

Evaluation of the Relationship between Epiphytic Diatoms and Water Quality Parameters in the Büyükçekmece Reservoir

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ABSTRACT

Objective: In this study carried out in Büyükçekmece Reservoir, the composition, distribution, seasonal changes of epiphytic diatoms that live on the surfaces of plants, and the effects of environmental parameters on these organisms were investigated, and it was aimed to reveal the water quality of the reservoir.

Materials and Methods: In order to determine the seasonal changes of epiphytic diatom species in Büyükçekmece Reservoir, water and material samples were collected from five stations in 2019. In the study, water temperature, salinity, conductivity, dissolved oxygen, and pH values, which are among the basic ecological variables, were measured. Epiphytic diatom samples were obtained from *Phragmites* sp. species. Also, Spearman's rank correlation, Shannon-Weaver diversity index, Cluster (Bray-Curtis and Euclidean Distance), and ordination analysis (DCA and CCA) were applied in the study.

Results: 66 epiphytic diatom species were identified in this study, and 36 of these species are new records for the reservoir. Most epiphytic diatom species were obtained in August, and the lowest number was obtained in November. According to the pH values, it was determined that the reservoir is alkaline. In addition, it was determined that the main factors affecting the distribution of epiphytic diatom species in the reservoir are temperature and conductivity, and it was revealed that ecological variables affect species distribution.

Conclusion: According to conductivity and DO values, it was determined that the reservoir was of very good and of good quality, and in terms of DO values, the reservoir was mainly oligotrophic. However, station 5 was mesotrophic during the August sampling period, station 4 was mesotrophic, and station 5 was eutrophic in November. Also, Büyükçekmece Reservoir was found in poor and moderate status according to *H'* classification.

Keywords: Epiphytic diatom, Bacillariophyceae, Correlation, Water quality, Istanbul, Turkey

INTRODUCTION

Diatoms (Bacillariophyceae) are among the unicellular, microscopic groups of algae with high distribution in freshwaters. Their existence on Earth, dating back 185 million years ago, has been proven by the fossil records

(1). Diatoms are responsible for almost 20-25% of the oxygen produced on Earth in aquatic ecosystems (2). Diatoms constitute the vast majority of benthic algae species in freshwater and seas (3,4), and they are distributed in almost all habitats. Due to their high tolerance range against environmental factors, they



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spread in a wide variety of aquatic environments (5-7). In their environment, they play an important role in the food chain for other aquatic organisms (8). By taking part in the carbon cycle through the photosynthesis process they perform, these organisms present in the photic zone play a key role in the elimination of atmospheric greenhouse gases that significantly contribute to global warming (9). They are used in biological monitoring studies because they respond to environmental parameters and the changes of these parameters faster than other living things. The presence of diatoms in all kinds of aquatic ecosystems, their ability to reach a high number of species even in small areas, including polluted and clean waters, and easy sampling are why they are preferred for comparing aquatic ecosystems with each other.

In recent years, the growths in industrialization, the excessive proliferation of the human population, and human insensitivity to the ecosystem have brought many environmental problems. It is worrying for humanity that freshwater reserves necessary for life are rapidly depleted or have become unusable. Protection of surface water resources and monitoring water pollution are among the priority points of many countries. For this reason, the use of biological organisms has increased in recent years in monitoring water pollution situations. Many countries have defined the biological quality steps by continuously following their current water potentials and have developed a national water quality system to monitor these resources in certain periods. While European Union member countries carry out these studies within the scope of the EU Water Framework Directive (WFD) (10), in Turkey, according to the Water Pollution Control Regulation (11) and the Surface Water Quality Control Regulation (12), determinations can be made about the water quality status of the resources. Although the commonly used parameters are various basic ecological variables such as water temperature, pH, dissolved oxygen, and nutrients, the excessive increase or decrease of some biological groups depending on these variables are observed. In particular, species composition and the abundance status of diatoms change depending on these variables and are used as an important indicator in determining the trophic status of lakes (13-16).

When the studies carried out in Büyükçekmece Reservoir are evaluated, it has been seen that the studies include all algae groups which are generally living in benthic and pelagic plankton (17-24). Also, studies on benthic algae have also been carried out, and it has been revealed that the diatoms are dominant organisms compared to the other groups in terms of the number of species in all of the studies. Among these studies, Temel (17) conducted a study on epipelagic algae in the reservoir and defined the benthic flora of the lake as very poor in terms of species and abundance. The same researcher studied epiphytic and epilithic algae in another study and reported that 43 diatom species were encountered in the epiphytic habitat in the Büyükçekmece Reservoir (18). In addition to these studies carried out in the reservoir, the importance of the water catchment areas is another reason for this study. Lakes, one of the most important freshwater reserves, are important natural areas with

many features such as their biological life and their roles in fishing, recreation, tourism, and the hydrological cycle. Since the water catchment basins of the reservoirs are wider than natural lakes, they are more affected by the pollution in the basin. Therefore, it is necessary to carry out monitoring studies, especially in areas where drinking water is supplied (25). In this context, in this study carried out in Büyükçekmece Reservoir, the composition, distribution, seasonal changes of epiphytic diatoms that survive on plants, and the effects of environmental parameters on these organisms were investigated, and it was aimed to reveal the water quality of the reservoir.

MATERIALS AND METHODS

Study Area

While Büyükçekmece Reservoir was one of the coastal lagoons of the Sea of Marmara until 1989, it was disconnected from the sea with an earth-filled embankment and took its current form (26). The reservoir, which is one of the drinking water resources of Istanbul today, is located between the Büyükçekmece, Çatalca, and Esenyurt districts on the European continent of Istanbul. The surface area of this reservoir, which is 2 km wide and 7 km long, is 43 km². 400,000 m³ of drinking water is obtained per day from the reservoir, which has a maximum water accumulation volume of approximately 149×10⁶ m³ (27).

Sampling and Analysis of Biotic and Abiotic Variables

In order to determine the seasonal changes of epiphytic diatom species in the Büyükçekmece Reservoir, water and material samples were collected from five stations in 2019 (February, May, August and November) (Figure 1). The main ecological variables of the environment; water temperature, salinity, conductivity, dissolved oxygen, (DO) and pH values; were measured during the field studies with the YSI-556 model multiprobe.

Diatom samples were obtained by taking 10 cm long sections from the part of the *Phragmites* sp. species within the water and 30 cm below the water surface. In November, it was observed that the water level in the reservoir decreased by up to 40% (28). In this season, since *Phragmites* sp. was not found within the water in stations except for station 2, no epiphytic diatom sampling was performed at other stations. The sections taken from the *Phragmites* sp. species were repeated as three replications for each station. These sections, which were taken into plastic containers with 100 ml of distilled water, were shaken moderately to mix the diatom species with the water, and 4% formaldehyde (buffered with borax) was added to ensure fixation (29). The samples brought to the laboratory immediately after the field study were kept at room temperature.

