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EPIPHYTIC DIATOMS IN ENVIRONMENTAL BIOINDICATION: A CASE STUDY OF A SIGNIFICANT NATURAL LAKE IN THE NORTHWEST OF TURKEY

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ABSTRACT

Aim of the study
The Gala Lake, which has a status of National Park and is a protected area, is the one of the most important natural stagnant water bodies in the Marmara Region of Türkiye. However, it is under effect of a significant agricultural stress, mainly resulting from paddy cultivation of rice. In this research, epiphytic diatoms of Gala Lake were investigated, and trophic status of the lake was assessed by applying the Biological Diatom Index (BDI).

Material and methods
Epiphytic diatom samples were collected from the submerged macrophytes from 5 selected locations on the lake (G1–G5) with varying ecological character, and observed to be exposed to different pollution pressures.

Results and conclusions
As a result of collecting taxonomic data, 37 diatom species were recorded by identifying a total of 2095 valves, and *Cyclotella meneghiniana*, *Bacillaria paxillifera*, and *Navicula recens* were found as the most dominant species for the Gala Lake. According to the results of bioindication data, Gala Lake was found to be in a "eutrophic state"—"having poor water quality" in terms of applied BDI.

Keywords: Gala Lake, epiphytic diatoms, Biological Diatom Index

INTRODUCTION

Diatoms, which can survive in all kinds of ecological conditions from upstream to downstream settings, and from very clean water to very polluted water where the oxygen level is almost zero, constitute one of the most significant groups of organisms in aquatic habitats. Diatoms have a very efficient cellular system and chlorophylls of type a and c, which are known as significant light-absorbing molecules. Therefore, they form the first step of the aquatic food chain. Diatoms are also known to be highly diverse in water ecosystems, and

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they may be more productive than other algal species (Ács et al., 2004; Solak et al., 2007; 2020; Solak and Ács , 2011; Tokatlı et al., 2020a; 2020b).

Bioindicator organisms are beneficial tools to reflect the current conditions of the environment, and they have been commonly used for quality evaluation of water ecosystems all over the globe (Gomà et al., 2004; Solak and Ács, 2011; Delgado et al., 2012). Diatoms that have very fast reactions to changes in environmental conditions are among the most significant members of aquatic bioindicator groups. Therefore, they have long been used as effective water pollution bioindicators (Ács et al., 2004; Torrisi and Dell'Uomo, 2006; Coste et al., 2009; Kalyoncu et al., 2009; Tokatlı et al., 2020a; 2020b). The Biological Diatom Index (BDI), calculated by using the structure of the diatom communities, is among the most convenient and widely used bioindicators. Based on 209 diatom species, the BDI is a standardized biological risk assessment method of the trophic status of freshwater habitats (Zelinka and Marvan, 1961; Coste et al., 2009; Szulc and Szulc, 2013; Tokatlı et al., 2020a; 2020b).

Gala Lake is an A Class Wetland and a Ramsar Area, and it has a special importance with its biological diversity and natural beauty, not only in the context of Turkey but also all of Europe. The lake that is in the delta of Meriç River is the most important natural lentic freshwater habitats of the Thrace Region. However, the Meriç Delta has a great potential of wet agriculture, and some of the most significant rice cultivation areas in Turkey are located in this region. As a consequence, rice paddy fields are known as an intensive stress factor, increasing nutrient levels in the system (Elipek et al., 2010; Tokatlı, 2022; Varol and Tokatlı, 2021; 2022).

Although many studies have been carried out in Gala Lake to date, there is no research that would evaluate water quality using the diatom indices. The objective of this particular investigation was to identify the epiphytic diatoms of Gala Lake and to assess the trophic status of the lake by bioindication using BDI.

MATERIAL AND METHOD

Gala Lake and Collection of Diatoms

Gala Lake, which is surrounded by rice paddy fields, is located in the north-western part of Turkey in the Thrace Region. It is an A Class Wetland, which means the lake has an important stopover wetland potential for various species of migratory birds. It also has the status of a National Park and a protected area in Turkey. The lake is mainly fed by rainwater, however, the drainage water coming from rice cultivation areas with high nutritional content is also a significant water source for the lake (Batur and Maktav, 2019; Tokatlı, 2022). In the present study, epiphytic diatoms were collected from 5 locations on the lake (G1–G5) in the dry season (summer of 2019) (Figure 1).

