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RESEARCH ARTICLE

Ecological status estimation of eight creeks in the Lake Sapanca Basin (Sakarya, Turkey) using diatom indices

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Abstract – It is important to determine the water quality of the creeks in the Lake Sapanca basin since it is used for drinking water supply. For this purpose, environmental parameters and diatom assemblages as biological quality components were investigated to determine the ecological status of eight creeks with monthly intervals between March 2015 and February 2016. During the studied period, 19 taxa increased their relative abundance higher than 30% in at least one sample and showed a different seasonal pattern. Main nutrients [(nitrate-nitrogen, orthophosphate, total phosphorus (TP)] and some other parameters (specific conductance, temperature, pH, and dissolved oxygen) had strong impacts on the distribution of diatom assemblages. The ecological status of the creeks was characterized by using four different diatom indices, however, only Trophic Index Turkey (TIT) represented significant positive correlations with log (TP) gradient and separated the creeks as good and moderate ecological status. According to TIT, the 4th and 6th stations had a good ecological condition and were characterized by pollution-sensitive species such as *Cymbella affinis*, *Reimeria sinuata*, and *Nitzschia dissipata.* On the other hand, TIT resulted in the other stations having moderate ecological conditions, which had high nutrient levels and EC. Moreover, the occurrence of pollution-tolerant taxa such as *Gomphonema angustatum*, *Ulnaria ulna*, and *Achnanthidium affine* endorsed the moderate ecological conditions in these creeks. Based on the results, the TIT as a biological metric could be a useful tool for the assessment of running waters in the Sakarya river basin.

Keywords: Bacillariophyceae / biomonitoring / running waters / seasonal variation / trophic index Turkey

1 Introduction

In the last century, the importance of water quality and pollution research has increased due to the deterioration of water quality that arises from various reasons such as mining operations, domestic and industrial wastes, and agricultural activities (Tepe and Boyd, 2002). Diatom communities are an important element of water quality monitoring studies, as species composition or diversity can alter according to water quality and the environmental conditions (Palmer, 1980; Ács *et al.*, 2004). These organisms are an important group in different aquatic ecosystems (Ács *et al.*, 2004; Solak and Àcs, 2011), and they can respond quickly to many environmental parameters (Palmer, 1980; Armbrust, 2009). Besides, benthic diatom communities are useful in detecting anthropogenic effects on water composition change, and also they are used as model organisms in ecological, paleolimnological, and monitoring studies (Stoermer and Smol, 1999; Ács *et al.*, 2004; Solak and Àcs, 2011). Because of these reasons, they are considered key organisms of water ecology, and have been used as indicators of water pollution for more than a few decades (Kelly and Whitton, 1995; Stevenson *et al.*, 1999; Ács *et al.*, 2004; Solak, 2011; Solak and Àcs, 2011; Atıcı and Yıldız, 2012).

According to the European Union's Water Framework Directive (WFD) (EC, 2000), both biotic and abiotic parameters are used to determine the environmental conditions of different water bodies. Five biological elements including diatoms (phytobenthos) are currently being employed by the WFD (EC, 2000) for ecological status evaluation. For this reason, different diatom indices have been developed especially in European countries. Cemagref (1982) has created the Specific Pollution Sensitivity Index (IPS) for France but it is widely used in Mediterranean countries. Dell'uomo *et al.* (1999) have developed the Eutrophication/Pollution Index (EPI-D), and this index is based on the sensitivity of diatoms to organic matter, nutrients, and mineralization of water for the Italian rivers. Kelly and Whitton (1995) have developed the Trophic Diatom Index (TDI), which is widely used in European countries. In Turkey, Çelekli *et al.* (2017, 2019a)

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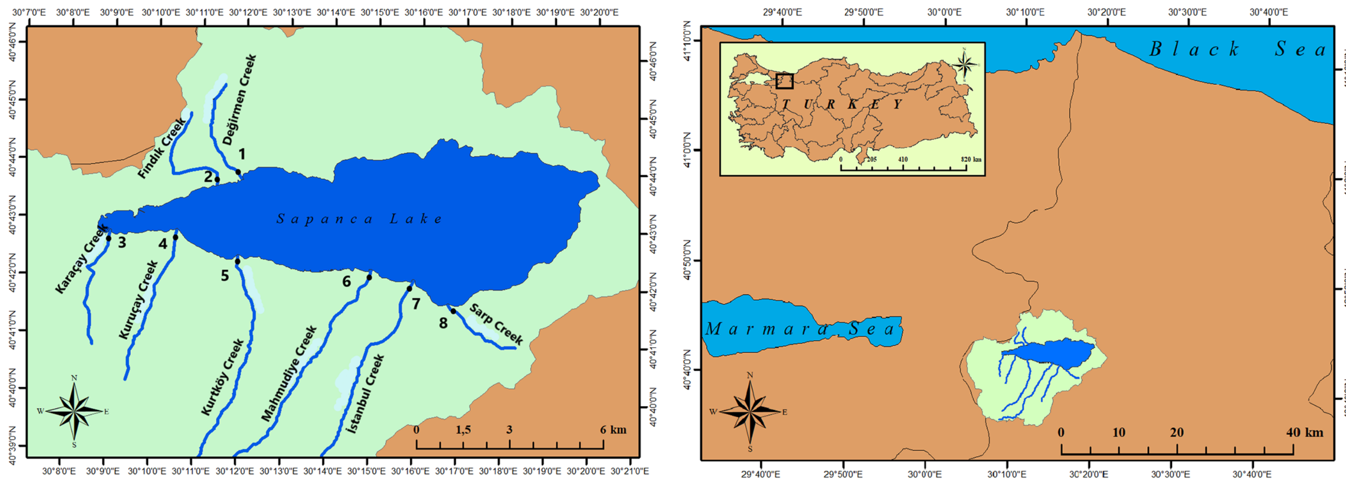

Fig. 1. Map of the Lake Sapanca and location of the sampling stations in the creeks.

have created the Trophic Index Turkey (TIT) based on data collected from 225 running water bodies from eight basins of Turkey. TIT was successfully tested in Northern Aegean, Western Mediterranean, and Aras basins, and in Gaziantep regions (Toudjani *et al.*, 2017; Çelekli *et al.*, 2018, 2019b; Çelekli and Kapı, 2019; Çelekli and Arslanargun, 2019).