Pre-Treatment of Diatom Samples, Preparations of Permanent Slides and Identification

Diatom frustules were burned and permanent slides prepared according to Hendey (30) and Battarbee et al. (31). Accordingly, in order to eliminate the organic material in the cells, the samples were first kept in a 10% hydrochloric acid (HCl) solution overnight and then washed with distilled water. Then, hydrogen peroxide (H₂O₂) was added to the samples on a hotplate,

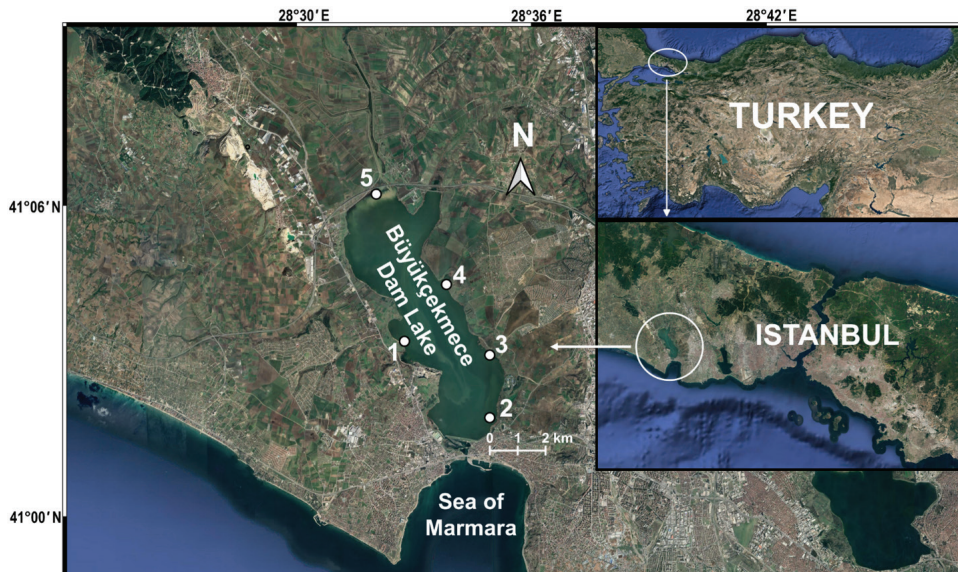


Figure 1. Sampling area and location of stations in the Büyükçekmece Reservoir.

the samples were boiled at 150°C for about 5 hours, and their SiO₂-containing skeletons were exposed. Naphrax was used in the preparation of permanent slides, and the prepared slides were examined under an Olympus BX51 light microscope at ×1000 magnification. In the identification of the species, Hustedt (32), Patrick and Reimer (33,34), Round et al. (2), and Krammer and Lange-Bertalot (35-38) were used. For each sample from the permanent slides prepared for counting, 300 diatom frustules were counted randomly under the microscope, and the relative abundance of the species was computed as a percentage.

Statistical Analysis of the Biotic and Abiotic Variables

Spearman's rank correlation was used in determining the relationship between biotic and abiotic variables (39), Shannon-Weaver diversity index (40) was used in determining the species diversity of stations, and Bray-Curtis similarity analysis was used in determining the similarity of stations according to epiphytic diatom species and individual numbers. Euclidean Distance was used in determining the similarity of stations in terms of ecological variables (41). Before clustering analysis, Bray-Curtis ($\log x + 1$) and Euclidean Distance (Normalisation) data were transformed. From statistical analysis, Spearman's rank correlation was analyzed in the SPSS v.25 package program, while Shannon-Weaver diversity index, Bray-Curtis similarity analysis, and Euclidean Distance were analyzed in the Primer v.6 programs.

Ordination analysis was carried out to reveal the relationship between environmental variables and the relative abundance data of the species. While the method was preferred, firstly, the detrended corresponding analysis (DCA) stated by Lepš and Šmilauer (42) was employed by means of the PC-ORD 6.0 program (43). As the longest gradient was obtained as 4.002 (Axis 1, *Eigenvalue*: 0.81737) as a result of DCA analysis, the direct gra-

dient analysis canonical correspondence analysis (CCA) was preferred for ordination analysis. The first two CCA axes explained a total of 37.9% of the cumulative variance in species data, and the correlation between the response variable (epiphytic diatoms) and the predictive variables (ecological parameters) was determined as 93.5%. Environmental variables used in CCA were tested in the SPSS 25.0 program with the Monte Carlo test (with 499 permutations) ($p < 0.05$). The abundance data of diatoms were analyzed by including all sampling periods and species with an observation frequency of "> 5%" at stations (42), and the CCA ordination diagram was drawn in the PAST 4.0 program (44). In addition, according to the Surface Water Quality Control Regulation (12), the water quality classes and trophic status of the reservoir were revealed. Also, the ecological status of the reservoir has been classified according to Molvær et al. (45), and this classification was based on H' values. In this classification, they have been classified into 5 ecological groups as follows: "High status" > 3.8; "Good status" 3.0–3.8; "Moderate status" 1.9–3.0; "Poor status" 0.9–1.9; "Bad status" < 0.9.

RESULTS

Ecological Variables

Results of ecological variables recorded at five stations in Büyükçekmece Reservoir are given in Figure 2. In the measurements performed in the reservoir, it was recorded that the water temperature was between 5.01-26.65°C. The lowest water temperature was measured at station 3 in the February sampling, and the highest water temperature was measured at station 4 in the August sampling. The values measured in the February sampling are much lower than in the other sampling periods. The highest water temperature in this period was determined as 5.64°C. During the sampling periods, the highest water temperature variation between stations was observed in the May sampling. Considering the salinity values of the lake during the

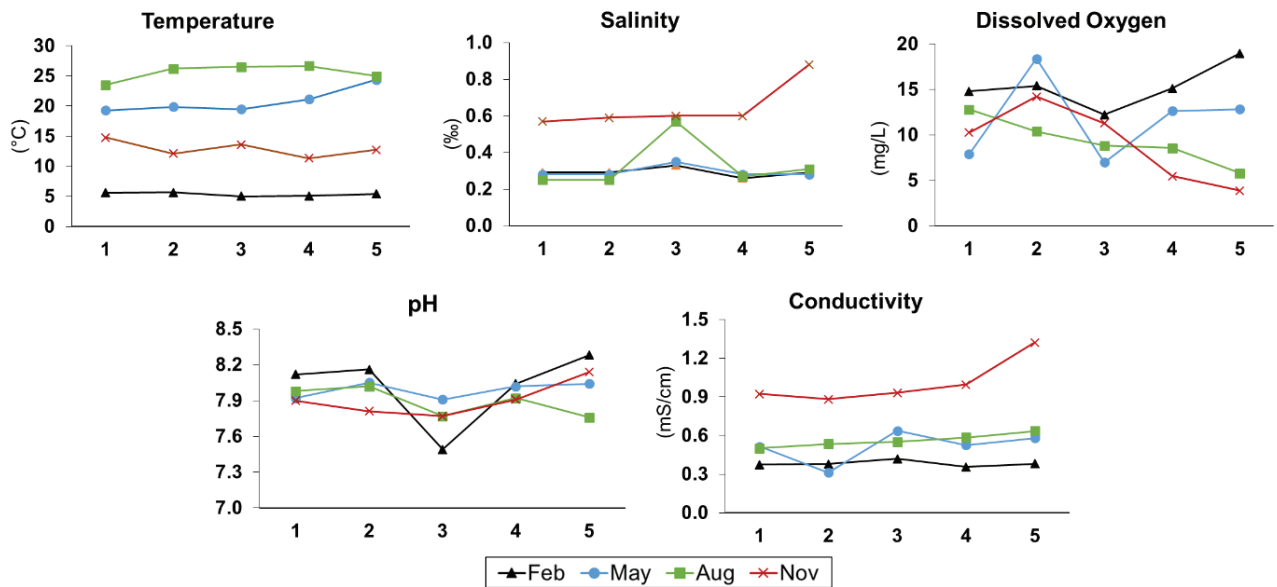


Figure 2. Changes of ecological variables in the Büyükçekmece Reservoir.

year, it was observed that it was below 1% in all sampling periods and varied between 0.25-0.88 ‰. The lowest value was measured from stations 1 and 2 in the August period, and the highest value was measured from station number 3 in November. During the study, it was observed that the salinity rate of the reservoir was higher in the November sampling, which is the period when the occupancy rate of the reservoir is the lowest, compared to other periods. Dissolved oxygen (DO) values were recorded between 3.87 and 18.96 mg/L. The lowest DO value was measured from station 5 in the November sampling, and the highest value was measured from station 5 in the February sampling.

