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Bioassessing ecological status of surface waters in the Araban-Yavuzeli catchment (Turkey): application of diatom indices

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Abstract: Within the scope of the European Union Water Framework Directive, diatom assemblages as biological quality components were used to evaluate the ecological status of 12 surface waters in the Araban-Yavuzeli catchment between October 2013 and October 2014. A total of 75 diatom species were identified during the study period. *Amphora ovalis*, *Denticula elegans*, *Gomphonema parvulum*, *Gomphonema truncatum*, and *Navicula cryptocephala* were commonly observed. The relationship between diatom assemblages and environmental factors was assessed by canonical correspondence analysis and weighted average regression. Dissolved oxygen, temperature, nitrate, biological oxygen demand, lead, and copper played significant roles in the distribution and composition of diatom assemblages ($P < 0.05$). The ecological status of the stations in Araban and Yavuzeli was characterized using the trophic index-Turkey (TIT), trophic index (TI), and eutrophication and/or pollution index-diatom (EPI-D) indices. According to the TIT, Ardıl Creek1 had very good ecological conditions and was characterized by the occurrence of pollution-sensitive diatom taxa (e.g., *Cymbella affinis*, *Encyonema silesiacum*, *Navicula radiosa*), indicated by multivariate analyses. The significant positive correlation of the TIT ($P < 0.01$, $r = 0.789$) with $\log PO_4$ indicated that TIT may be used as an appropriate diatom metric to assess the ecological status of surface waters in the Araban-Yavuzeli catchment.

Key words: Bioassessment, diatoms, Araban-Yavuzeli catchment, trophic index-Turkey

1. Introduction

Lotic ecosystems (e.g., rivers, streams, and creeks) are fundamental components of regional and global biogeochemical cycles. They are sources of drinking water, irrigation supplies, fisheries, wastewater removal systems, and other uses (Feld et al., 2018). These environments are characterized by complex interactions among chemical, physical, hydromorphological, and biological processes. The degree of complexity increases when the ecosystems are far away from their resources downstream.

Increased loading of nutrients, metals, and other undesired compounds into surface waters has become one of the main environmental problems threatening the world (Feld et al., 2018). Anthropogenic activities have resulted in increased impairments of surface waters. Along with being a primary producer in the food web, algae are one of the potentially important biotic users or accumulators of pollutants (e.g., excess nutrients in stream ecosystems) (Hering et al., 2016).

The European Water Framework Directive outlines the level of health of surface waters as an ecological status that is usually evaluated by biological assessment with physicochemical elements and hydromorphology properties of ecosystems (European Communities, 2009). In the biological assessment, the analysis of various characteristics of five biological quality indicators (fish, invertebrates, macrophytes, phytobenthos, and phytoplankton) are commonly used (European Communities, 2009).

Biological assessment can be defined through the use of biological responses to estimate changes in ecosystems and this information can be used for estimating water quality. The biological response can be measured by using biological indicators in complex aquatic ecosystems that have complex interactions and responses to physicochemical variables, hydromorphological structure, and climatic changes. Biological monitoring is also a very useful method for assessing the status of water resources due to its integrative nature (Angermeier and Karr, 1994; Stevenson, 1998; Hering et al., 2006; Birk et al., 2012).

Benthic diatoms as bioindicators have been used in monitoring studies because of their short life cycles, availability in almost all aquatic habitats, and rapid response to various stressors (Rott et al., 2003; Hering et

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al., 2006; Bona et al., 2007; Kelly et al., 2008; Wang et al., 2014; Rimet et al., 2016). Bioassessment of water quality monitoring based on diatom communities, especially in lotic ecosystems, is widely accepted. Many diatom indices (e.g., trophic index (Rott et al., 1999), specific pollution index (Cemagref, 1982), eutrophication and/or pollution index-diatom (Dell'Uomo, 2004), and trophic diatom index (Kelly et al., 2008)) have been developed for the biological assessment of complex ecological quality of running waters.

