes	-	-	-	-	-	1.45	-	-
Dinophyceae									
62	<i>Peridinium</i> sp.	-	-	-	-	-	0.74	1.26	-
63	<i>Prorocentrum cordatum</i> (Ostenfeld) J.D.Dodge	32.2	27.4	31.3	33.1	14.9	68.0	81.6	32.4

As a result of the identification, it was determined that *Coscinodiscus granii*, *Prorocentrum cordatum* and *Chaetoceros muelleri* were dominant on station #1 and #8.

Coscinodiscus granii, *Prorocentrum cordatum* and *Nitzschia* spp were dominant on station #2 and #3. *Ulnaria*

ulna, *Prorocentrum cordatum* and *Coscinodiscus granii* were dominant on station #4. *Ulnaria ulna*, *Prorocentrum cordatum* and *Licmophora* sp. were dominant on station #5. *Ulnaria ulna*, *Prorocentrum cordatum* and *Lepocinclis acus* were dominant on station #6. *Ulnaria ulna*, *Prorocentrum cordatum* and *Nodularia spumigena* were dominant on station #7 (Figure 3).

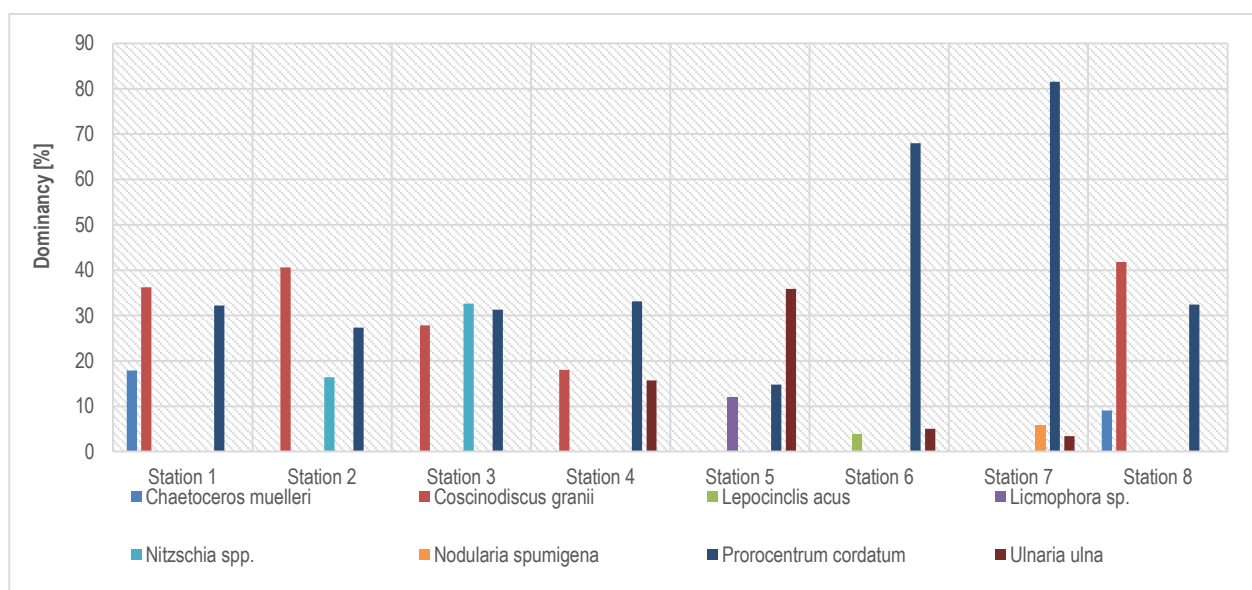


Figure 3. The most dominant phytoplankton species at the stations in Lake Bafa

On the basis of UPGMA, the classification of the sampling stations by phytoplankton composition was defined at Figure 4. Cluster analysis was used to classify the stations detected on Lake Bafa according to phytoplankton species. As a result of the UPGMA analysis, station #1 and station #2 were the most similar to each other (88%). Another high similarity was determined between the station #2 and station #3 (78%).