Conductivity in water was measured as 0.312-1.322 mS/cm between sampling periods. The lowest conductivity was recorded at station 2 in the May sampling, and the highest was recorded at station 5 in the November sampling. The highest conductivity difference between the stations was obtained in the November sampling. As the pH values in the reservoir varied between 7.49 and 8.28, it was determined that the reservoir is of alkaline characteristics. The highest (St.5) and lowest (St.3) pH values were measured in the February sampling, and the highest pH difference between stations was observed in this period.

Epiphytic Diatoms Composition and Abundance

In this seasonal study conducted in Büyükçekmece Reservoir, 66 epiphytic diatom species were identified, 5 of which were genus level (Figure 3-5). In the study, one (1.5%) species from centric diatom and 65 (98.5%) species from pennate diatoms were obtained (Table 1). 36 of the identified species are new records for the reservoir, and the genera *Eunotia*, *Geissleria*, *Hippodonta*, and *Tabularia* were reported for the first time with this study (Table 1). Most species in the study belonged to *Navicula* (8 species), followed by *Gomphonema* (7 species) and

Cymbella (6 species). While the highest number of epiphytic diatom species was obtained in August (43 species) and May (38 species), fewer species numbers were obtained in February (28 species) and November (25 species).

When the number of species obtained at stations was evaluated, the highest number of species was obtained from station 5 (18 species), and the lowest number of species was obtained from station 3 (5 species) in the February sampling. During this sampling period, *Fragilaria vaucheriae*, *Fragilaria* sp.2, and *Gomphonella olivacea* were found in all stations (100%). When evaluated in terms of relative abundance (Figure 6a), it was determined that *G. olivacea* was dominant in all stations (>49%) and reached the highest abundance (74%) at station 1. In the study, *Fragilaria* sp.1, *Gomphonema* sp., *Navicula capitatoradiata*, *Nitzschia intermedia*, and *Tabularia fasciculata* were observed only in this period, and their relative abundance at the stations where they were observed remained below 2%. During this period, a total of 8 cells were found at station 3, and the targeted 300 cells in terms of relative abundance could not be reached. Among the obtained cells, *G. olivacea* (50%) was found to be dominant as in other stations.

In the May sampling, the highest number of species was obtained from station 4 (21 species) and the least number of species from station 2 (12 species). During this period, *Achnantheidium* sp., *Cymbella affinis*, *Encyonopsis minuta*, *Fragilaria perminuta*, and *Gomphonema pumilum* were recorded from all stations and in terms of relative abundance (Figure 6b). *Cymbella lange-bertalotii* (34%) at station 1, *C. affinis* (56%) at station 2, *Achnantheidium* sp. (40%) at station 3, *Encyonema auerswaldii* at station 4 (22%), and *G. pumilum* (29%) at station 5 were observed to be dominant. *Eunotia bilunaris*, *Geissleria decussis*, *Hippodonta hungarica*, *Navicula novaesiberica*, and *Tryblionella*

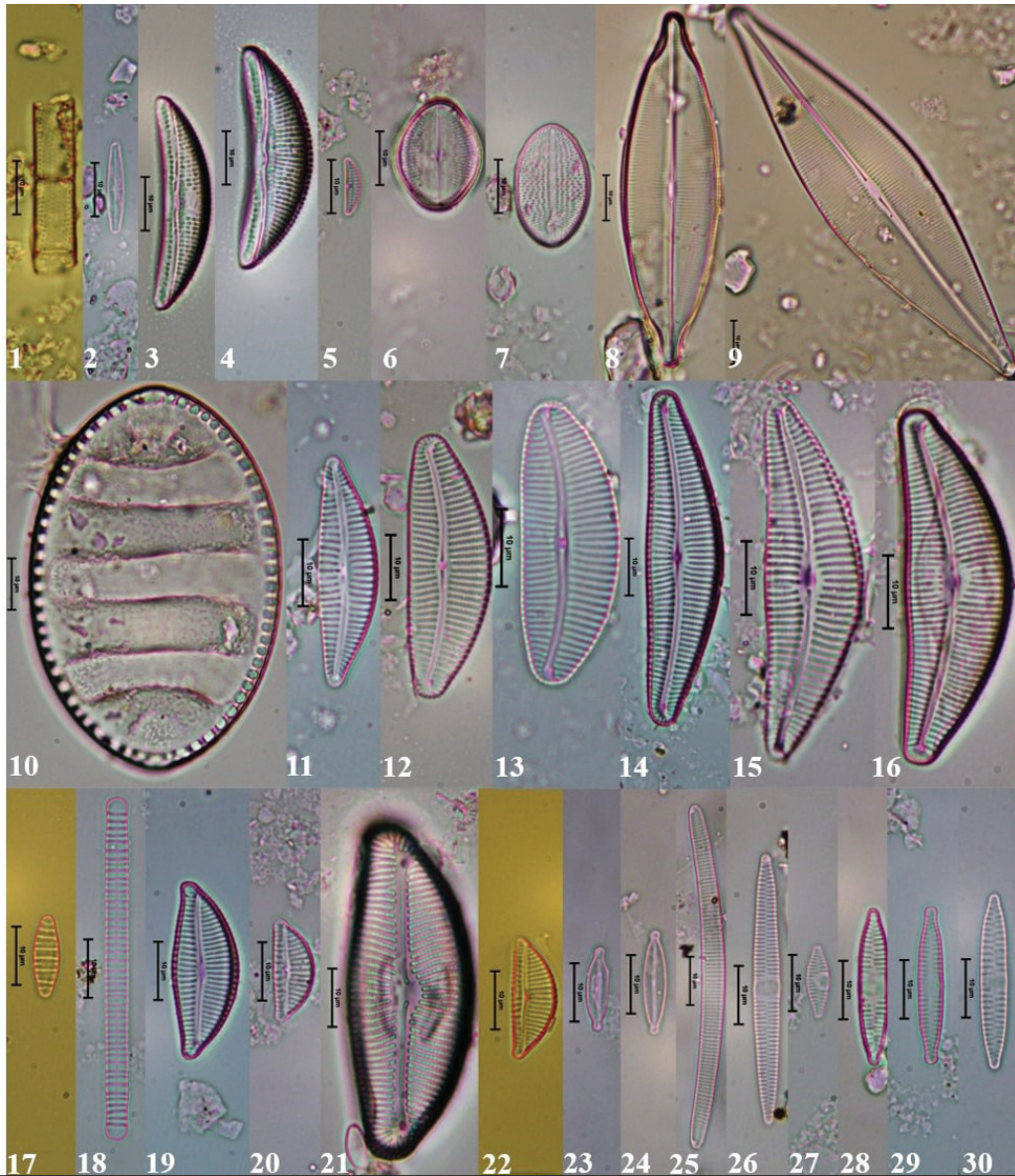


Figure 3. 1) *Aulacoseira granulata*, 2) *Achnanthidium* sp., 3) *Amphora copulata*, 4) *A. ovalis*, 5) *A. pediculus*, 6) *Cocconeis pediculus*, 7) *C. placentula*, 8) *Craticula* cf. *ambigua*, 9) *C. cuspidata*, 10) *Cymatopleura elliptica*, 11) *Cymbella affinis*, 12) *C. cantonatii*, 13) *C. compacta*, 14) *C. lange-bertalotii*, 15) *C. neocistula*, 16) *C. tumida*, 17) *Diatoma mesodon*, 18) *D. tenuis*, 19) *Encyonema auerswaldii*, 20) *E. minutum*, 21) *E. prostratum*, 22) *E. ventricosum*, 23) *Encyonopsis minuta*, 24) *E. subminuta*, 25) *Eunotia bilunaris*, 26) *Fragilaria* cf. *capucina*, 27) *F. perminuta*, 28) *F. vaucheriae*, 29) *Fragilaria* sp.1, 30) *Fragilaria* sp.2.

hungarica were observed only in this season, and their relative abundance is less than 4%.