Using species' robust responses to the changes in environmental variables as a biological quality tool for monitoring provides temporal and spatial information about the ecological status of ecosystems due to a direct measure of ecological integrity of bioindicator organisms (Karr, 1991; Rott et al., 1999; European Communities, 2009; Çelekli et al., 2019). Diatom metrics in Europe (Cemagref, 1982; Rott et al., 1999; Dell'Uomo, 2004; Kelly et al., 2008) have been successfully used for the assessment of water ecological quality. However, the available European diatom indices have not been used efficiently in the Mediterranean region for the interpretation of water quality (Toudjani et al., 2017; Lazaridou et al., 2018). This can be due to the impact of ecoregional factors (e.g., geology, climate, land use, and anthropogenic activities) on the optimum and tolerance of diatom assemblages (Soininen, 2007; Toudjani et al., 2017).

The ecological preferences of diatom species can change with temporal and spatial variation in different ecoregions. The investigation of the diatom flora of Turkey may be remarkable due to the current poor knowledge. A recently developed trophic diatom index for evaluating water quality using diatoms, trophic index-Turkey (TIT; Çelekli et al., 2019), was dedicated to the Anatolian catchment and the Mediterranean region. An assessment of the ecological status of surface waters based on diatom assemblages was not found in the southeast of Anatolia. In this study, the overall hypothesis was that direct use of foreign diatom index scores obtained from different ecoregions could lead to a wrong interpretation of water quality. Considering this hypothesis, the aim of this research was to be the first attempt of using diatom indices developed from different ecoregions for assessing the limnoecological status of various sampling stations of the Araban-Yavuzeli catchment (Turkey). This study also aimed to define the most important environmental variable(s) driving the distribution of diatom assemblages and to evaluate the ecological preferences of diatom species that were elucidated by multivariate approaches.

2. Materials and methods

2.1. Study area and sampling

The study was carried out in the Araban-Yavuzeli catchment in Turkey (Figure 1). Diatom and water samples were taken from 12 surface waters in October 2013, May 2014, and October 2014. The names of the locations and their main characteristics are summarized in Table 1. The catchment in the north of Gaziantep includes two districts: the Yavuzeli catchment, with 7 sampling stations (under the pressures of municipal wastes, livestock farming, and mining, with an altitude of >385 m), and the Araban catchment with Ardıl Creek1 and 2 and Karasu Creek1 and 2 stations (under the impacts of municipal wastes and agricultural activities, with an altitude of >512 m). The Euphrates (Fırat) River, as a transboundary river, flows along the border of the Gaziantep-Şanlıurfa catchment to the Syrian border. These water resources were commonly used for irrigation purposes.

Before the epilithic diatom sampling in situ, pH, water temperature, electrical conductivity (EC), dissolved oxygen (DO), and salinity were measured using an YSI Professional Plus oxygen-temperature meter. A geographical positioning system was used to determine geographical data. Water samples were then taken and preserved in a storage container with ice packs until transfer to the laboratory. At least five stones were randomly collected in the riffle sections of running water systems for the epilithic diatom samples. Subsequently, the upper surface of substrata was scraped and scrubbed with a hard-bristled toothbrush in 100 mL of distilled water by following standard methods of the European Committee for Standardization (2004, 2014), and fixed with Lugol's solution with glycerol.

2.2. Laboratory analyses

Chemical variables such as nitrate-nitrogen (N-NO_3), ammonium-nitrogen (N-NH_4), nitrite-nitrogen (N-NO_2), and orthophosphate (P-PO_4) were measured by standard methods (APHA, 1989) using ion chromatography (Thermo Scientific Dionex ICS-5000, HPIC system). Heavy metal (copper, chromium, nickel, and zinc) contents of samples were analyzed by the use of inductively coupled plasma-optical emission spectrometry (ICP-OES, PerkinElmer, Optima 2100 DV).

After the diatom cleaning process, diatom permanent slides were prepared using Naphrax (European Committee for Standardization, 2004). At least 500 diatom valves were counted under a light microscope (Olympus BX53 attached to a DP73 model) at a magnification of 1000×. Taxonomic keys provided by Krammer and Lange-Bertalot (1991a, 1991b, 1997, 1999a, 1999b), Lange-Bertalot (2001), Krammer (2000, 2002), and Bey and Ector (2013) were used for the identification of diatom species.