Two biometric approaches were used for evaluating the ecological quality of Lake Bafa are illustrated in Table 4. According to the Q index, the highest score value belong to station #3. The station #3 is determined as medium (moderate) ecological status. On the other hand, station #6, #7 and #8 determined as poor ecological status. In this study, trophic characterization of Lake Bafa was determined using the Carlson Trophic State Index concerning all the TSI components: SD, Chl *a* amount and TP, respectively. The TSI index diversified between the scores of 49 to 59 in the spring and summer period, in Lake Bafa. This result indicated that up to the limit of mesotrophic grade (50) in terms of the Carlson model, which classifies Lake Bafa as slightly eutrophic. TSI index varied between the values 42 to 49 on winter and autumn period.

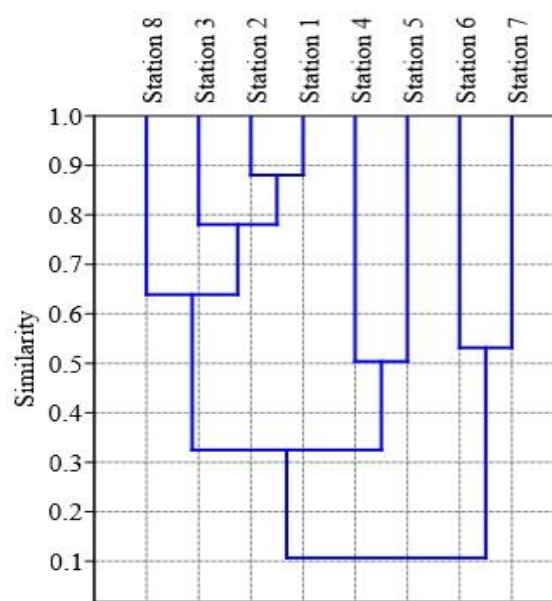


Figure 4. Classification of stations based on similarities of phytoplankton communities

Table 4. Score values of all indices and trophic status

Indices		Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Biotic indices									
Q Indice	Score	2.30±0.03	2.40±0.05	2.50±0.04	2.20±0.06	2.00±0.10	1.80±0.14	1.40±0.15	1.60±0.15
	Class	medium	medium	medium	medium	medium	poor	poor	poor
TSI	Score	45±2.27	43±1.65	42±1.14	46±1.76	49±2.04	51±1.56	59±1.88	53±1.03
	Class	mesotrophic	mesotrophic	mesotrophic	mesotrophic	mesotrophic	eutrophic	eutrophic	eutrophic
Species Diversity Indices									
SDI		0.72±0.17	0.71±0.15	0.71±0.13	0.81±0.16	0.82±0.14	0.53±0.05	0.33±0.04	0.71±0.12
SWDI		1.38±0.37	1.38±0.41	1.41±0.33	1.94±0.36	2.16±0.27	1.53±0.14	0.91±0.019	1.55±0.22
MDI		1.26±0.33	1.04±0.38	1.62±0.27	1.54±0.12	1.91±0.33	3.56±0.46	2.56±0.51	1.31±0.19
Menhinick		0.08±0.01	0.06±0.02	0.10±0.01	0.05±0.01	0.07±0.02	0.07±0.02	0.04±0.01	0.10±0.03
Fisher- Alpha		1.40±0.21	1.15±0.10	1.82±0.17	1.70±0.14	2.14±0.25	4.08±0.78	2.85±0.22	1.46±0.13
Brillouin		1.38±0.33	1.38±0.16	1.41±0.11	1.94±0.23	2.16±0.14	1.53±0.13	0.91±0.18	1.55±0.15
Evenness Index									
Evenness E1		0.28±0.07	0.33±0.08	0.23±0.08	0.37±0.09	0.38±0.06	0.10±0.01	0.07±0.01	0.34±0.06
Dominancy Index									
Berger- Parker		0.36±0.09	0.41±0.10	0.33±0.07	0.33±0.07	0.36±0.09	0.68±0.15	0.82±0.17	0.42±0.11

Average ± standard deviation

SDI: Simpson Diversity Index, SWDI: Shannon Weaver Diversity Index, MDI: Margalef Diversity Index

In this study, the SWDI, SDI, MDI, Menhinick, Brillouin and Fisher-Alpha diversity indices were calculated for each sampling station to assign species diversity. According to SWDI, the highest diversity score was found at station #5 (2.16), while the lowest diversity scores were found at station #1 and #2 (1.38). According to SDI, the highest diversity score was found at station #5 (0.82), while the lowest diversity score was found at station #7 (0.33). According to MDI, the highest diversity score was found at station #6 (3.56), while the lowest diversity score was found at station #2 (1.04). According to

Menhinick Index, the highest diversity scores were found at station #3 and #8 (0.10), while the lowest diversity score were found at station #7 (0.04). According to Fisher-Alpha Index, the highest diversity score was found at station #6 (4.08), while the lowest diversity score was found at station #2 (1.15). According to Brillouin Index, the highest diversity score was found at station #5 (2.16), while the lowest diversity score was found at station #7 (0.91). According to Evenness E1 index, the highest evenness score was observed at station #5 (0.38), while the lowest evenness value was seen at station #7 (0.07).