In the August sampling, the highest number of species was determined at station 5 (27 species), and the least number of species were determined at station 3 (11 species). *Achnanthidium* sp., *Cocconeis placentula*, *Fragilaria perminuta*, and *Navicula reichardtiana* were observed in all stations. In terms of relative abundance, in this period, *C. affinis* (27%) at station 1, *C. placentula* (30%) at station 2, *Achnanthidium* sp. (67%) at station 3, *C. placentula* (82%) at station 4, and *E. auerswaldii* (43%) at

station 5 (Figure 6c) were strikingly dominant. *Aulacoseira granulata*, the only member of centric diatom observed in the study in this sampling period, *Amphora copulata*, *Craticula* cf. *ambigua*, *Craticula cuspidata*, *Gomphonema acuminatum*, *G. augur*, *Planothidium lanceolatum*, and *Tryblionella apiculata* from pennate diatoms were found only in this season, and the relative abundance of species other than *P. lanceolatum* (5%) remained below 1%.

In November, no *Phragmites* sp. were encountered. For this reason, sampling was performed only at station 2, and 25

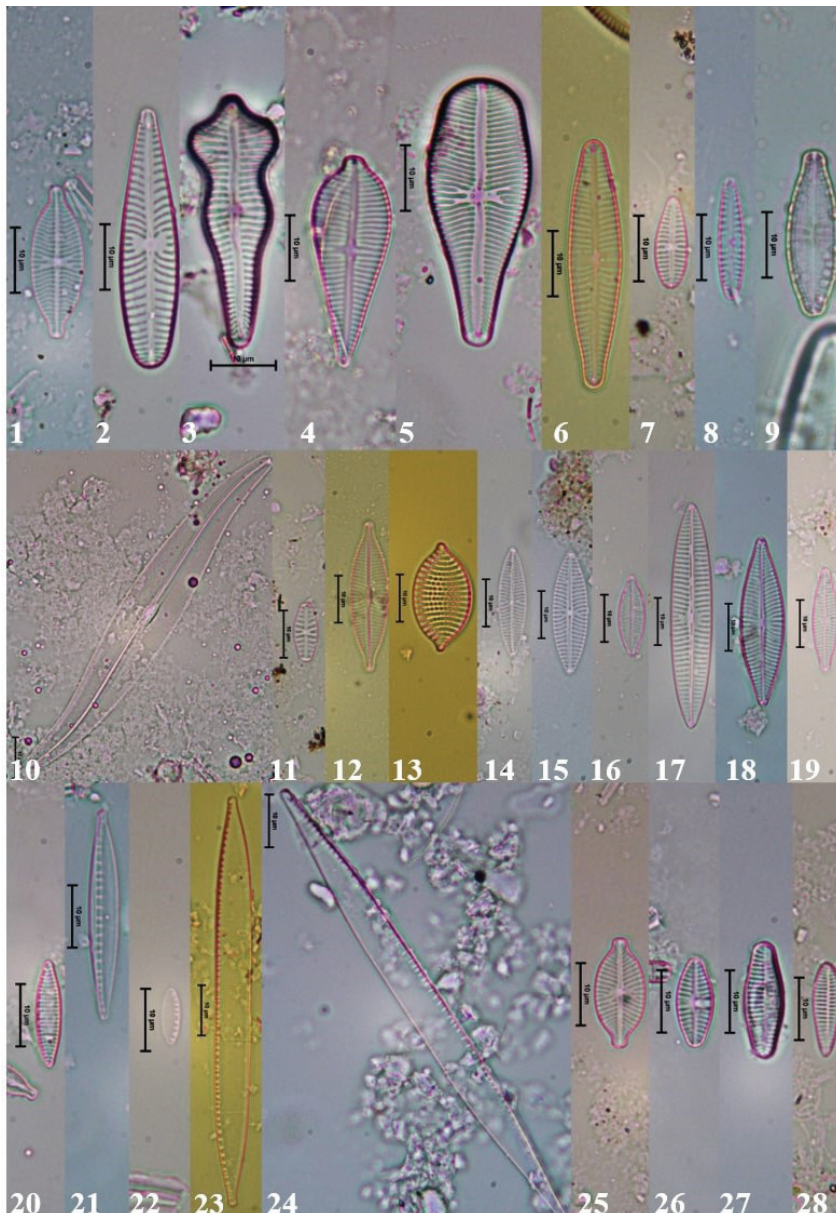


Figure 4. 1) *Geissleria decussis*, 2) *Gomphonella olivacea*, 3) *Gomphonema acuminatum*, 4) *G. augur*, 5) *G. italicum*, 6) *G. micropus*, 7) *G. minuta*, 8) *G. pumilum*, 9) *Gomphonema* sp., 10) *Gyrosigma kuetzingii*, 11) *Hippodonta hungarica*, 12) *Navicula capitoradiata*, 13) *N. compressa*, 14) *N. cryptotenelloides*, 15) *N. novaesiberica*, 16) *N. reichardtiana*, 17) *N. tripunctata*, 18) *N. trivialis*, 19) *N. veneta*, 20) *Nitzschia amphibia*, 21) *N. dissipata*, 22) *N. inconspicua*, 23) *N. intermedia*, 24) *N. recta*, 25) *Placoneis* sp., 26) *Planothidium frequentissimum*, 27) *P. lanceolatum*, 28) *Rhoicosphenia abbreviata*.

epiphytic diatom species were found. *Fragilaria perminuta* (31%) and *Navicula tripunctata* (29%) were identified as the dominant species in this period (Figure 6d). *Navicula compressa*, *Nitzschia inconspicua*, *N. recta*, and *Rhoicosphenia abbreviata* were also found only in this period, and the relative abundance of the species was observed to be below 1%.

Statistical Evaluation of Data

In order to reveal the relationship between the number of species of epiphytic diatoms in the reservoir and environmental

parameters, Spearman's rank correlation was performed (Table 2), and it was determined that there was only a positive correlation between the number of epiphytic diatom species and the conductivity ($p < 0.05$).

Ordination analyses were run to reveal the relationship between epiphytic diatom species and ecological variables (Figure 7). In the CCA analysis performed, the results show that environmental factors are effective in the distribution of epiphytic diatom assemblages. The most effective explanatory factors