2.3. Statistical analyses

Spearman rank correlation analysis was used to elucidate the relationships between diatom indices and environmental variables. According to the detrended correspondence analysis, the gradient length was found

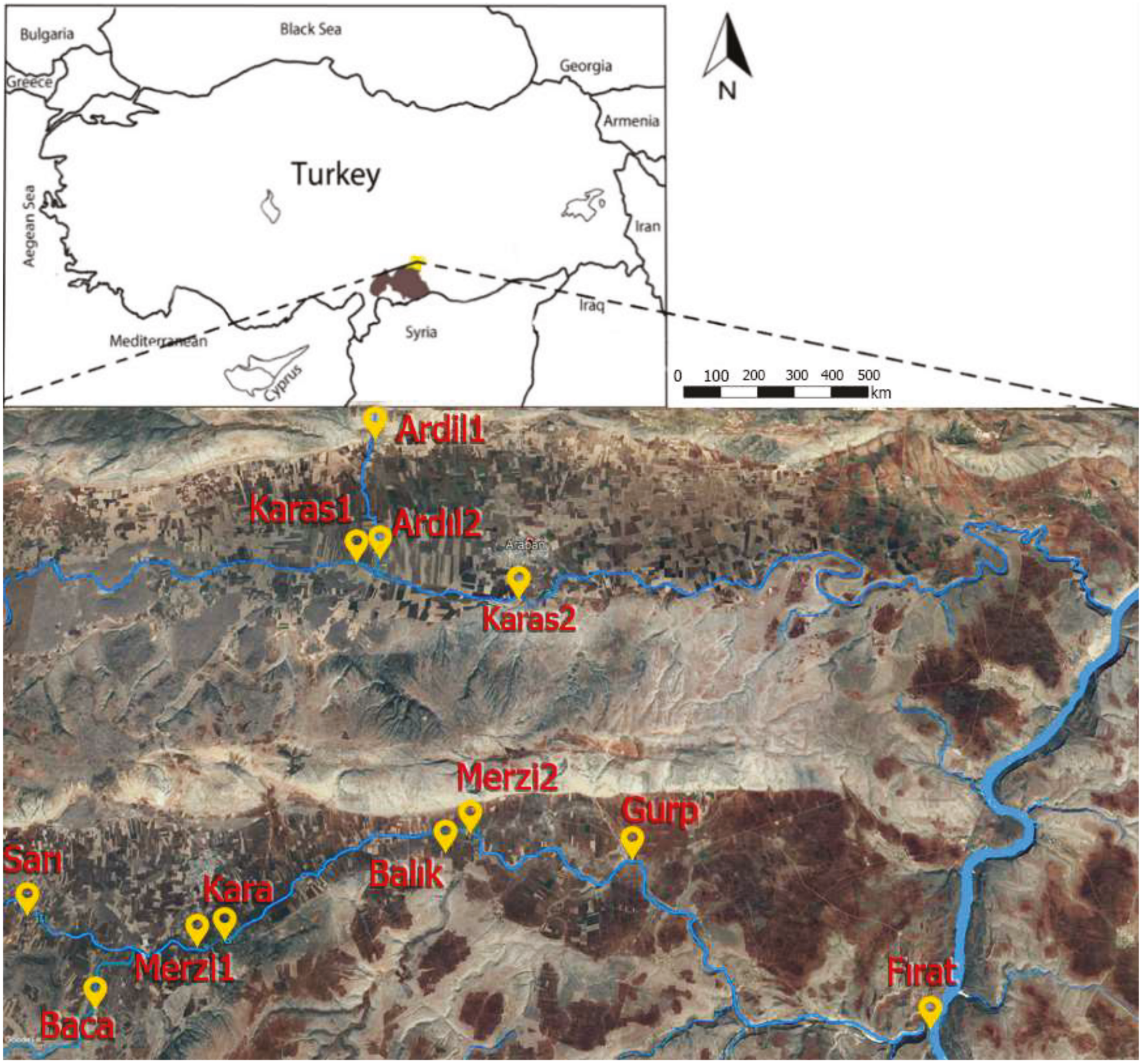

Figure 1. Location of the sampling sites in the Araban and Yavuzeli catchment.