Studies on diatom indices to evaluate water quality in Turkey are still insufficient despite intensive research over the past decade. Some studies on different rivers, lakes, or river basins using diatom indices were done in the past. In these studies, the trophic status of Akçay Stream (Pabuçcu *et al.*, 2007), Upper Porsuk Creek (Solak, 2011), Acarlar Floodplain Lake (Sevindik and Kücük, 2016), and Meriç and Tunca Rivers (Tokatlı *et al.*, 2019) were evaluated. Moreover, various watercourses in the western Mediterranean (Toudjani *et al.*, 2017), North Aegean (Çelekli *et al.*, 2018), and Gaziantep region (Çelekli and Arslanargun, 2019) were studied using these indices. Although there are some studies on Lake Sapanca (Temel, 1996; Akçaalan *et al.*, 2007; Yılmaz and Aykulu, 2010), and on its creeks (Arman *et al.*, 2009; Ateş *et al.*, 2020; Akıner and Akıner, 2021), no studies were done on the diatom flora or diatom indices to evaluate the water quality of the creeks feeding the lake. For this reason, this study aims to assess the ecological status of eight creeks feeding Lake Sapanca using diatom indices developed from different ecoregion and to define the most important environmental factor(s) driving the distribution of epilithic diatom assemblages.

2 Material and methods

2.1 Study area

Lake Sapanca is a freshwater ecosystem in the province of Sakarya and is fed by nineteen creeks with seasonally changing flow rates. The only outlet of the lake is Çark Creek, and a sluice on this creek is opened only when the water level of the lake is high. This large lake is located in the Sakarya river basin. The surface area of the lake is about 45 km^2 and the size of the catchment is about 296 km^2. The coastline within the borders of Sakarya province is 26 km; and of Kocaeli province is 13 km (Kahveci, 2015). The lake is used for drinking water supply by Kocaeli and Sakarya cities (Akçaalan *et al.*, 2014). The number of heavy industrial establishments is very few, and agriculture is not very intense around the lake (Arman *et al.*, 2009; Akçaalan *et al.*, 2014). However, uncontrolled agricultural and domestic wastewaters inflows which are mainly carried by the tributary creeks have affected the lake (Arman *et al.*, 2009). Moreover, the lake basin is surrounded by two highways and a railway. They all have negative effects on the creeks and Lake Sapanca (İleri, 1997).

Although the lake is fed by 19 creeks, most of them dry up in the summer months. Eight creeks that are not dry up throughout the year were selected for sampling. Epilithic diatom samples and environmental parameters were obtained from these creeks in Lake Sapanca Basin as shown in Figure 1, and their general features and geographical locations were summarized in Table 1. Değirmen and Fındık creeks are located to the north of the lake, and they are under the pressure of industrial and agricultural activities. The other creeks (Karaçay, Kuruçay, Kurtköy, Mahmudiye, İstanbul, and Sarp) located at the south of the lake are commonly impacted by the domestic and agricultural wastes.

2.2 Analysis of epilithic diatoms

Ephilithic diatom sampling was monthly done between March 2015 and February 2016. Sampling stations were chosen in the creeks approximately 500 m – 1 km far from the point where the creeks flow into the lake. At least five stones were randomly selected in the creeks and the upper surface of the stones was brushed with the bristle brush in 100 mL of distilled water following standard methods (European Committee for Standardization, 2004). Samples were fixed with Lugol's solution. In the laboratory, diatom samples were cleaned with hydrochloric acid and hot hydrogen peroxide, and permanent slides were mounted with Naprax according to the European Committee for Standardization (2004). Identification and counting of the diatom samples were done with an Olympus BX51 microscope using 1000× magnifications.

Table 1. General features of sampling stations of creeks in the Lake Sapanca Basin.

Creeks	Station number	Latitude	Longitude	Length (km)	Mean annual discharge ($m^3 s^{-1}$) (TUBİTAK, 2010)
Değirmen Creek	1st station	40° 43′ 47″ N	30° 11′ 52″ E	11.0	0.130
Fındık Creek	2th station	40° 43′ 37″ N	30° 11′ 23″ E	8.0	0.100
Karaçay Creek	3rd station	40° 42′ 35″ N	30° 08′ 57″ E	10.5	0.276
Kuruçay Creek	4th station	40° 42′ 28″ N	30° 10′ 26″ E	11.8	0.452
Kurtköy Creek	5th station	40° 42′ 17″ N	30° 11′ 55″ E	12.5	0.113
Mahmudiye Creek	6th station	40° 41′ 53″ N	30° 14′ 44″ E	13.4	0.485
İstanbul Creek	7th station	40° 41′ 51″ N	30° 15′ 47″ E	12.8	0.526
Sarp Creek	8th station	40° 41′ 21″ N	30° 16′ 28″ E	4.0	0.100

At least 400 diatom valves were counted for each slide for all samples. Diatom species were identified according to Krammer and Lange-Bertalot (1986, 1991a, 1991b, 1999) and Krammer (2003). The taxonomy of algae was checked according to Guiry and Guiry (2021). A total of 96 samples were used for diatom indices. The mean values of 12 months for each station were used in determining the ecological status. TIT was calculated according to Çelekli *et al.* (2017, 2019a) and Toudjani *et al.* (2017). The 'OMNIDIA' program (Lecointe *et al.*, 1993) was used to calculate three different diatom indices described before (EPI-D, IPS, and TDI). Calculations of EPI-D indice took into account more than 75% of the taxa, and TIT, IPS and TDI about 95%. Species with relative frequency higher than 30% in at least one sample were accepted as dominant taxa. In these taxa, 10 species with an average annual relative frequency of ~5% or higher at least one station were determined to show their distribution in eight creeks.