Preparation and Identification of Epiphytic Diatoms

Epiphytic diatoms were collected from the *Potamogeton crispus*, *Ceratophyllum demersum,* and *Myriophyllum spicatum*, which are the dominant macrophyte species (submerged) in the Gala Lake and found almost anywhere, throughout the entire lake. Three macrophyte individuals were selected randomly from each station for diatom samples. The macrophytes were pooled together in three-litre receptacles and washed with distilled water. The diatoms were ensured to pass from the immersed macrophytes to the distilled water by shaking the containers for about two minutes.

Diatoms were taken by using polyethylene containers. Then, they were cleaned in the laboratory by boiling with an acid mixture (98% H_2SO_4 and 35% HNO_3) in order to remove and eliminate organic content. The acid mixture was then removed from the samples by washing the frustules with distilled water in a centrifuge (2500 RMP) (ECS, 2014).

Diatoms were then transferred to an Olympus branded trinocular light microscope with a camera for observation and for photo shoots of valves. Permanent slides were prepared by using naphrax, a chemical solution for advanced diatom structure embedding, and approximately 400 valves were itemised on the prepared slides (Sladeckova, 1962; Round, 1993; Cox, 1996). Diatom species were identified according to reputable diatom identification references (Krammer and Lange-Bertalot, 1986; 1988; 1991a; 1991b).

Calculation of Biotic Index

The BDI values of each location selected on the Gala Lake were calculated automatically by using the "Calculate IBD with Excel" program. According