to be higher than 3.0, which indicates the suitability of applying a direct gradient analysis technique (ter Braak and Šmilauer, 2002). Canonical correspondence analysis (CCA) was performed to assess the relationship between predictor (environmental) factors and response (diatom assemblages) variables in the 12 sampling sites of the Araban-Yavuzeli catchment by the use of the CANOCO program, version 4.5 (ter Braak and Šmilauer, 2002). To reduce skewness, log(x+1) transformation was applied to environmental variables, except for pH (ter Braak and Šmilauer, 2002). Partial CCA was used to determine the most important explanatory variable(s) that drive the distribution of diatom composition. The Monte Carlo permutation test was performed to determine which environmental factors played significant roles in the distribution of diatom assemblages. Thus, the CCA consisted of 42 species of diatom species, six environmental variables, and 12 sampling sites as supplementary variables. Weighted averaging regression was used (Juggins and ter Braak, 1992) to estimate the optimum and tolerance levels of diatom taxa for various environmental variables. Total taxa number (75) was reduced to 42 diatom species; species whose relative abundance was above 1% and occurrence was greater than one were selected for statistical analyses.

Table 1. Sampling stations in the Araban and Yavuzeli catchment.

Station	Code	Latitude, N	Longitude, E	Altitude (m)
Ardıl Creek1	Ardil1	37°28′15″	37°37′02″	590
Ardıl Creek2	Ardil2	37°25′00″	37°37′27″	531
Bacalı Creek	Baca	37°16′37″	37°31′57″	560
Balıklı Pond	Balik	37°19′26″	37°40′01″	511
Fırat River	Firat	37°16′25″	37°50′23″	386
Gürpınar Creek	Gurp	37°19′04″	37°43′56″	467
Karapınar Pond	Kara	37°17′28″	37°34′46″	535
Karasu Creek1	Karas1	37°24′58″	37°37′19″	530
Karasu Creek2	Karasu2	37°24′25″	37°41′14″	513
Merzimen Creek1	Merzi1	37°17′32″	37°34′22″	528
Merzimen Creek2	Merzi2	37°19′37″	37°40′08″	504
Sarıbuğday Creek	Sari	37°17′43″	37°30′50″	559

2.4. Determination of ecological status

The TIT (Çelekli et al., 2019) was computed using the following equation:

$$TIT = \sum_{i=1}^{n} b_i \times e_i \times c_i / \sum_{i=1}^{n} e_i \times c_i \qquad (1)$$

where b_i is i-diatom taxon trophic weight, e_i is i-diatom taxon indicator score, and c_i is the percentage of i-diatom species.

Ecological quality ratios (EQRs) were calculated based on TIT scores. EQR values close to 0 indicate poor ecological condition, whereas EQR values approaching 1 indicate high ecological condition.

The trophic index (TI) (Rott et al., 1999) was used to assess the ecological quality of water bodies using the following equation:

$$TI = \sum_{i=1}^{n} TW_i \times G_i \times H_i / \sum_{i=1}^{n} G_i \times H_i \qquad (2)$$

where TW_i is i-taxon trophic weight, Gi is i-taxon indicator value, and Hi is i-taxon's valve number.

The eutrophication and/or pollution index-diatom (EPI-D) (Dell'Uomo 2004) was used to evaluate the water quality of sampling sites using the following equation:

$$EPI - D = \sum_{i=1}^{n} a_j \times r_j \times i_j / \sum_{i=1}^{n} a_j \times r_j \qquad (3)$$

where a_j is abundance of species j, r_j is reliability of species j inversely proportional to its ecological "range", 5 is an optimum indicator, 3 is a good indicator, 1 is a sufficient indicator only, i_j is the weighted sensitivity index of species j, and values are assigned from 0 (for environment of excellent quality) to 4 (degraded water body).

3. Results

3.1. Physical and chemical variables

Measured physical and chemical variables are given in Table 2. Mean water temperature varied from 18.2 °C in Bacalı Creek to 22.4 °C in Ardıl Creek2. The highest mean conductivity (540 µS/cm) and salinity (0.30 ppt) values were obtained from Bacalı Creek. Ardıl Creek1 had the lowest conductivity (320 µS/cm) and salinity (0.19 ppt) values. Other studied stations had relatively similar conductivity values (Table 2). Sampled water bodies in the Araban-Yavuzeli catchment generally had slightly alkaline water (pH range 7.34–8.98, Table 2).