According to Berger-Parker index, the highest dominance value was observed at station #7 (0.82), while the lowest dominance value were observed at station #3 and #4 (0.33) (Table 4).

Table 5, summarizes the correlations of Chl a, SD, TP, Q index, TSI index and species diversity indices. In this study, the random sample cases (10% select case) were made on the biotic and diversity indices to verify datasets and to determine that the data was entered without errors in the SPSS version 20.0. The correlation between Chl- a and SD (r = -0.305;

p<0.01) was slightly strong. Between all biotic indices the highest significant correlation was determined between Q and TSI (r = 0.987, p<0.01). TSI showed positive correlation with both TP and chl a while it showed significant negative correlation with SD. Among species diversity indices, evenness indice and dominance indice, the highest significant correlation was found between MDI and Fisher- Alpha (r = 1.000, p<0.01), SWDI and Brillouin D (r = 1.000, p<0.01), SDI and Evenness E1 (r = 0.926, p<0.01). However, an increase in the results in Q index and TSI shows bad ecological quality.

Table 5. Correlation assesment between biotic and diversity indices used in Lake Bafa

	SD	TP	Chl-a	Q index	TSI	SDI	SWDI	MDI	Menhinick	Fisher_alpha	Brillouin	Evenness E1	Berger-Parker
SD	1	0.133	-0.305	0.634	-0.649*	0.247	-0.29	-0.539	0.268	-0.531	-0.29	0.162	-0.428
TP		1	0.431	0.439	0.399*	0.445	0.314	-0.545	-0.511	-0.551	0.314	0.598	-0.396
Chl-a			1	-0.543	0.577*	-0.845**	-0.467	0.906**	-0.477	0.902**	-0.467	-0.900**	0.907**
Q index				1	0.987**	0.657	0.267	-0.532	0.233	-0.522	0.267	0.465	-0.759*
TSI					1	-0.720*	-0.33	0.543	-0.328	0.531	-0.33	-0.524	0.804*
SDI						1	0.800*	-0.641	0.411	-0.631	0.800*	0.926**	-0.959**
SWDI							1	-0.136	0.145	-0.131	1.000**	0.722*	-0.62
MDI								1	-0.287	1.000**	-0.136	-0.771*	0.762*
Menhinick									1	-0.271	0.145	0.266	-0.493
Fisher_alpha										1	-0.131	-0.767*	0.753*
Brillouin											1	0.722*	-0.62
Evenness E1												1	-0.874**
Berger-Parker													1

** . Correlation is significant at the 0.01 level (2-tailed)

* . Correlation is significant at the 0.05 level (2-tailed)

Phytoplankton species and three environmental variables (SD, TP and Chl a) were only used in CCA analysis according to the Kaiser-Meyer-Olkin (KMO) Sample Proficiency Test (Figure 5). The obtained results of the KMO Sample Proficiency Test were calculated as 0.744 and show that the sample size is quite good and sufficient. The CCA analysis led to the explanation total of 72% variance according to phytoplankton species.

The distributions of *Lyngbya sp.*, *Chaetoceros muelleri*, *Coscinodiscus granii*, *Nitzschia incerta* and *Cladophora glomerata* are positively correlated to the SD. The distributions of *Phormidium spp.*, *Campylodiscus hibernicus*, and *Licmophora sp.* are positively correlated to the TP. The distributions of *Cylindrospermopsis raciborskii*, *Biddulphia sp.*, *Navicula sp.*, *Desmodesmus communis* and *Lepocinclis acus* are positively correlated to the chl a.