2.3 Analysis of environmental variables

Sampling for chemical analyses and the measurement of physical variables were carried out in conjunction with diatom sampling. Specific conductance (EC), pH, dissolved oxygen (DO), and water temperature (T) were measured from 10 cm below the surface using a YSI ProPlus water quality instrument. For the analysis of chemical variables, samples were collected 10 cm below the surface in 1000 mL polyethylene bottles and stored at 4 °C. Concentrations of total phosphorus (TP), orthophosphate (PO_4-P), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), and soluble silica (Si) were determined spectrophotometrically according to Strickland and Parsons (1972) and Technicon Industrial Methods (1977a, 1977b).

2.4 Data analysis

Physical and chemical variables were logarithmically transformed. A total of 96 samples for diatom indices and environmental variables were used to maintain the statistical analyses. An analysis of variance (one-way ANOVA) test was applied to data for determining the statistical differences in chemical and physical parameters among the eight selected creeks using SPSS 20.0 software. Spearman correlations between the physicochemical parameters and diatom indices were also determined using the SPSS 20.0 software. Linear regression analyses were used to test the significant effect of TP and diatom indices using the SPSS 20.0 software. Mean indices and TP values of 12 months for each station were used in linear regression. Diatom species with an abundance larger than 1%, and occurring in more than three samples were used in the statistical analyses. To check the suitability of canonical correspondence analysis (CCA), gradient length was measured at first by detrended correspondence analysis (DCA). Since the gradient was 1.43 SD units long, the linear method, Redundancy Analysis (RDA) was carried out using CANOCO software (Ter Braak and Smilauer, 2002). To determine the relationship between the relative abundance of dominant diatoms, sampling stations, and environmental variables, RDA was carried out on the log-normal transformed abundance data. Statistical significance of the environmental predictor variables was assessed by 999 restricted Monte Carlo permutations. To analyze the relationship between the relative abundance of diatoms and environmental variables (T, pH, EC, DO, NO_3-N, NO_2-N, TP, PO_4-P, and Si), we performed a RDA using the relative abundance values of the 63 diatom taxa in the creeks. The RDA was performed initially with overall environmental and diatom datasets. Forward selection indicated that seven environmental variables (T, pH, EC, DO, NO_3-N, TP, and PO_4-P) made a significant contribution to the variance in the diatom data. Because of the 63 diatom taxa and 96 samples included in the analysis, the RDA graph was divided into two parts to make it more comprehensible.

3 Results

3.1 Environmental variables

The mean and standard deviations of environmental parameters obtained from eight creeks were given in Table 2. EC and NO_3-N values were high at 1st station [F (two sets of degrees of freedom) = 24.69, F = 5.07, respectively, $P < 0.01$], while PO_4-P values were high at 8th station (F = 3.88, $P < 0.01$) and TP values were high at 7th and 8th stations (F = 7.54, $P < 0.01$). EC, PO_4-P, TP, and NO_3-N values of the 4th and 6th stations were relatively lower than other stations.

Table 2. The mean and standard deviation (SD) of environmental variables measured in eight creeks feeding Lake Sapanca (T: water temperature, EC: specific conductance, DO: dissolved oxygen, PO_4–P: orthophosphate, TP: total phosphorus, NO_3-N: nitrate-nitrogen, NO_2-N: nitrite-nitrogen, Si: soluble silica).

Variable	1st station	2nd station	3rd station	4th station	5th station	6th station	7th station	8th station
T (°C)	17.44 ± 7.68	15.39 ± 6.76	15.82 ± 4.62	13.72 ± 4.95	14.51 ± 6.52	13.79 ± 6.31	14.37 ± 5.13	15.68 ± 4.64
pH	8.09 ± 0.31	8.02 ± 0.26	8.07 ± 0.22	8.13 ± 0.18	8.17 ± 0.22	8.24 ± 0.14	8.20 ± 0.16	8.27 ± 0.16
EC (μS cm^{-1})	511.20 ± 88.96	304.17 ± 74.14	362.76 ± 57.40	230.53 ± 114.04	191.78 ± 64.36	170.19 ± 56.13	214.99 ± 62.06	329.52 ± 93.05
DO (mg L^{-1})	3.40 ± 2.24	3.02 ± 1.54	3.23 ± 2.07	3.72 ± 2.16	3.55 ± 2.02	4.32 ± 2.04	4.28 ± 2.28	3.99 ± 2.32
PO_4–P (mg L^{-1})	0.07 ± 0.16	0.08 ± 0.07	0.08 ± 0.12	0.04 ± 0.07	0.04 ± 0.04	0.02 ± 0.02	0.11 ± 0.24	0.20 ± 0.34
TP (mg L^{-1})	0.12 ± 0.21	0.09 ± 0.05	0.09 ± 0.06	0.04 ± 0.03	0.12 ± 0.13	0.05 ± 0.04	0.28 ± 0.17	0.24 ± 0.20
NO_3-N (mg L^{-1})	1.17 ± 1.01	0.44 ± 0.51	0.72 ± 0.68	0.28 ± 0.30	0.34 ± 0.34	0.10 ± 0.14	0.34 ± 0.37	0.33 ± 0.29
NO_2-N (mg L^{-1})	0.02 ± 0.04	0.02 ± 0.02	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.05
Si (mg L^{-1})	14.35 ± 8.03	12.50 ± 10.28	14.91 ± 14.20	12.85 ± 15.84	14.46 ± 9.16	15.42 ± 21.57	16.33 ± 15.53	26.35 ± 19.47