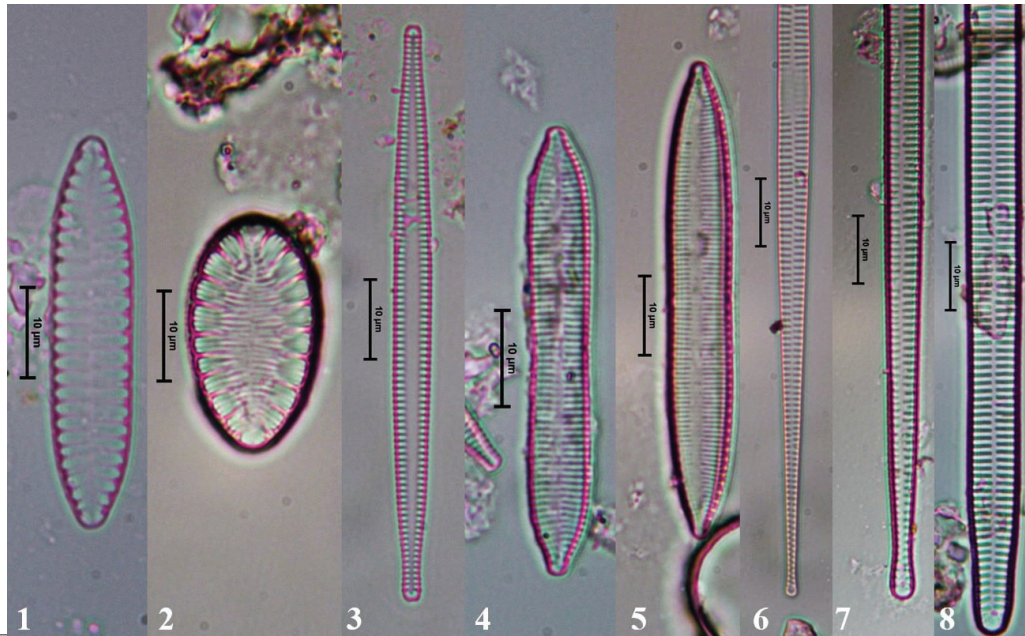


Figure 5. 1) *Surirella angusta*, 2) *S. brebissonii*, 3) *Tabularia fasciculata*, 4) *Tryblionella apiculata*, 5) *T. hungarica*, 6) *Ulnaria acus*, 7) *U. biceps*, 8) *U. ulna*.

Table 1. The list of epiphytic diatoms in the Büyükçekmece Reservoir ("*" shows the new record species in the reservoir).

Taxa	February	May	August	November
Centric diatoms				
<i>Aulacoseira granulata</i> (Ehrenberg) Simonsen, 1979			+	
Pennate diatoms				
<i>Achnanthydium</i> sp.		+	+	+
* <i>Amphora copulata</i> (Kützing) Schoeman&Archibald, 1986			+	
<i>Amphora ovalis</i> (Kützing) Kützing, 1844		+	+	
* <i>Amphora pediculus</i> (Kützing) Grunow, 1875			+	+
* <i>Cocconeis pediculus</i> Ehrenberg, 1838		+	+	+
<i>Cocconeis placentula</i> Ehrenberg, 1838	+	+	+	+
* <i>Craticula</i> cf. <i>ambigua</i> (Ehrenberg) Mann, 1990			+	
<i>Craticula cuspidata</i> (Kützing) Mann, 1990			+	
<i>Cymatopleura elliptica</i> (Brébisson) Smith, 1851			+	+
<i>Cymbella affinis</i> Kützing, 1844	+	+	+	+
<i>Cymbella cantonatii</i> Lange-Bertalot, 2002	+			
<i>Cymbella compacta</i> Østrup, 1910		+	+	
* <i>Cymbella lange-bertalotii</i> Krammer, 2002		+	+	
* <i>Cymbella neocistula</i> Krammer, 2002	+		+	
<i>Cymbella tumida</i> (Brébisson) Van Heurck, 1880		+	+	

Table 1 (Continued)				
Taxa	February	May	August	November
Pennate diatoms (Continued)				
* <i>Diatoma mesodon</i> (Ehrenberg) Kützing, 1844	+			+
* <i>Diatoma tenuis</i> Agardh, 1812		+		
* <i>Encyonema auerswaldii</i> Rabenhorst, 1853	+	+	+	
* <i>Encyonema minutum</i> (Hilse) Mann, 1990	+	+	+	
<i>Encyonema prostratum</i> (Berkeley) Kützing, 1844			+	
<i>Encyonema ventricosum</i> (Agardh) Grunow, 1875	+	+	+	
* <i>Encyonopsis minuta</i> Krammer&Reichardt, 1997	+	+	+	+
<i>Encyonopsis subminuta</i> Krammer&Reichardt, 1997			+	
* <i>Eunotia bilunaris</i> (Ehrenberg) Schaarschmidt, 1880		+		
* <i>Fragilaria cf. capucina</i> Desmazières, 1830		+		+
* <i>Fragilaria perminuta</i> (Grunow) Lange-Bertalot, 2000	+	+	+	+
* <i>Fragilaria vaucheriae</i> (Kützing) Petersen, 1938	+	+	+	+
<i>Fragilaria</i> sp.1	+			
<i>Fragilaria</i> sp.2	+	+	+	
* <i>Geissleria decussis</i> (Østrup) Lange-Bertalot&Metzeltin, 1996		+		
<i>Gomphonella olivacea</i> (Hornemann) Rabenhorst, 1853	+	+	+	+
<i>Gomphonema acuminatum</i> Ehrenberg, 1832			+	
<i>Gomphonema augur</i> Ehrenberg, 1841			+	
* <i>Gomphonema italicum</i> Kützing, 1844		+	+	
* <i>Gomphonema micropus</i> Kützing, 1844	+	+		+
* <i>Gomphonema minuta</i> Fusey, 1953	+	+	+	+
* <i>Gomphonema pumilum</i> (Grunow) Reichardt&Lange-Bertalot, 1991		+	+	+
<i>Gomphonema</i> sp.	+			
* <i>Gyrosigma kuetzingii</i> (Grunow) Cleve, 1894		+	+	
* <i>Hippodonta hungarica</i> (Grunow) Lange-Bertalot, Metzeltin&Witkowski, 1996		+		
* <i>Navicula capitatoradiata</i> Germain in Gasse, 1986	+			
* <i>Navicula compressa</i> (Ehrenberg) De Toni, 1891				+
* <i>Navicula cryptotenelloides</i> Lange-Bertalot, 1993		+	+	+
* <i>Navicula novaesiberica</i> Lange-Bertalot, 1993		+		
* <i>Navicula reichardtiana</i> Lange-Bertalot, 1989	+	+	+	+
<i>Navicula tripunctata</i> (Müller) Bory, 1822	+	+	+	+
<i>Navicula trivialis</i> Lange-Bertalot, 1980	+	+	+	+

Table 1 (Continued)

Taxa	February	May	August	November
Pennate diatoms (Continued)				
* <i>Navicula veneta</i> Kützing, 1844		+	+	+
* <i>Nitzschia amphibia</i> Grunow, 1862		+	+	
* <i>Nitzschia dissipata</i> (Kützing) Rabenhorst, 1860	+	+		+
* <i>Nitzschia inconspicua</i> Grunow, 1862				+
* <i>Nitzschia intermedia</i> Hantzsch in Cleve&Grunow, 1880	+			
* <i>Nitzschia recta</i> Hantzsch in Rabenhorst, 1862				+
<i>Placoneis</i> sp.			+	
* <i>Planothidium frequentissimum</i> (Lange-Bertalot) Lange-Bertalot, 1999			+	
<i>Planothidium lanceolatum</i> (Brébisson in Kützing) Lange-Bertalot, 1999			+	
<i>Rhoicosphenia abbreviata</i> (Agardh) Lange-Bertalot, 1980				+
<i>Surirella angusta</i> Kützing, 1844	+			
<i>Surirella brebissonii</i> Krammer&Lange-Bertalot, 1987	+	+	+	
* <i>Tabularia fasciculata</i> (Agardh) Williams&Round, 1986	+			
* <i>Tryblionella apiculata</i> Gregory, 1857			+	
<i>Tryblionella hungarica</i> (Grunow) Frenguelli, 1942		+		
<i>Ulnaria acus</i> (Kützing) Aboal, 2003		+		
<i>Ulnaria biceps</i> (Kützing) Compère, 2001	+			
<i>Ulnaria ulna</i> (Nitzsch) Compère, 2001	+	+	+	
Total Number of Species in Seasons	28	38	43	25
Total Number of Species	66			

are temperature and conductivity, respectively, and these variables played an important role in the distribution of the species ($p < 0.05$). It was determined that temperature, conductivity, DO, and pH had a strong positive correlation with Axis 1, and salinity had a strong positive correlation with Axis 2 ($p < 0.05$). According to CCA, it was revealed that the environmental variables measured in this study did not affect the distribution of *C. affinis* and *C. lange-bertalotii*. It was determined that temperature was positively related with *E. minuta*, *G. kuetzingii*, and *N. veneta* while being negatively related with *N. dissipata* and *U. ulna*. In addition, conductivity had a positive correlation with *E. minuta* and *E. ventricosum* while having a negative correlation with *C. compacta* and *U. ulna*. Furthermore, this analysis shows that *E. minuta*, *N. trivialis*, and *N. veneta* are negatively affected by DO and pH, and *F. vaucheriae*, *G. pumilum*, *N. dissipata*, and *S. brebissonii* by salinity.