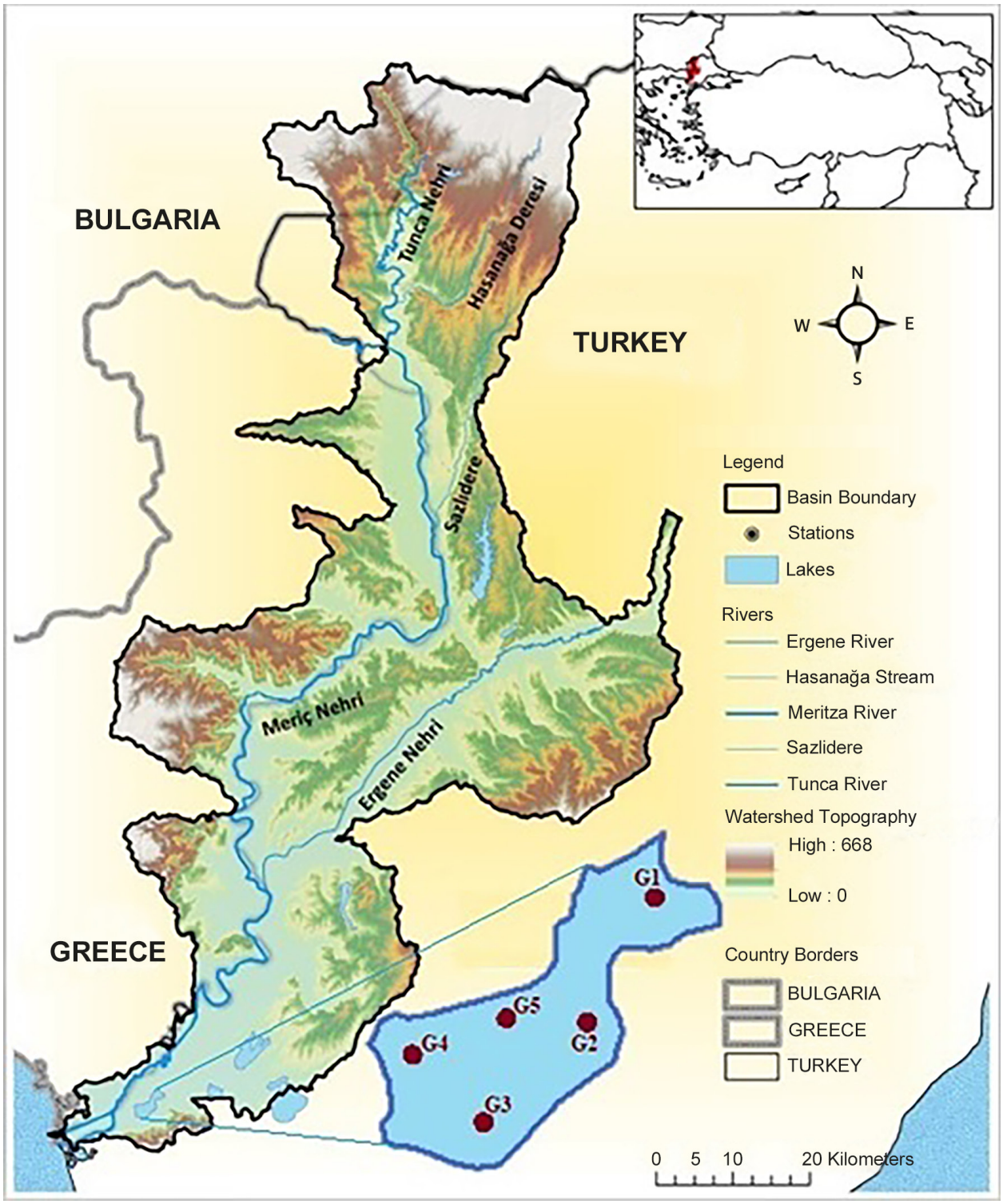

Fig. 1. Watershed of Meriç River and Gala Lake with the selected sampling locations (source: Tokatlı, 2022)

to the applied BDI, the determined classes of freshwater habitats with respect to trophic status are as follows (Lenoir and Coste, 1996): > 17: "High Water Quality" – "Oligotrophic State"; 15–17: "Good Water Quality" – "Oligo – Mesotrophic State"; 12–15: "Moderate Water Quality" – "Mesotrophic State"; 9–12: "Low Water Quality" – "Meso – Eutrophic State"; < 9: "Poor Water Quality" – "Eutrophic State".

RESULTS AND DISCUSSION

During the present research, 37 epiphytic diatom taxa were identified for the Gala Lake by diagnosing a total of 2095 valves from microscope photographs. The determined diatom species with the values of relative abundance and with their assigned codes are listed in Table 1. Microscope images of the 37 diatom species that were recorded are presented in Figure 2.

Table 1. Frequency values diatom species in Gala Lake (source: authors' own research)

Code	Diatom Taxa*	G1	G2	G3	G4	G5
1	*Anomoeoneis sphaerophora* Pfitzer 1871	0.00	0.95	0.00	0.00	0.00
2	*Aulacoseira granulata* (Ehrenberg) Simonsen 1979	**19.2**	0.00	**1.91**	0.00	**17.0**
3	*Bacillaria paxillifera* (O.F. Müller) T. Marsson 1901	10.7	58.6	13.6	3.03	14.1
4	*Caloneis amphisbaena* (Bory) Cleve 1894	0.71	0.00	0.24	0.00	0.74
5	*Cocconeis pediculus* Ehrenberg 1838	0.00	0.00	0.48	0.00	0.00
6	*Conticribra weissflogii* (Grunow) Stachura-Suchoples & D.M. Williams 2009	**1.66**	0.24	0.00	0.00	0.00
7	*Ctenophora pulchella* (Ralfs ex Kützing) D.M. Williams & Round 1986	0.00	0.00	0.00	0.23	0.00