Nutrient concentrations changed substantially in the sampling sites during the present study period. Ardıl Creek1 had lower nutrient values (e.g., 26.63 µg/L $P\text{-}PO_4$ and 0.01 mg/L $N\text{-}NO_2$) than those of other sampling stations in the Araban-Yavuzeli catchment. On the other hand, this creek had high values of several metals (e.g., 0.25 mg/L Pb^{2+}, 0.40 mg/L Ni^{2+}, and 0.18 mg/L Cr^{2+}).

3.2. Diatom assemblages–environment relationship

A total of 75 diatom taxa were identified in the water bodies of the Araban-Yavuzeli catchment (Table 3). *Amphora ovalis*, *Cymbella tumida*, *Gomphonema parvulum*, *Gomphonema truncatum*, and *Navicula cryptocephala* were frequently observed species during the study.

The first two axes of CCA explained 0.952 of correlations between species and used environment variables with 12.6% of the cumulative variance of taxa data (P = 0.012, F = 2.305). With regard to the results of

Table 2. Physical and chemical variables of Araban-Yavuzeli catchment. Mean values ± SD (standard deviation). Abbreviations of sampling stations are given in Table 1.

		Baca	Sarı	Kara	Merzi1	Karas1	Ardil1	Ardil2	Karas2	Gurp	Firat	Merzi2	Balik
Temp.	°C	18.2 ± 1.2	18.3 ± 1.3	20.5 ± 1.9	19.1 ± 2.7	20.7 ± 3.9	19.3 ± 1.9	22.4 ± 4.7	22.2 ± 5.4	19.6 ± 3.6	19.2 ± 4.5	20.1 ± 3.3	21.7 ± 0.6
EC	µS/cm	540 ± 47	507 ± 32	473 ± 37	515 ± 58	482 ± 48	320 ± 68	372 ± 17	458 ± 60	498 ± 51	405 ± 32	504 ± 101	501 ± 16
TDS	mg/L	392 ± 22	376 ± 12	337 ± 14	375 ± 20	339 ± 10	252 ± 53	338 ± 16	379 ± 110	353 ± 11	266 ± 9	365 ± 14	316 ± 9
Sali.	ppt	0.30 ± 0.02	0.28 ± 0.01	0.25 ± 0.01	0.28 ± 0.01	0.25 ± 0.02	0.19 ± 0.04	0.25 ± 0.01	0.23 ± 0.01	0.27 ± 0.01	0.20 ± 0.01	0.27 ± 0.01	0.24 ± 0.01
DO	mg/L	5.94 ± 1.28	6.61 ± 1.92	5.14 ± 1.01	5.96 ± 2.04	6.46 ± 3.16	6.65 ± 2.64	6.45 ± 1.81	6.32 ± 3.31	6.03 ± 2.21	5.91 ± 1.67	6.26 ± 1.73	5.20 ± 1.06
pH		7.98 ± 0.49	8.08 ± 0.28	7.34 ± 0.14	7.98 ± 0.42	8.98 ± 1.21	8.07 ± 0.18	8.12 ± 0.16	8.27 ± 0.11	8.43 ± 0.13	8.21 ± 0.17	8.52 ± 0.27	7.70 ± 0.34
ORP	mV	152.7 ± 35.5	147.3 ± 14.8	191.3 ± 10.1	140.3 ± 5.5	100.3 ± 65.8	147.7 ± 13.1	138.7 ± 20.3	139.0 ± 9.0	128.2 ± 14.4	153.3 ± 26.7	121.7 ± 22.2	170.0 ± 25.7
BOD_5	mg/L	3.83 ± 2.51	3.42 ± 2.32	3.54 ± 2.23	4.61 ± 2.64	3.74 ± 2.72	3.06 ± 1.64	4.23 ± 2.34	5.28 ± 2.67	4.53 ± 2.74	3.32 ± 2.36	4.55 ± 2.43	3.14 ± 2.12
PO_4	µg/L	33.17 ± 6.14	33.83 ± 4.91	29.30 ± 3.98	33.29 ± 14.73	32.30 ± 31.89	26.63 ± 4.76	31.89 ± 6.51	31.06 ± 6.53	33.36 ± 8.74	30.61 ± 5.53	31.62 ± 7.15	31.63 ± 4.21