In order to reveal the epiphytic diatom species diversity, the Shannon–Weaver (H') diversity index was employed based on

the number of species and individuals in all sampling periods (Figure 8). Due to the low water level in November, only station 2 ($H' = 3.13$) could be sampled, so other stations were not included in the measurement. Considering all the sampling periods, it was determined that the index varied between 1.24 (August) and 3.38 (May).

Clustering analyses were used to determine the similarities of the stations investigated in Büyükçekmece Reservoir. Accordingly, while investigating the similarities of the stations in terms of biotic variables, Bray–Curtis similarity analysis was employed (Figure 9a), and it was determined that the highest similarity was between stations 1 and 2 (69.1%). The lowest similarity rate was observed between stations 2 and 3 (44.5%). It was also noted that station 3 had a low similarity rate with other stations (<54%) and differed from other stations. By using Euclidean distance (ED) to determine the similarity between the stations in terms of ecological variables (Figure 9b), stations 2 and 4 were found to be the closest stations (ED= 4.8), and stations 3 and 5 were found to be

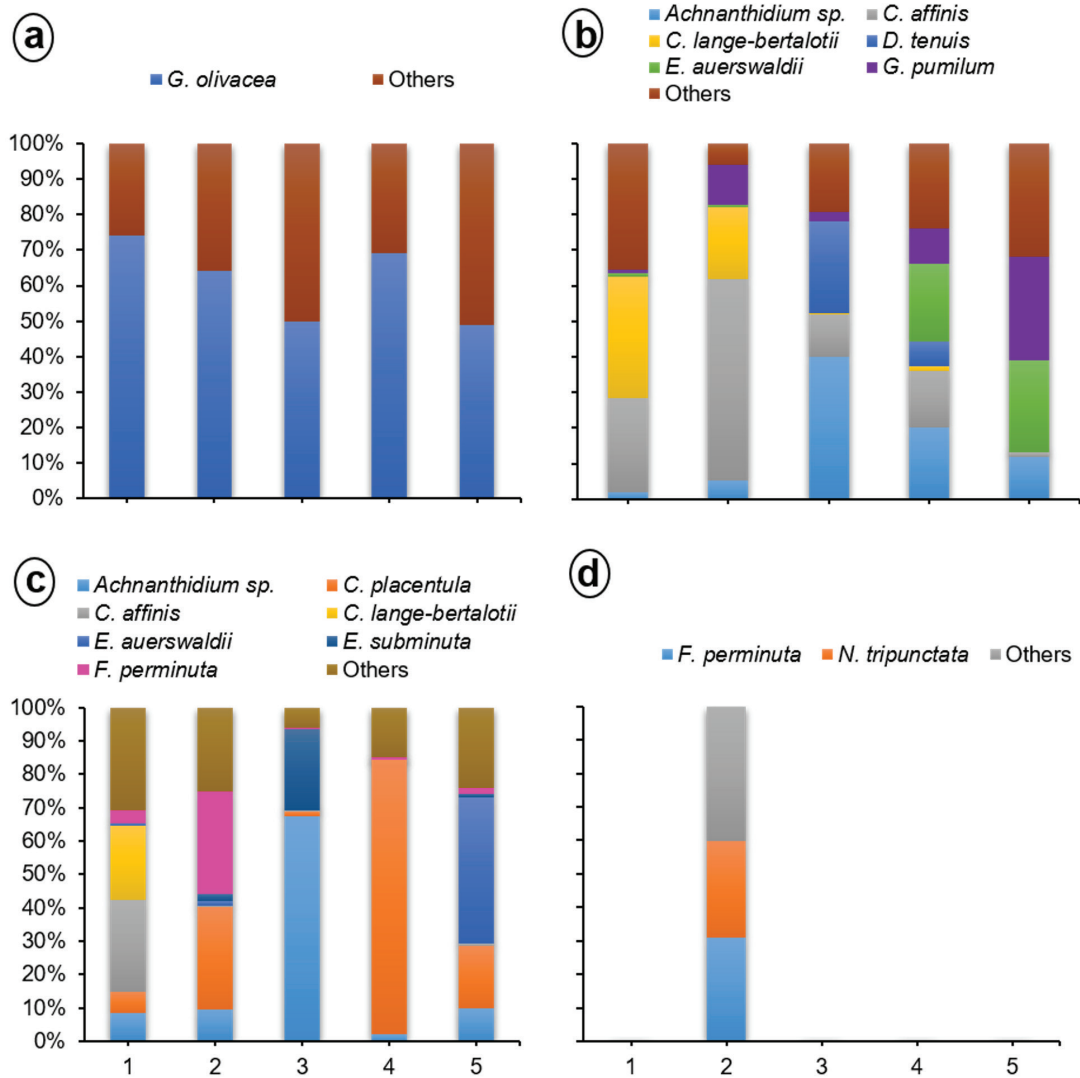


Figure 6. The relative abundance of the dominant epiphytic diatom species (> 20%) in the Büyükçekmece Reservoir (a) February, b) May, c) August and d) November; *Cocconeis placentula*: *C. placentula*, *Cymbella affinis*: *C. affinis*, *Cymbella lange-bertalotii*: *C. lange-bertalotii*, *Diatoma tenuis*: *D. tenuis*, *Encyonema auerswaldii*: *E. auerswaldii*, *Encyonopsis subminuta*: *E. subminuta*, *Fragilaria perminuta*: *F. perminuta*, *Gomphonella olivacea*: *G. olivacea*, *Gomphonema pumilum*: *G. pumilum*, *Navicula tripunctata*: *N. tripunctata*).

Table 2. Spearman's rank correlation between environmental parameters and epiphytic diatoms (** $p < 0.01$, * $p < 0.05$, H' : Shannon-Weaver diversity index).

	Temperature	Salinity	Conductivity	Dissolved oxygen	pH	Epiphytic diatoms
Salinity	-0.236					
Conductivity	0.553*	0.355				
Dissolved oxygen	-0.541*	-0.126	-0.691**			
pH	-0.287	-0.417	-0.651**	0.784**		
Epiphytic diatoms	0.276	-0.051	0.587*	-0.264	-0.169	
H'	0.062	-0.037	0.370	-0.118	-0.168	0,845**