8	*Cyclotella meneghiniana* Kützing 1844	**44.4**	0.00	**14.8**	**10.5**	**40.3**
9	*Cymatopleura solea* (Brébisson) W. Smith 1851	0.00	0.48	0.24	0.00	0.00
10	*Cymbella tumida* (Brébisson) Van Heurck 1880	**1.43**	**4.04**	0.00	**7.46**	**1.48**
11	*Epithemia sorex* Kützing 1844	0.24	0.00	**2.63**	0.00	0.00
12	*Gomphonema acuminatum* Ehrenberg 1832	0.00	0.00	0.24	0.00	0.00
13	*Gomphonema parvulum* (Kützing) Kützing 1849	**7.60**	0.00	0.00	0.00	**12.8**
14	*Gyrosigma attenuatum* (Kützing) Rabenhorst 1853	0.00	0.00	0.48	0.47	0.00
15	*Halamphora veneta* (Kützing) Levkov 2009	0.24	0.00	0.00	0.00	0.00
16	*Haslea spicula* (Hickie) Bukhtiyarova 1995	0.00	0.00	**6.44**	**3.03**	0.00
17	*Karayevia nitidiformis* (Lange-Bert.) Bukht. 2006	0.48	0.00	0.00	0.00	0.00
18	*Lemnicola exigua* (Grunow) Kulikovskiy, Witkowski & Plinski 2011	0.24	0.00	0.24	0.00	0.25
19	*Melosira varians* C. Agardh 1827	**1.19**	0.71	**7.88**	**11.9**	**2.47**
20	*Navicula erifuga* Lange-Bertalot 1985	0.71	0.00	0.00	0.00	0.74
21	*Navicula germainii* J.H. Wallace 1960	0.00	0.00	0.24	0.23	0.00
22	*Navicula gregaria* Donkin 1861	0.00	0.00	**4.53**	0.00	0.00
23	*Navicula recens* (Lange-Bertalot) Lange-Bertalot 1985	3.33	11.4	39.9	59.9	1.73
24	*Navicula rostellata* Kützing 1844	0.24	0.00	0.00	0.00	0.00
25	*Navicula salinarum* Grunow 1880	0.00	**4.99**	**4.06**	0.00	0.00
26	*Navicula tripunctata* (O.F.Müller) Bory 1822	0.00	0.00	0.00	0.23	0.00
27	*Nitzschia acicularis* (Kützing) W.Smith 1853	0.00	0.24	0.00	0.00	0.00
28	*Nitzschia elegantula* Grunow 1881	0.00	0.95	0.95	0.00	0.00