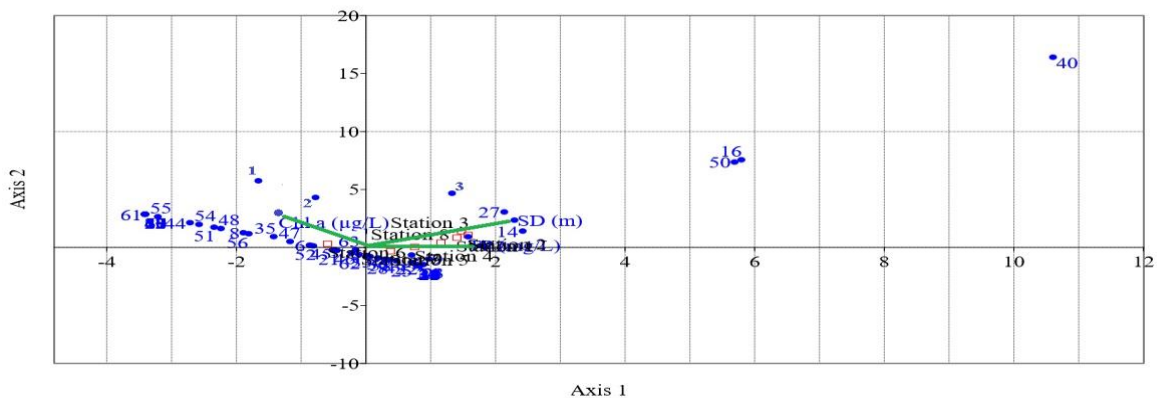


Figure 5. CCA plot of reference-, test-, and the phytoplankton species distributions with environmental variables

DISCUSSION

In this study, total of 63 taxa were revealed during the survey. After the classification of collected samples, Cyanophyceae (11.2%), Bacillariophyceae (49.2%), Chlorophyceae (23.8%), Xanthophyceae (1.5%), Euglenophyceae (11.2%) and Dinophyceae (3.1%) classis were determined. Cyanobacteria members were commonly detected in eutrophic lakes in our country (Cirik-Altındağ, 1982; Sömek and Balık, 2009) and they had excessive growth in eutrophic lakes rich in nutrients in summer months (Vaitomaa, 2006). In this study, a few taxa (*Cylindrospermopsis raciborskii*, *Lyngbya sp.* and *Nodularia spumigena*) were also frequently encountered in inland water ecosystems in Turkey (Taş and Gönülol, 2007; Çelekli et al., 2007). *Peridinium sp.*, was detected at the 6th and 7th stations of Lake Bafa, which was also found in inland water ecosystems with mesotrophic or eutrophic character in our country (Sömek et al., 2005; Ongun-Sevindik, 2010).

The biological assessment based on phytoplankton metrics provides a more integrative approach to determine the ecological status for the conservation and restoration of the lentic ecosystems (Padişák et al. 2006; Ptacnik et al. 2009). Usages of phytoplankton indices in the evaluation of water quality have played a crucial role in water resource management worldwide (Padişák et al. 2006; Marchetto et al. 2009). Çelekli and Lekesiz (2020) reported the low cyanobacterial biovolume was found in Yapraklı Reservoir, Lake Gölhisar, and Çavdır Reservoir with good ecological conditions based on the results of the modified PTI and Med-PTI. Bacillariophyta showed the highest contribution (54.6%) to total phytoplankton community in Çavdır Reservoir. Low cyanobacteria and high diatom biovolume levels support good ecological conditions. Kazancı et al. (2008) were determined 15 species of phytoplankton from 4 different algal groups (Dinophyta, Chlorophyta, Bacillariophyta and Cyanophyta) in Lake Bafa on July 1996-1997. Although the number of Bacillariophyta species was higher than the other taxa, Dinophyta was the dominant group in the lake. According to Kazancı et al. (2008), all dominant species belong to Dinophyta. *Prorocentrum minimum* was the most dominant species with 78.8 % (11.000 org ml⁻¹, organism per millilitre) of total phytoplankton whilst second dominant species was *Prorocentrum micans* (19.37 % of total phytoplankton and 2704.43 org ml⁻¹). *Peridinium spp* was third dominant species with 1.78 % (248.29 org ml⁻¹). Kazancı et al. (2008) also calculated the diversity of the phytoplankton according to the SWDI. The diversity was found low (0.58) in the Lake Bafa because of the high quantity of *Prorocentrum minimum* (11 000 org ml⁻¹ and 78.8% of total phytoplankton). In this study, all trophic components apparently were coherent in the determination of the trophic status of the Lake Bafa. Studies conducted in the lake, indicate the differences between the Chl *a* values and total phytoplankton which showed in some samples was likely due to high abundance of a broad algae masses in Lake Bafa on all seasons. Shekhar et al., (2008)