3.2 Epilithic diatoms

A total of 132 diatom taxa were recorded during the studied period in eight creeks. 63 of them that constituted >1% of the total relative abundance, and occurred in at least three samples were shown in Table 3. Dominant taxa (>30% in at least one sample) with an average annual relative frequency of ~5% or higher at least one station were shown in Supplementary Material Figure 1. *Achnanthidium minutissimum* was found as dominant species in almost all the stations, however, its relative abundance was relatively low in the summer months. Similarly, *Cocconeis placentula* was found in high proportion in all stations except 1st station, and its relative abundance increased in spring and fall where DO concentration was relatively high. *Achnanthidium affine* increased especially between October 2015 and February 2016 at the first three stations. Although *Gomphonema minusculum* and *Gomphonema angustatum* were found in low percentages at other stations, they were the prominent taxa in the 1st station in August 2015 and January 2016, respectively. The relative abundance of *Nitzschia dissipata* was remarkable at the 6th and 7th stations, however, it became the dominant taxon in the 6th station between October 2015 and January 2016. *Didymosphenia geminata* occurred in the 6th and 8th stations, and its relative abundance increased (>35%) in June 2015 at the 8th station where PO_4-P value was 0.073 mg L^{-1}, TP was 0.29 mg L^{-1}, and the water temperature was 17.6 °C. At the 4th station, *Cymbella affinis* increased its relative abundance in November 2015, while *Reimeria sinuata* were found as dominant taxa between April and June 2015. *Ulnaria ulna* was observed in high percentages in April 2015 at the 3rd station, and in November 2015 at the 5th station. Besides the mentioned taxa, *Diatoma vulgaris, Achnanthes* sp., *Gomphonema truncatum, Gomphonema parvulum, Navicula lanceolata, Surirella brebissonii, Nitzschia capitellata, Pleurosigma* sp., and *Surirella* sp. significantly contributed to relative abundance in different months and different stations (Supplementary Material Table 1).

3.3 Epilithic diatoms and environmental parameters

The results of RDA using 7 variables were illustrated in Figure 2. The eigenvalues of RDA axis 1 (0.06) and axis 2 (0.04), accounted for 9.9% of the cumulative variance in the diatom data. The diatom − environmental correlations of RDA axis 1 and 2 were high and the first two axes account for 66.6% of the variance in the diatom–environmental relationships. The ordination of the RDA indicated that predictor variables (environmental factors) affect the distribution of diatom assemblages in the creeks of the Sapanca Basin. As shown in Figure 3, nutrient-rich stations such as 1st, 2nd, 3rd, 5th, 7th, and 8th were mostly distributed in the positive part of the second axis. On the other hand, low nutrient sampling stations (mostly 4th and 6th) were located in the opposite part. *Achnanthidium minutissimum* was centered around the RDA diagram, which means that it had a wide tolerance to surrounding explanatory factors during the study. Other species such as *Gomphonema minusculum, Gomphonema angustatum, Ulnaria ulna,* and *Achnanthidium affine* were related to high water EC, T, NO_3-N, PO_4-P, TP. On the other hand, *Cymbella affinis* and *Nitzschia dissipata* were related to low nutrients and EC, while *Reimeria sinuata, Cocconeis placentula,* and *Didymosphenia geminata* were correlated with pH, and DO.

3.4 Ecological status

The bioassessments of the sampling creeks feeding Lake Sapanca based on diatom indices using mean values were shown in Table 4, and monthly data were given in Supplementary Material Table 2. TIT values of the 4th and 6th stations indicated good water quality, while other stations were detected as moderate ecological status. EPI-D indicated good, and IPS determined moderate ecological status in all stations, while TDI exhibited moderate or good water quality for the stations. IPS was positively correlated with Si ($R = 0.24$, $P < 0.05$), while TIT was positively correlated with TP ($R = 0.23$, $P < 0.05$). To compare the diatom indices in the creeks, TIT, EPI-D, IPS, and TDI were regressed against log (TP). These relationships were shown in Figure 3. Based on the R^2 of the regressions, a higher proportion of variance of TIT was explained by log (TP) ($R^2 = 0.69$, $P < 0.05$) compared with the other three indices.

4 Discussion

In the creeks, the 1st station had higher EC and NO_3-N values than those of the other sites. The deterioration of the water quality of the mentioned station could be the

Table 3. List of diatom species occurring at least three sample with an relative abundance larger than 1% in the sampling stations of eight creeks feeding Lake Sapanca. (**D:** occurred as dominant in at least one sample, >30%, **ND:** occurred as non-dominant, <30%, **A:** absent, **st:** station).