Code	Diatom Taxa*	G1	G2	G3	G4	G5
29	*Nitzschia filiformis* (W. Smith) Van Heurck 1896	**2.61**	**2.38**	0.24	**3.03**	0.00
30	*Nitzschia intermedia* Hantzsch 1880	0.48	0.71	0.00	0.00	0.49
31	*Nitzschia reversa* W. Smith 1853	**3.09**	**5.46**	0.00	0.00	**4.69**
32	*Rhopalodia gibba var. minuta* Krammer 1987	0.00	**4.28**	0.00	0.00	0.00
33	*Surirella brebissonii* Krammer & Lange-Bertalot 1987	0.00	**3.33**	0.00	0.00	0.00
34	*Tryblionella apiculata* W. Gregory 1857	0.24	0.95	0.00	0.00	0.00
35	*Tryblionella brunoi* (Lange-Bertalot) Cantonati & Lange-Bertalot 2017	0.00	0.00	0.72	0.00	0.00
36	*Tryblionella hungarica* (Grunow) Frenguelli 1942	0.95	0.24	0.24	0.00	**2.96**
37	*Ulnaria acus* (Kützing) Aboal 2003	0.24	0.00	0.00	0.00	0.25

* The relative abundance values higher than 1% are given in bold

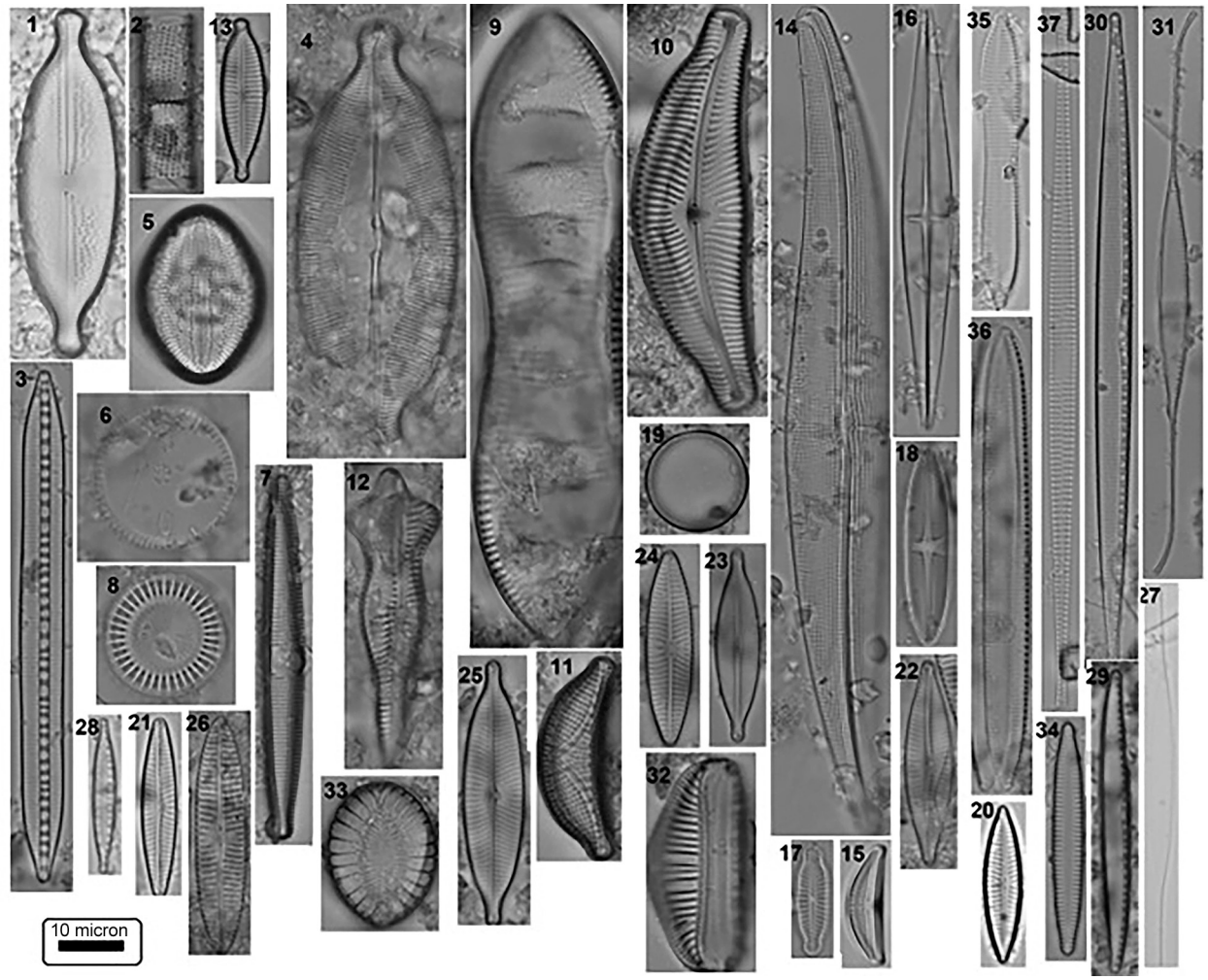

Fig. 2. Microscope images of Gala Lake diatoms (source: authors' own elaboration)

Cyclotella meneghiniana, *Bacillaria paxillifera,* and *Navicula recens* were recorded as the most dominant species in Gala Lake. The Bacillaria genus, which grows in colonies in benthic, epipelic, epiphptic, or planktonic habitats, has relatively wide distribution from freshwater to brackish waters. *B. paxillifera* is considered to be indicative of human-induced pollution in freshwater habitats able to tolerate fluctuations in salinity. *C. meneghiniana* is widespread and particularly common in shallow, nutrient-rich waters, and *N. recens* is also known to prefer brackish water and eutraphentic freshwaters of quite high mineral and nutrient content (Jahn and Schmid, 2007; Taylor et al., 2007; Houk et al., 2010). Similar to the biotic data obtained in the current investigation, it has been unambiguously reported in many studies that the Gala Lake tends towards salty water characteristics, and that the nutrient content of the water is very high and has reached critical levels (Varol and Tokatlı, 2021; Aydın and Çamur, 2021; Tokatlı, 2022).

According to the results of applied BDI, Gala Lake was determined to be in a "eutrophic state"—"have poor water quality" (score range of <9), and the spatial order of the trophic levels in terms of determined BDI values in Gala Lake was found as follows: G4 (9.52) > G3 (8.55) > G1 (7.87) > G5 (7.60) > G2 (5.82).

The chemical water quality parameters can only indicate the current situation of freshwater ecosystems. However, diatoms, which should be applied for the ecological evaluation and monitoring of freshwater according to the Water Framework Directive (WFD), can indicate long-term effects on aquatic ecosystems. Therefore, they are widely used in the bioassessment of lotic and lentic ecosystems in almost all of the European countries (Torrisi and Dell'Uomo, 2006; Martín et al., 2010; Pham, 2017; Tokatlı et al, 2020a; 2020b).