NO_2	mg/L	0.03 ± 0.04	0.04 ± 0.04	0.03 ± 0.05	0.07 ± 0.03	0.20 ± 0.15	0.01 ± 0.01	0.10 ± 0.05	0.10 ± 0.09	0.17 ± 0.05	0.02 ± 0.02	0.15 ± 0.18	0.02 ± 0.02
NO_3	mg/L	9.12 ± 5.90	10.65 ± 5.95	14.78 ± 8.86	11.79 ± 7.41	14.33 ± 13.08	10.76 ± 6.51	18.91 ± 14.86	11.67 ± 8.18	11.27 ± 6.51	3.14 ± 1.69	11.09 ± 6.26	9.11 ± 5.32
NH_4	mg/L	0.05 ± 0.03	0.07 ± 0.04	0.07 ± 0.09	0.13 ± 0.04	0.12 ± 0.06	0.02 ± 0.02	0.09 ± 0.10	0.06 ± 0.04	0.12 ± 0.04	0.03 ± 0.03	0.18 ± 0.13	11.34 ± 22.61
Mg	mg/L	19.5 ± 6.8	22.7 ± 6.7	18.4 ± 5.5	19.2 ± 2.3	21.3 ± 3.1	12.2 ± 0.7	17.4 ± 0.9	18.2 ± 1.2	19.3 ± 0.2	21.3 ± 4.6	16.1 ± 6.9	17.4 ± 2.8
Ca	mg/L	56.6 ± 41.2	63.7 ± 12.7	79.7 ± 10.2	73.6 ± 6.3	68.7 ± 3.4	82.4 ± 11.9	61.9 ± 6.8	63.6 ± 6.6	63.2 ± 4.6	52.5 ± 14.0	71.4 ± 13.4	102.6 ± 50.4
Al	mg/L	0.04 ± 0.03	0.05 ± 0.04	0.01 ± 0.02	0.18 ± 0.17	0.34 ± 0.46	0.02 ± 0.01	0.09 ± 0.05	0.10 ± 0.08	0.46 ± 0.37	0.07 ± 0.08	0.07 ± 0.07	0.01 ± 0.01
Cu	mg/L	0.21 ± 0.20	0.20 ± 0.20	0.19 ± 0.20	0.21 ± 0.26	0.21 ± 0.22	0.20 ± 0.16	0.21 ± 0.23	0.23 ± 0.25	0.18 ± 0.18	0.22 ± 0.20	0.48 ± 0.65	0.21 ± 0.19
Pb	mg/L	0.27 ± 0.43	0.34 ± 0.58	0.28 ± 0.48	0.20 ± 0.34	0.27 ± 0.47	0.25 ± 0.44	0.23 ± 0.39	0.28 ± 0.48	0.37 ± 0.64	0.28 ± 0.46	0.35 ± 0.60	0.35 ± 0.51
Ni	mg/L	0.06 ± 0.05	0.02 ± 0.01	0.01 ± 0.01	0.03 ± 0.04	0.05 ± 0.06	0.40 ± 0.04	0.38 ± 0.17	0.01 ± 0.01	0.08 ± 0.06	0.08 ± 0.06	0.04 ± 0.06	0.03 ± 0.03
Cr	mg/L	0.01 ± 0.02	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.02	0.18 ± 0.25	0.01 ± 0.04	0.01 ± 0.02	0.03 ± 0.04	0.03 ± 0.05	0.01 ± 0.01	0.01 ± 0.01
Cl	mg/L	14.3 ± 14.2	10.0 ± 1.90	12.4 ± 3.40	15.7 ± 8.50	9.81 ± 2.78	4.81 ± 1.00	7.50 ± 3.00	7.98 ± 3.36	18.30 ± 4.46	13.85 ± 5.64	16.54 ± 6.48	85.55 ± 158.37
Na	mg/L	19.41 ± 15.44	13.54 ± 0.47	8.760 ± 2.20	11.56 ± 5.16	11.11 ± 1.11	4.35 ± 0.10	7.25 ± 1.09	8.75 ± 2.83	13.86 ± 1.74	15.38 ± 3.52	12.25 ± 5.63	91.28 ± 71.94
Mn	mg/L	0.026 ± 0.006	0.006 ± 0.004	0.003 ± 0.001	0.007 ± 0.006	0.013 ± 0.015	0.005 ± 0.002	0.008 ± 0.005	0.014 ± 0.08	0.005 ± 0.003	0.004 ± 0.002	0.009 ± 0.010	0.008 ± 0.002
CN	mg/L	0.009 ± 0.005	0.006 ± 0.005	0.006 ± 0.005	0.009 ± 0.009	0.009 ± 0.008	0.004 ± 0.002	0.010 ± 0.010	0.002 ± 0.001	0.005 ± 0.003	0.003 ± 0.002	0.007 ± 0.006	0.002 ± 0.002

Temp.: temperature; EC: electrical conductivity; TDS: total dissolved solid; sali.: salinity; DO: dissolved oxygen; ORP: oxidation reduction potential; NH_4: ammonium; PO_4: orthophosphate.