reported that they determined the classis of Chrysophyceae (2%), Cyanophyceae (25%), Bacillariophyceae (20%), Chlorophyceae (36%) and Euglenophyceae (17%) in the Bhadta Reservoir. Shekhar et al., (2008) determined in polluted zones, percentage of Cyanophyceae and Euglenophyceae was higher when compared to Chlorophyceae and Bacillariophyceae. Ochocka and Pasztalenice (2016) reported that they determined the classis of Cyanophyceae, Bacillariophyceae, Chlorophyceae, Cryptophyceae and Dinophyceae in the Masurian Lake. Ochocka and Pasztalenice (2016) stated that dominant group was filamentous cyanobacteria species (Planktothrix, Limnothrix, Planktolynbya, Pseudoanabaena) in the lake.

Results of SD in the present study are relatively similar compared to mesotrophic lakes (Vollenweider and Kerekes, 1982). Similarly, the fact that chl *a* concentrations were determined to be moderate indicates that the moderately light transmission is not due to phytoplankton. In this study, the lakes were determined at the border of the mesotrophic state or slightly above the average TDI values calculated by using the chl *a* and SD measurement values.

In this study, the Chl *a* value varied between 6.00-82.8 µg/L at the stations in Lake Bafa. Sakamoto (1966) reported the degree of chlorophyll *a* as 5.00-140 µg/L for eutrophic lakes, 1.00-15.0 µg/L for mesotrophic lakes and 0.30-2.50 µg/L for oligotrophic lakes. The stations #1, #2, #3, #4, #5 and #8 are mesotrophic in Bafa Lake according to Sakamoto (1966) while the stations #6 and #7 are eutrophic in Bafa Lake.

In this study, it has been reported that the *Ulnaria ulna* which is frequently detected in Lake Bafa, is found in waters rich in nutritious minerals and high turbidity, and is a characteristic species of eutrophic lakes (Hustedt, 1930; Reynolds et al., 2002). Algae species, *Euglena sp.*, *Oscillatoria sp.*, *Scenedesmus sp.*, and *Nitzschia sp.* was found on summer and autums in Lake Bafa, which are found in polluted waters (Nandan and Aher 2005; Çelekli and Lekesiz, 2020).

Çelekli et al. (2007) performed the multivariate approaches in three Aegean reservoirs. CCA analysis indicated that phytoplankton composition and distribution were mainly governed by environmental factors by TP, DO, TKN, BOD₅, TOC and temperature. The first two CCA axes explained 31% of cumulative percentage variance of species data with 97.7% between species-environment correlations during the study period. With regard to the ecological status, values of the Med-PTI indicated good quality waters for Ayvacık and Bayramiç Reservoirs, while Sevişler Reservoir had a moderate water quality. Based on the PTI, Bayramiç and Sevişler Reservoirs were classified as or moderate ecological status, while Ayvacık Reservoir indicated a good water quality. In Lake Bafa, The CCA analysis led to the explanation total of 72% variance according to phytoplankton species. The distributions of *Lyngbya sp.*, *Chaetoceros muelleri*, *Coscinodiscus granii*, *Nitzschia incerta* and *Cladophora glomerata* are positively correlated to the SD. The distributions of *Phormidium spp.*,

Campylodiscus hibernicus, and *Licmophora* sp. are positively correlated to the TP. The distributions of *Cylindrospermopsis raciborskii*, *Biddulphia* sp., *Navicula* sp., *Desmodesmus communis* and *Lepocinclis acus* are positively correlated to the chl a.

Chlorococcales in Lake Bafa was the dominant order in the second dominant group of Chlorophyceae. Likely, *Scenedesmus* and *Pediastrum* species had been found abundantly in oligomesotrophic reservoirs and eutrophic lakes in Turkey (İşbakan-Taş et al., 2002; Kıvrak and Gürbüz, 2005; Ongun-Sevindik, 2010; Çelekli et al., 2018).

Wetzel (1975) reported that members of the Euglenophyceae classis were mostly found in shallow waters rich in organic matter. The *Lepocinclis fusiformis*, *Lepocinclis ovum* and *Phacus acuminatus* species identified in the research area are widely found in mesotrophic or eutrophic inland water ecosystems in our country (Cirik-Altındağ, 1982; Kılınc, 1998; Ersanlı and Gönülol, 2003).