Although water quality evaluation using diatoms is a relatively new topic in Turkey, many investigations have been conducted, especially in recent years. In research, SI and TDI were applied to evaluate water quality of the Karasu River, and it was determined that the system was polluted eutrophically (Gürbüz and Kıvrak, 2002). In another investigation, pollution of Darıören Stream was investigated with ecological methods, by using epilithic diatom communities. According to the results of that study, the stream water was recorded as mesotrophic – hypertrophic from the upstream to the downstream section (Kalyoncu et al., 2009). In another study performed in Kütahya, DESCY, SLA, TDI, and EPI-D diatom indices were used to assess water quality of the Upper Porsuk River (Solak, 2011). In several investigations implemented in the Central Anatolia Region of Turkey, similar to the current study, BDI was used to evaluate water quality of Gürleyik, Ankara and Seydisuyu Streams. As a result of these studies, the three streams were found to be in "mesotrophic" state, in line with the physicochemical data examined (Atıcı and Ahiska, 2005; Atıcı et al, 2016; 2018). In a number of other investigations performed in the Thrace Region of Turkey, BDI was applied as a diatom based bioindication tool to assess trophic statuses of the Tunca, Ergene and Meriç Rivers. As a result of these studies, the trophic statuses of the Meriç and Tunca Rivers were determined to be "meso – eutrophic", whereas the Ergene River was found to be "eutrophic", similarly to the Gala Lake (Tokatlı et al, 2020a; 2020b).

The BDI was used to evaluate water quality of the Gala Lake and, similar to the chemical results of previous studies performed in Gala Lake (Tokatlı and Ustaoğlu, 2020; Varol and Tokatlı, 2021; Tokatlı, 2022; Tokatlı and İslam, 2022), the system was determined to be in relatively eutrophic condition, having relatively poor water quality, concluding from the applied BDI. Rice cultivation in the region has continued without any interruptions for more than about sixty years, therefore, applications of fertilizers have reached critical levels. It is reported in many investigations that the Gala Lake is getting shallower and more eutrophic day by day, and that nutrient contents in the water of the lake have reached alarming rates (Öterler, 2017; Varol and Tokatlı, 2021; Aydın and Çamur, 2021; Tokatlı, 2022).

CONCLUSIONS

Bioindicative freshwater quality assessment is more effective than chemical data alone, and to provide a better risk assessment, chemicals should be supported by biotics. In this research, epiphytic diatoms collected and identified from Gala Lake were used to determine water quality in different locations within the lake. For this purpose, the BDI values of all locations were calculated according to the identified dia-

tom species, and trophic statuses of the lake waters were revealed. According to taxonomic data, 37 diatom species were identified, with *Cyclotella meneghiniana, Bacillaria paxillifera, and Navicula recens* (species with high ecological valence) being the most dominant diatom taxa for the Gala Lake. According to the BDI data, similar to the previous limnological study data conducted in the lake, it was determined that the waters of all the investigated stations in the lake were in a "eutrophic state" and had "poor water quality" (BDI < 9). The findings of this study clearly demonstrate the advantages of using biotic factors to evaluate water quality, and while the sampling frequency is insufficient for the current investigation, the data obtained has the characteristics of preliminary bioindication research.

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OKRZEMKI EPIFITYCZNE W BIOINDYKACJI ŚRODOWISKOWEJ: STUDIUM PRZYPADKU ZNACZĄCEGO NATURALNEGO JEZIORA W PÓŁNOCNO-ZACHODNIEJ TURCJI

ABSTRAKT

Cel badań
Jezioro Gala, które ma status Parku Narodowego i jest obszarem objętym ochroną, to jeden z najważniejszych naturalnych zbiorników wód stojących w regionie Marmara w Turcji. Jezioro poddawane jest znacznej presji ze strony rolnictwa, przede wszystkim upraw ryżu. W ramach przedstawionych tu badań zbadano okrzemki epifityczne jeziora Gala i oceniono stan troficzny jeziora za pomocą biotycznego wskaźnika okrzemek (BDI).

Materiał i metody
Próbki okrzemek epifitycznych pobrano z zanurzonych makrofitów, w 5 wybranych lokalizacjach na jeziorze (G1–G5), o różnych cechach ekologicznych, narażonych na zanieczyszczenie o zróżnicowanym natężeniu.

Wyniki i wnioski
Na podstawie danych taksonomicznych zarejestrowano 37 gatunków okrzemek na podstawie identyfikacji w 2095 zastawkach. Za gatunki dominujące w jeziorze Gala uznano *Cyclotella meneghiniana*, *Bacillaria paxillifera* oraz *Navicula recens*. Zgodnie z wynikami danych bioindykacyjnych, na podstawie zmierzonego wskaźnika BDI stwierdzono, że jezioro Gala znajduje się w „stanie eutroficznym" – tzn. ma złą jakość wody.

Słowa kluczowe: jezioro Gala, okrzemki epifityczne, biotyczny wskaźnik okrzemkowy (BDI)