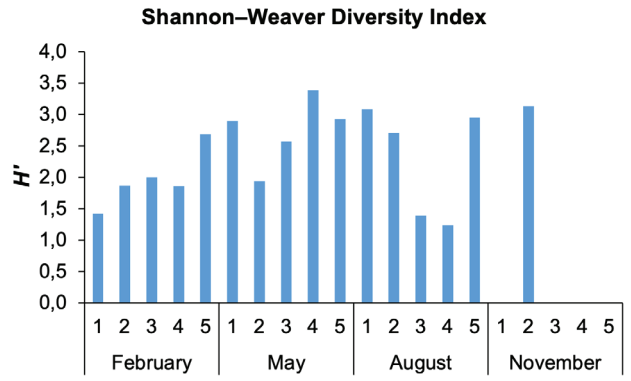
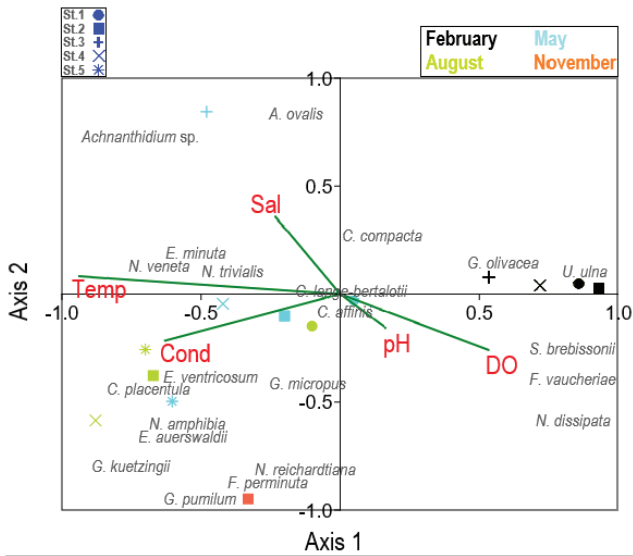


Figure 8. Shannon-Weaver diversity index in the sampling periods.

Figure 7. CCA results showing relationships between environmental variables and epiphytic diatom taxa distributions ($p < 0.05$). (Cond: Conductivity, DO: Dissolved oxygen, Sal: Salinity, Temp: Temperature; *Amphora ovalis*: *A. ovalis*, *Cocconeis placentula*: *C. placentula*, *Cymbella affinis*: *C. affinis*, *Cymbella compacta*: *C. compacta*, *Cymbella lange-bertalotii*: *C. lange-bertalotii*, *Encyonema auerswaldii*: *E. auerswaldii*, *Encyonopsis minuta*: *E. minuta*, *Encyonema ventricosum*: *E. ventricosum*, *Fragilaria perminuta*: *F. perminuta*, *Fragilaria vaucheriae*: *F. vaucheriae*, *Gomphonella olivacea*: *G. olivacea*, *Gomphonema micropus*: *G. micropus*, *Gomphonema pumilum*: *G. pumilum*, *Gyrosigma kuetzingii*: *G. kuetzingii*, *Navicula reichardtiana*: *N. reichardtiana*, *Navicula trivialis*: *N. trivialis*, *Navicula veneta*: *N. veneta*, *Nitzschia amphibia*: *N. amphibia*, *Nitzschia dissipata*: *N. dissipata*, *Surirella brebissonii*: *S. brebissonii*, *Ulnaria ulna*: *U. ulna*).

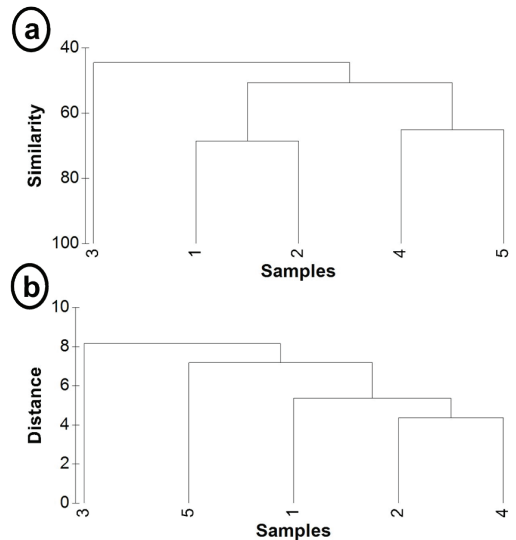


Figure 9. Dendrograms of cluster analysis based on Bray-Curtis similarity index (a) and Euclidean Distance (b) in the Büyükçekmece Reservoir.

the most distant to each other (ED= 8.1). In terms of Euclidean Distance, it was observed that station 3 differed from other stations, similar to the Bray-Curtis similarity analysis.

The Status of Büyükçekmece Reservoir in Terms of Water Quality Parameters

According to the measured DO and conductivity in the study, it was aimed to ascertain the ecological water quality class and trophic level of the reservoir (Table 3). According to the Surface

Water Quality Control Regulation (12) considering the conductivity and DO values, the reservoir is of very good (I) and good

Table 3. Ecological water quality status and trophic level of the lake according to conductivity and dissolved oxygen values (Classification: "I" Very good, "II" good, "III" Moderate; Trophic Level: "O" oligotrophic, "M" mesotrophic, "E" Eutrophic).

Stations	Conductivity				Dissolved Oxygen				Trophic Status (DO)			
	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov
1	I	II	II	II	I	II	I	I	O	O	O	O
2	I	I	II	II	I	I	I	I	O	O	O	O
3	II	II	II	II	I	II	I	I	O	O	O	O
4	I	II	II	II	I	I	I	III	O	O	O	M
5	I	II	II	III	I	I	III	III	O	O	M	E

(II) quality, but in terms of DO values in some seasons and stations (August and November), it is at the moderate (III) class water quality level. At the same time, when the trophic level of the lake was evaluated according to DO, it was determined that oligotrophic conditions prevailed throughout the study, and the eutrophic situation prevailed only at station 5 in the November sampling period. When the reservoir is classified according to H' values, stations 1, 2, and 4 were poor, stations 3 and 5 were moderate in February; stations 1, 2, 3, and 5 were moderate, and station 4 was good in May; stations 3 and 4 were poor, stations 2 and 5 were moderate, and station 1 was good in August while station 2 was of good status in November.

DISCUSSION

In this study conducted seasonally on epiphytic diatoms in Büyükçekmece Reservoir, 66 species were identified. 36 of the identified species (54.4%) are new records for the reservoir, and some genera (*Eunotia*, *Geissleria*, *Hippodonta*, and *Tabularia*) were first encountered in this study in the reservoir. Also, in addition to these 36 new species records, the species which were reported by Balkis–Ozdelice et al. (24) as new record species for the reservoir (*Cymbella cantonatii*, *C. compacta*, *Encyonopsis subminuta*, *Navicula trivalis*, and *Suriella brebissonii*), were also found in this study.

In Büyükçekmece Reservoir, only one study covering epiphytic diatoms was carried out (18), and 42 species were reported. Of the species acquired by Temel (18), 13 species (13.7%) were common, 29 species (30.5%) were found only in the study of Temel (18), and 53 species (55.8%) were detected only in the present study. According to these two studies, the number of epiphytic diatom species of the reservoir was determined to be 95. In addition to epiphytic algae in the reservoir, epilithic, epipellic, and phytoplanktonic organisms in the water column were also analysed (17–24). The species obtained from all these studies are presented in a list (24). According to Balkis–Ozdelice et al. (24), a total of 333 phytoplankton species were reported in the reservoir, and it was stated that 128 of these species were reported to be composed of diatoms. By adding 36 epiphytic diatom species obtained in this study to the list, this number was updated as 164 for diatoms and 369 for total phytoplankton. When considering the epiphytic diatom studies carried out in lakes and reservoirs in Turkey; 39 epiphytic diatom species from Karkamış and Birecik Reservoirs (46), 31 from Lake Liman (47), 66 from Lake Gala (48), and 61 from Lake Mogan (49) have been reported. Accordingly, it has been determined that Büyükçekmece Reservoir has a similar number of epiphytic diatom species with other lakes and reservoirs.