Code	Species	1st st.	2nd st.	3rd st.	4th st.	5th st.	6th st.	7th st.	8th st.
ACAF	*Achnanthidium affine* (Grunow) Czarnecki	D	D	D	ND	ND	D	ND	ND
ADMI	*Achnanthidium minutissimum* (Kützing) Czarnecki	D	D	D	D	D	D	D	D
ACHS	*Achnanthes* sp.	ND	D	ND	ND	ND	ND	ND	ND
AEXM	*Amphora eximia* Carter	ND	A	ND	A	A	A	A	A
CAFF	*Cymbella affinis* Kützing	ND	ND	ND	D	ND	ND	ND	ND
CTUM	*Cymbella tumida* (Brébisson) Van Heurck	ND	ND	A	A	ND	ND	ND	ND
CPLA	*Cocconeis placentula* Ehrenberg	ND	D	D	D	D	D	D	D
CRCU	*Craticula cuspidata* (Kützing) Mann	A	ND	ND	A	ND	ND	A	A
CHAL	*Craticula halophila* (Grunow) Mann	A	ND	ND	A	ND	A	A	A
CBAM	*Cymbopleura amphicephala* (Nageli ex Kütz.) Kram.	ND	A	ND	A	A	A	A	A
CBCU	*Cymbopleura cuspidata* (Kützing) Krammer	ND	ND	ND	A	A	A	A	A
CYRE	*Cymbopleura reinhardtii* (Grunow) Krammer	ND	ND	ND	ND	ND	ND	ND	ND
DEHR	*Diatoma ehrenbergii* Kützing	ND	A	A	A	A	ND	ND	ND
DVUL	*Diatoma vulgaris* Bory	D	ND	ND	ND	ND	D	ND	ND
DGEM	*Didymosphenia geminata* (Lyngbye) Schmidt	A	A	A	A	A	ND	A	D
ENMI	*Encyonema minutum* (Hilse) Mann	ND	ND	ND	ND	ND	ND	ND	ND
ESLE	*Encyonema silesiacum* (Bleisch) Mann	ND	ND	ND	A	ND	ND	ND	ND
EBIL	*Eunotia bilunaris* (Ehrenberg) Schaarschmidt	ND	ND	ND	ND	A	ND	ND	A
FLEN	*Fallacia lenzii* Lange-Bertalot	A	ND	ND	A	A	A	ND	A
FCAP	*Fragilaria capucina* Desmazières	ND	ND	ND	ND	ND	ND	ND	ND
GACU	*Gomphonema acuminatum* Ehrenberg	A	ND	ND	A	ND	A	A	A
GAFF	*Gomphonema affine* Kützing	ND	ND	ND	A	A	A	A	A
GANG	*Gomphonema angustatum* (Kützing) Rabenhorst	D	A	ND	A	A	A	A	ND
GMIS	*Gomphonema minusculum* Krasske	D	ND	ND	ND	ND	ND	ND	ND
GMIN	*Gomphonema minutum* (Agardh) Agardh	ND	ND	ND	ND	ND	ND	ND	ND
GOLI	*Gomphonella olivacea* (Hornemann) Rabenhorst	ND	ND	ND	ND	ND	ND	ND	ND
GPAR	*Gomphonema parvulum* (Kützing) Kützing	D	ND	ND	ND	ND	ND	ND	ND
GTRU	*Gomphonema truncatum* Ehrenberg	ND	ND	ND	ND	ND	D	D	ND
GOMS	*Gomphonema* sp.	ND	ND	ND	ND	ND	ND	ND	ND
GYAC	*Gyrosigma acuminatum* (Kützing) Rabenhorst	A	ND	ND	A	A	A	A	A
GSCA	*Gyrosigma scalproides* (Rabenhorst) Cleve	A	ND	ND	A	A	A	A	A
HLMO	*Halamphora montana* (Krasske) Levkov	A	ND	ND	A	ND	ND	ND	ND
HAMP	*Hantzschia amphioxys* (Ehrenberg) Grunow	A	ND	ND	A	A	A	A	ND
MLIN	*Melosira lineata* (Dillwyn) Agardh	A	ND	ND	ND	ND	ND	ND	ND
MCIR	*Meridion circulare* (Greville) Agardh	ND	ND	A	ND	ND	ND	A	ND
NBOT	*Navicula bottnica* Grunow	ND	ND	ND	ND	ND	ND	ND	ND
NCRY	*Navicula cryptocephala* Kützing	ND	ND	ND	ND	ND	ND	ND	ND
NCTE	*Navicula cryptotenella* Lange-Bertalot	ND	A	A	A	A	A	A	A
NLAN	*Navicula lanceolata* Ehrenberg	ND	D	ND	ND	ND	D	ND	ND
NMGL	*Navicula margalithii* Lange-Bertalot	ND	ND	ND	ND	ND	ND	ND	ND
NMCA	*Navicula microcari* Lange-Bertalot	A	A	ND	A	ND	A	A	ND
NRHY	*Navicula rhynchocephala* Kützing	A	ND	A	A	ND	ND	ND	A
NTRV	*Navicula trivialis* Lange-Bertalot	ND	ND	ND	A	A	A	ND	ND
NASP	*Navicula* sp.	ND	ND	ND	ND	ND	ND	ND	ND
NCPL	*Nitzschia capitellata* Hustedt	ND	ND	ND	A	ND	ND	ND	D
NDIS	*Nitzschia dissipata* (Kützing) Rabenhorst	ND	ND	ND	ND	ND	D	D	ND
NPAL	*Nitzschia palea* (Kützing) Smith	ND	ND	ND	ND	ND	ND	ND	ND
NREC	*Nitzschia recta* Hantzsch ex Rabenhorst	ND	ND	ND	A	A	A	ND	ND
NSIO	*Nitzschia sigmoidea* (Nitzsch) Smith	ND	ND	ND	A	ND	ND	ND	ND
DMES	*Odontidium mesodon* (Kützing) Kützing	A	ND	ND	A	ND	ND	ND	A
OHYE	*Odontidium hyemale* (Roth) Kützing	A	A	A	A	ND	ND	ND	A
PSAL	*Pleurosigma salinarum* (Grunow) Grunow	A	ND	A	ND	A	ND	A	A
PLSP	*Pleurosigma* sp.	A	D	A	A	A	A	A	ND
ADSL	*Psammothidium subsalsum* (Petersen) Kulikowskiy *et al.*	ND	ND	ND	A	A	ND	ND	A
RSIN	*Reimeria sinuata* (Gregory) Kociolek & Stoermer	ND	ND	ND	D	ND	ND	ND	ND
SSMI	*Stauroneis smithii* Grunow	ND	A	ND	A	A	A	A	A

Table 3. (continued).