The UPGMA is a simplest method in order to constructing a tree from distance matrix which has been used often in ecology, systematics and taxonomy. The clustering technique that used in this method based on arithmetic averages of the measures of dissimilarity and similarity (James and McCulloch, 1990). In this study, the station #1 and #2 were the most similar to each other according to phytoplankton community. These two stations are located in the middle of the lake and they are far from the drainage points of Büyük Menderes River. Other high similarities were determined between the station #2 and #3 while the lowest similarities was determined between the station #6 and #8. The station #2 and #3 are located relatively close to each other and the station #3 is located close to the lake shore. The station #6 and #8 differ in depth and sediment structure. The lake is shallow and the bottom structure is muddy in the station #6 while, the lake is relatively deep and macrophytes are predominant in the station #8.

On the basis of diversity indices, species diversity values ranged from 0.04 to 4.08. According to Mason (2002), SWDI values ranges from >3 it indicates clean water, 1-3 shows moderate pollution, and 1< shows severe pollution, respectively. Ghosh and Biswas (2005) reported that the diversity value ranges from 0 (low density) to 1 at the SDI. Lake Bafa is oligotrophic state according to TP values while mesotrophic-eutrophic state according to chl a values. Lakes with a SD depth of more than 4 m are oligotrophic and 2-4 m are mesotrophs. Average SD depth in Lake Bafa is 2.47 m. When Lake Bafa is examined seasonally in terms of this parameter, it shows oligotroph-mesotroph lake characteristics. The TSI index results showed that Lake Bafa was from the limiting mesotrophic to slightly eutrophic. Sömek and Ustaoglu (2016) stated that oligotrophic and mesotrophic indicator species are found together in the phytoplankton composition of Saklıgöl, Karagöl, Gökçeova Pond and Kartal Lake, and considering the TSI values, the productivity status of the studied lakes is still oligotrophic but has a transition trend towards mesotrophic state. According to Akçalan et al. (2007), in the research carried out in Sapanca Lake, which is

an oligo-mesotrophic lake, diatom was reported to be predominantly found during the research period. According to Fakioglu and Demir (2011), the trophic level of Beyşehir lake is mesotrophic according to total phosphorus concentration, phytoplankton, chl a concentration value. The variation of the TP value of the Lake Bafa was examined and the TP value was found at the bottom depth and low on the surface. This is thought to be due to the release of phosphorus from the sediment. Lake Bafa is classified as mesotrophic according to the depth of Secchi. However, the low depth of Secchi may be caused by the increase of turbidity with the mixture from the bottom in shallow water. In addition, some eutrophic species have been found in the phytoplankton composition, Cyanophyceae have shown periodic increases, and the species and numbers of the Euglenophyceae groups which show organic contamination have increased.

Ongun-Sevindik et al. (2017) determined ecological status of two Mediterranean lakes with Q index. The average Q index was found as 3.05 for Lake Taşkısığı and 2.56 for Lake Akgöl, which reflect good and medium water qualities, respectively. The Q quality index generally varied between 2 and 4 (medium to good), and it was higher during winter in both of the lakes. Values were slightly higher in Lake Taşkısığı than Lake Akgöl during the studied period ($f = 11.13$, $P < 0.05$). In Lake Bafa, the highest Q index score values obtained from station #3, and the station #3 also is determined as a moderate ecological status. In this study, the sampling stations #6, #7 and #8 determined as a bad ecological status.

Considering the TDI values in the phytoplankton composition of the lake, it can be said that although the productivity status of the studied lake is still "mesotrophic", it has a tendency towards "eutrophic" state. According to the Q values, the first five stations reflect the moderate ecological state, while the 6th, 7th and 8th stations represent the poor ecological state.

CONCLUSION

The dataset obtained for two years study period in Lake Bafa indicated that the variability of trophic status of the lake. Q index and the TSI index classified Lake Bafa as moderate (medium) and meso-eutrophic, respectively. According to the obtained biological dataset from Lake Bafa, it is clear that due to the pollution factors as intense domestic and industrial wastes cause pollution pressure on Lake Bafa. Industrial establishments located around the lake should be inspected frequently and prevented from giving their wastes to the system without treatment. Intermittent monitoring of Lake Bafa is beneficial to prevent the negative effect of pollutants. As a result of this study, there is an importantly need for the constitute of biotic indices-based phytoplankton species to assess with high accuracy freshwaters.

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