While Temel (18) noted that *Cocconeis placentula*, *Navicula tripunctata* (= *N. gracilis*), and *Nitzschia palea* were common and numerous, *C. placentula* and *N. tripunctata* were widely observed in our study whereas *N. palea* was not found. In addition, in the present study, *C. affinis*, *E. minuta*, *F. perminuta*, *F. vaucheriae*, *G. olivacea*, *G. minuta*, *N. reichardtiana*, *N. tripunctata*, and *N. trivalis* were widely recorded (in all seasons). Additionally, *E.*

minuta and *G. pumilum*, which are reported to be rare species for Turkish freshwater diatom flora (50), are commonly encountered in the reservoir, and *E. subminuta*, another rare species in Turkey, was rarely observed in the Büyükçekmece Reservoir.

In this study, it was observed that pennate diatom members from epiphytic diatoms are dominant, especially *G. olivacea* in the February sampling, *C. affinis* in May, *Achnanthydium* sp. and *C. placentula* in August, and *F. perminuta* in November. The dominance of pennate diatoms in the epiphytic habitat compared to centric diatoms is similar to the previous study in the reservoir (18), as well as with the studies performed in other lakes (51–53). In addition, Round (54) reported that *Fragilaria*, *Cocconeis*, *Gyrosigma*, *Caloneis*, *Navicula*, *Amphora*, *Cymbella*, and *Nitzschia* are very common in calcareous waters while *Pinnularia* and *Neidium* are very common in acidic waters. In addition, Round (55,56) reported that in addition to these genera, *Cymatopleura elliptica* species increased in neutral and slightly alkaline waters, and *Amphora ovalis* increased significantly in alkaline waters. In this study, the prevalence of the common species in calcareous waters and the absence of *Pinnularia* and *Neidium*, representing acidic environments in epiphytic habitats, showed that the environment was calcareous and alkaline. One of the ecological variables, the pH value between 7.49 and 8.28 also supports this finding.

As is known, diatoms are used as indicators of pH, conductivity, salinity, and trophic level (57). Lange-Bertalot et al. (58) stated that *Navicula veneta*, which was also observed in this study, is one of the diatom types that can be used as a pollution indicator, but the relative abundance of this species in the stations analysed in Büyükçekmece Reservoir remained below 1%. Overall in the study, *G. olivacea* is the species that increased its abundance at low temperature and high pH values. Similarly, Koçer and Şen (59) stated in their study in Lake Hazar that this species is dominant under similar ecological conditions. Since the relationship of this species with temperature and pH could not be revealed in the CCA analysis, it was not possible to conclude whether it could be used as an indicator or not. Also, in CCA analysis, it was determined that *N. veneta* had a positive relationship with temperature and *E. ventricosa* had a positive relationship with conductivity ($p < 0.05$). These species can be considered as potential indicators, but further studies are needed to verify their status as indicator species. Also, according to ordination analysis, temperature and conductivity were revealed to be the main factors affecting diatom distribution.

Suriella brebissonii, *F. vaucheriae*, and *N. dissipata*, which are epiphytic diatom species, were negatively correlated with temperature and salinity; *C. compacta* and *U. ulna* were negatively correlated with conductivity; *E. minuta*, *N. trivalis*, and *N. veneta* were negatively correlated with pH and DO. With the spring period, an increase in temperature and conductivity was observed, and it was determined that *C. affinis* and *C. lange-bertalotii*, which are dominant species in this period, were not affected by the ecological variables measured in the study. However, Kelly et al. (60) reported

that *C. affinis* could be specified as a high-quality indicator type for moderately alkaline lakes. In this study, pH varied between 7.91 and 8.05 during the periods when *C. affinis* was dominant. With temperature conditions reaching the optimum level (~25°C) during the summer period, *Achnanthydium* sp. and *C. placentula* became dominant. Among these species, *C. placentula* was found to show a positive correlation with temperature and conductivity. It was noted that this species was not observed under 0.500 mS/cm conductivity value and reached the maximum abundance at station 4 in August when the highest temperature value in the study was determined. Kindt and Small (61) reached similar results with this study and stated that the abundance of *C. placentula* increased with the increase in temperature.

Van Dam et al. (62) stated that the species belonging to the genus *Cymbella* and *Eunotia* were found in regions with high dissolved oxygen concentrations. Similarly, in the Büyükçekmece Reservoir, DO has reached a high concentration (18.4 mg/L) at station 2 in May while the relative abundance of *C. affinis* and *C. lange-bertalotii* at this station reached 76%. In addition, *Eunotia bilunaris* was observed only in the May sampling where the DO concentration was high. Cox (63) reported that *Navicula capitatoradiata* and *N. veneta* were more common in waters with high conductivity. Contrary to this finding, both species were found abundant in February and May samples (compared with other seasons), where the conductivity was low in the Büyükçekmece Reservoir. Reimer et al. (64) stated that *C. placentula* is a cosmopolitan species due to its high tolerance to the change of environmental factors. As similar, *C. placentula* was observed in almost every season in this study.

As it is known, as the temperature increases, the solubility of gases decreases. It was observed that the dissolved oxygen concentration increased with the decrease in temperature in cold periods (February, November) in the Büyükçekmece Reservoir. Similar results were found in a study conducted in Tasmanlı Pond (65). The number of species was also found to be high in May and August, which represent warm periods. However, in a study conducted in Topçu Lake (51), a decrease in the number of species was reported in July and August (in warm periods). This situation reveals that environmental factors may decrease or increase the number of species.

When the evaluation was made on the basis of stations, it was determined that station 3 was represented with fewer species than other stations in terms of the number of diatom species in the reservoir. Bray-Curtis and Euclidean Distance among the cluster analysis were applied in the study, and it was revealed that station 3 was separated from the other stations according to both analyses. Also, according to Spearman's rank correlation, a positive relationship was observed between conductivity and the number of epiphytic diatom species ($p < 0.05$). While the highest conductivity values in February and May were reached at station 3, there was no increase observed in terms of the number of species. In fact, it is remarkable that only 8 cells belonging to 5 species were found in the February sample.

Shannon-Weaver diversity index (H'), used for determining the structure of the communities, varied between 1.24 and 3.38 in the study. The lowest values in the study were obtained in August. During this period, *Achnanthydium* sp. (St.3, 67%) and *C. placentula* (St.4, 82%) were dominant species, and this situation caused a decrease in H' values. Also, it was determined that the diversity at station 5, which is located in the north of the reservoir and close to the stream, did not show a significant change seasonally. Molvær et al. (45) classified waters for the ecological quality. According to this classification, Büyükçekmece Reservoir was generally in poor and moderate status, and in some sampling periods, it was found to be in good status (St.4 in May, St.1 in August, and St.2 in November). In addition, it was observed that H' values obtained from studies on epiphytic diatoms in other freshwater resources ranged from 0.867 to 1.427 (47, 48). Accordingly, it was revealed that the diversity of Büyükçekmece Reservoir is at a higher level than the other sources.

CONCLUSION

As a result, this study aimed to determine the epiphytic diatoms and abundance conditions in the reservoir, and newly recorded species for the lake were reported. In the reservoir, it was also reported that according to the conductivity and DO values, the lake is of very good (I) and good (II) quality. Also, in terms of DO values, it was observed that the reservoir was oligotrophic during the February and May sampling periods, station 5 was mesotrophic, other stations were oligotrophic during the August sampling period, stations 1, 2, and 3 were oligotrophic, station 4 was mesotrophic, and station 5 was eutrophic during the November sampling period. Eutrophication conditions have occurred since station 5 is located close to the Karasu Stream, which is the biggest nutrient source of the reservoir and has been reported to carry a significant amount of nutrient load, and the occupancy rate of the reservoir had decreased to 40% during the November sampling period. Balkis-Ozdelice et al. (24) proposed that the phosphorus intake to Büyükçekmece Reservoir be controlled. Also, according to H' classification, Büyükçekmece Reservoir was generally in poor and moderate status. For these reasons, it is necessary to monitor the ecological quality status of the reservoir with monitoring studies.

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