Code	Species	1st st.	2nd st.	3rd st.	4th st.	5th st.	6th st.	7th st.	8th st.
SANG	*Surirella angusta* Kützing	A	ND	ND	A	A	ND	A	ND
SBRE	*Surirella brebissonii* Krammer & Lange-Bertalot	ND	D	ND	ND	D	ND	ND	ND
CSOL	*Surirella librile* (Ehrenberg) Ehrenberg	ND	ND	ND	A	A	A	A	A
SUMI	*Surirella minuta* Brébisson ex Kützing	ND	ND	ND	ND	ND	ND	ND	ND
SOVI	*Surirella ovalis* Brébisson	ND	ND	A	ND	ND	ND	A	A
SURS	*Surirella* sp.	A	A	A	A	ND	A	ND	D
UULN	*Ulnaria ulna* (Nitzsch) Compère	ND	ND	ND	ND	D	ND	ND	A

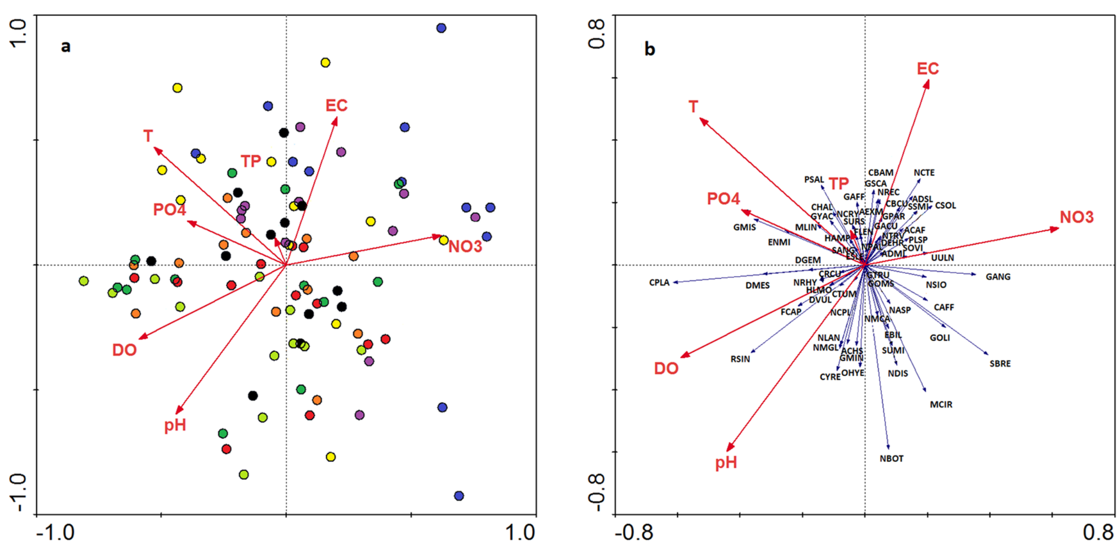

Fig. 2. (a) Ordination of the samples corresponding to the different sampling periods and creeks, (b) scores of diatoms relative abundance and environmental variables, along the redundancy analysis axes. Environmental variables: T: temperature, EC: specific conductance, DO: dissolved oxygen, NO3: nitrate-nitrogen, PO4: orthophosphate, TP: total phosphorus (blue: 1st station, yellow: 2nd station, purple: 3rd station, red: 4th station, dark green: 5th station, green: 6th station, orange: 7th station, black: 8th station). Full names and codes of species were given in Table 3.

consequence of discharges from the industrial establishment (food factory) which is located near the creek. Besides, due to the agricultural areas and small-scale settlements located near the first three stations, the level of nutrients was high in these stations. Moreover, PO_4-P and TP values were higher in İstanbul and Sarp creeks (7th and 8th stations) which are passing through the Sapanca town center. Probably, anthropogenic pressures including sewage discharges and partial interventions in the riverbed are the most considerable effects in these watercourses. On the other hand, sampling stations especially the 4th and 6th had the lowest nutrient content. This could be due to the stations' areas located in woodland and the absence of settlements and agricultural land use. Similar to our findings, Arman *et al.* (2009) have found the highest NO_3-N values in the 1st and 8th stations, and the highest PO_4-P values in the 8th station. Ateş *et al.* (2020) have pointed out that lithogenic, agricultural activities, industrial and domestic wastewater, and traffic load around the lake are the main sources responsible for toxic metal pollution and physico-chemical parameters regarding the Lake Sapanca water quality. In their study, they have mentioned the importance of the transport of chemicals by surface runoff. Moreover, Akıner and Akıner (2021) have evaluated 20 years of data obtained from these creeks and underlined that phosphorus loading shifts the lake from an oligotrophic to a eutrophic state. In studies conducted in the lake, attention was also drawn to the increase in the amount of phosphorus and it was mentioned that the lake tends to become eutrophic (Baykal *et al.*, 1996; Morkoç *et al.*, 1998; Yılmaz and Aykulu, 2010; Akçalan *et al.*, 2014; Altundag *et al.*, 2019). In most of the studies, the effects of anthropogenic pressures have already been shown in streams and lakes (Ács *et al.*, 2004; Çelekli *et al.*, 2018, 2019b; Çelekli and Kapı, 2019). Our results also support the importance of anthropogenic activities on the water quality of these running water systems, and therefore on Lake Sapanca.

RDA was effective in explaining diatom species-environment relationships. The results of RDA showed that dominant species such as *Gomphonema minusculum, G. angustatum, Ulnaria ulna,* and *Achnanthidium affine* were associated with high nutrient values. *U. ulna* has been reported as a species tolerant to pollution (Van Dam *et al.*, 1994). *G. angustatum* as a tolerant species especially to organic pollution (De Almeida and Gil, 2001) was also recorded in surface waters of

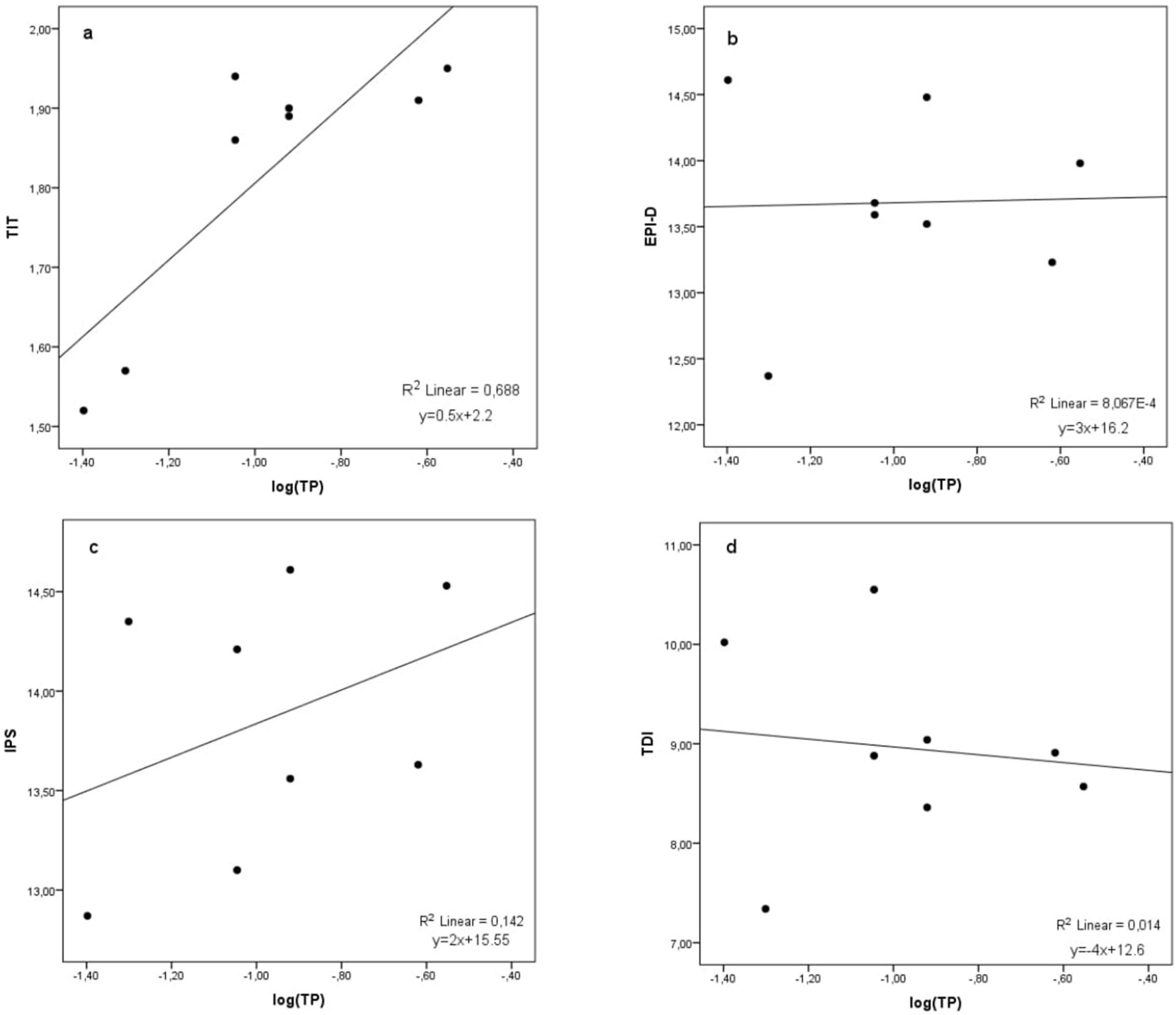

Fig. 3. Relationships between log(TP) and (a) TIT, (b) EPI-D, (c) IPS, (d) TDI at the sampling stations (Mean indices and TP values for each station were used).

Table 4. Characterization of the sampling stations in eight creeks feeding Lake Sapanca by the indices TIT (Trophic Index Turkey), EQR (Ecological Quality Ratio), EPI-D (Eutrophication and/or Pollution Index-Diatom), IPS (Specific Pollution Sensitivity Index), and TDI (Trophic Diatom Index). (Indices results show the mean values of 12 months for each station).

	1st station	2nd station	3rd station	4th station	5th station	6th station	7th station	8th station
TIT	1.89	1.86	1.94	1.52	1.90	1.57	1.95	1.91
EQR	0.61	0.55	0.60	0.74	0.61	0.72	0.61	0.59
Status	Moderate	Moderate	Moderate	Good	Moderate	Good	Moderate	Moderate
EPI-D	14.48	13.59	13.68	14.61	13.52	12.37	13.98	13.23
Status	Good	Good	Good	Good	Good	Good	Good	Good
IPS	14.61	14.21	13.10	12.87	13.56	14.35	14.53	13.63
Status	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
TDI	8.36	8.88	10.55	10.02	9.04	7.34	8.57	8.91
Status	Good	Good	Moderate	Moderate	Good	Good	Good	Good

Gaziantep district in stations with high PO_4-P contents (Çelekli and Arslanargun, 2019). The proliferation of this species especially in the 1st station, has also indicated organic pollution, probably as a result of industrial establishment. Besides, *A. affine* has been mainly found in the littoral of small flowing oligosaprobic to eutrophic waters; most common in moderate to the moderate-high concentration of electrolytes (Wojtal, 2014), and *G. minusculum* had a wide ecological amplitude from oligo- to eutrophic waters (Bąk *et al.*, 2012). All these species were abundant in stations such as 1st, 2nd, 3rd, 5th with high nutrient contents as confirmed by RDA.

On the other hand, dominant diatom taxa such as *Cymbella affinis, Nitzschia dissipata,* and *Reimeria sinuata* were generally abundant in 4th and 6th stations which had relatively low nutrients and EC. *C. affinis*, *N. dissipata,* and *R. sinuata* have been known as pollution sensitive diatom taxa (Bahls, 1973; Van Dam *et al.*, 1994; Delgado *et al.*, 2012; Wang *et al.*, 2014). The other species which was not correlated with high nutrient contents was *Didymosphenia geminata.* Its relative abundance was high in June 2015 at the 8th station. In some studies, *D. geminata* was described as a sensitive species (Krammer and Lange-Bertalot, 1986; Beltrami *et al.*, 2008), while in others it was regarded as a good indicator of very pure (xenosaprobic) waters (Sládeček, 1986). The massive growth of this species was generally reported in cold and oligotrophic waters of northern Europe and North America (Blanco and Ector, 2009), and high light intensity, low inorganic phosphate concentration, high ratio of organic to inorganic phosphate, cold water temperature, and hydrological regulation were described as the main environmental conditions for this growth (Kirkwood *et al.*, 2009; Whitton *et al.*, 2009; Kilroy and Bothwell, 2011; Cullis *et al.*, 2012; Bothwell *et al.*, 2014). In recent years, its massive growth was also reported in Mediterranean river basins, and similar factors were described such as low inorganic phosphate concentration, high light intensity, cold water temperature, and hydrological regulation for the growth of the living cells (Ladrera *et al.*, 2016). They have pointed out that PO_4-P concentrations higher than $0.100\,mg\,L^{-1}$ reduce the living cell density of this species. In our study, probably PO_4-P value ($0.073\,mg\,L^{-1}$) in June 2015 was appropriate for its development. Moreover, the water temperature was recorded as 17.6 °C in our study, and in some studies, living cells were detected with water temperatures higher than 17 °C (Kolayli and Sahin, 2007; Lindstrøm and Skulberg, 2008).

Cocconeis placentula was correlated with high DO values. *C. placentula* has been known as bioindicators of sufficiently oxygen-saturated waters (Toporowska *et al.*, 2008). Besides, the good correlation of this pioneer species with oxygen may also be related to its good response to the stress caused by the flow velocity (Plenković-Moraj *et al.*, 2008; Dedić *et al.*, 2019) during the spring and autumn periods when the flow velocity and the oxygen level in the water were high.

During the study, 19 taxa increased their relative abundance higher than 30% in at least one sample and showed a different seasonal pattern. It is not surprising that so many taxa contribute highly to abundance in different months as a result of their rapid response to changes in water chemistry due to seasonal variations (Leira and Sabater, 2005). Concerning *Achnanthidium minutissimum,* its abundance was high during fall to spring in all stations. Its high relative abundance was also reported in the Torna stream during fall (Stenger-Kovács *et al.*, 2006), and in a Spanish calcareous stream during spring (Sabater, 1990). The excessive increase in light intensity during summer may affect their abundance. As our study confirmed, other studies have also reported that its abundance did not fluctuate with different nutrient concentrations (Stenger-Kovács *et al.*, 2006; Verb and Vis, 2000). Besides, the relative abundance of *Achnanthidium affine*, which was mainly distributed in the first three stations, was high especially in fall and winter. This species was known as heat-sensitive species (Chakandinakira *et al.*, 2019). As can be seen from these examples, there are differences in the seasonal distribution of different species and it is important to keep the sampling frequency high to understand the observed change in the community.

Ecological characterizations of sampling stations were confirmed by performing four different indices. Relationships between TIT, EPI-D, IPS, TDI, and log (TP) indicated that TIT was better correlated to log (TP) than the other three indices. Results of TIT were more compatible with environmental parameters and pollution-tolerant or pollution-sensitive species. In other studies in the Sakarya river basin, EPI-D and IPS index were found more applicable and were highly correlated with environmental parameters (Solak *et al.*, 2009, 2020), however, these indices were not effective to characterize the ecological status of the creeks of Lake Sapanca basin in the present study as seen by the Figure 3.

In conclusion, a total of 132 diatom taxa were identified in eight creeks of the Lake Sapanca basin during the studied period. Environmental parameters (nitrate-nitrogen, orthophosphate, total phosphorus, specific conductance, temperature, pH, and dissolved oxygen) were effective on the distribution of diatom assemblages. Both environmental parameters, the relative abundance of indicator species, and TIT index results stated that 1st, 2nd, 3rd, 5th, 7th, and 8th stations had moderate, while 4th and 6th stations had good water quality. Since the pollution load of these creeks directly affects Lake Sapanca and the increasing pollution in the lake has been mentioned in different studies in recent years, measures should be taken in the management plans to reduce the pollution load, especially in these creeks. The good correlation of TIT index with log (TP), and its compatibility with the presence of indicator species at different stations indicates that this index could be used in the Lake Sapanca basin, and Sakarya basin where the lake basin is located. Although it was stated that diatom sampling should be done two or three times a year (WFD-UKTAG, 2014), increasing the sampling frequency, as seen in our study, gives a better idea for the community structure and the interpretation of the results of the index used. Therefore, we think that the sampling frequency should be kept high at the beginning of the monitoring studies to better understand the system.

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Supplementary Material

Figure 1. Distribution and mean annual relative abundance (%) of *Achnanthidium minutissimum, Achnanthidium affine, Cymbella affinis, Reimeria sinuata, Gomphonema angustatum,*

Gomphonema minusculum, Nitzschia dissipata, Cocconeis placentula, Didymosphenia geminata, and Ulnaria ulna in the eight creeks of Lake Sapanca.

Table 1. Monthly data of relative abundance (%) of 19 dominant diatom species (>30%) in the sampling stations of eight creeks feeding Lake Sapanca. (Codes of species were given in Table 3).

Table 2. Monthly data of TIT (Trophic Index Turkey), EQR (Ecological Quality Ratio), EPI-D (Eutrophication and/or Pollution Index-Diatom), IPS (Specific Pollution Sensitivity Index), and TDI (Trophic Diatom Index) indices of the sampling stations in eight creeks feeding Lake Sapanca.

The Supplementary Material is available at https://doi.org/10.1051/limn/2021012.

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