Table 3. List of diatom taxa in the sampling stations in the Araban-Yavuzeli catchment.

Code	Taxa
acs	*Achnanthes* sp.
amo	*Amphora ovalis* (Kützing) Kützing
aug	*Aulacoseira granulata* (Ehrenberg) Simonsen
cyi	*Cyclotella iris* Brun & Héribaud-Joseph in Héribaud-Joseph
cym	*Cyclotella meneghiniana* Kützing
cya	*Cymbella affinis* Kützing
cyam	*Cymbopleura amphicephala* (Nägeli) Krammer
cyc	*Cymbella cymbiformis* C.Agardh
cye	*Cymbella excisa* Kützing
cyh	*Cymbella hantzschiana* Krammer
cyn	*Cymbella neocistula* Krammer
cyp	*Cymbella parva* (W.Smith) Kirchner
cyt	*Cymbella tumida* (Brébisson) Van Heurck
dee	*Denticula elegans* Kützing
dek	*Denticula kuetzingii* Grunow
det	*Denticula tenuis* Kützing
div	*Diatoma vulgaris* Bory
ens	*Encyonema silesiacum* (Bleisch) D.G.Mann
epa	*Epithemia adnata* (Kützing) Brébisson
frc	*Fragilaria capucina* Desmazières
frr	*Frustulia rhomboides*(Ehrenberg) De Toni
goa	*Gomphonema acuminatum* Ehrenberg
goan	*Gomphonema angustatum* (Kützing) Rabenhorst
gop	*Gomphonema parvulum* (Kützing) Kützing
got	*Gomphonema truncatum* Ehrenberg
gya	*Gyrosigma acuminatum* (Kützing) Rabenhorst
hav	*Halamphora veneta* (Kützing) Levkov
nac	*Navicula cryptotenella* Lange-Bertalot
nacr	*Navicula cryptocephala* Kützing
nao	*Navicula oppugnata* Hustedt
nap	*Navicula phyllepta* Kützing
nar	*Navicula radiosa* Kützing
nat	*Navicula trivialis* Lange-Bertalot
natr	*Navicula tripunctata* (O.F.Müller) Bory
nav	*Navicula vulpina* Kützing
niu	*Nitzschia umbonata* (Ehrenberg) Lange-Bertalot
niv	*Nitzschia vermicularis* (Kützing) Hantzsch in Rabenhorst
pao	*Pantocsekiella ocellata* (Pantocsek) K.T.Kiss & E.Ács
pim	*Pinnularia macilenta* Ehrenberg
pimi	*Pinnularia microstauron* (Ehrenberg) Cleve
sua	*Surirella angusta* Kützing
ulu	*Ulnaria ulna* (Nitzsch) Compère

partial CCA, water temperature, nitrate, copper, lead, DO, and BOD$_5$ had significant effects on the distribution of diatom assemblages (Figure 2). Frequently observed diatom species, such as *A. ovalis*, *C. tumida*, *G. parvulum*, *G. truncatum*, and *N. cryptocephala*, were located closer to the center of the CCA diagram, which means they may have wider tolerances to these environmental factors. *Cymbella affinis*, *Encyonema silesiacum*, and *Navicula radiosa*, associated with Ardıl Creek1, were located on the positive side of the first axis. Several diatom assemblages, such as *A. ovalis*, *Aulacoseira granulata*, *Cymbella hantzschiana*, *Gomphonema angustatum*, *Navicula oppugnata*, and *Nitzschia vermicularis*, had a higher tolerance to Pb^{2+} and Cu^{2+} (Figure 2). The species *Denticula elegans*, *Fragilaria capucina*, and *Pantocsekiella ocellata* were related to water temperature.

The weighted average regression indicated that several diatom species, such as *A. ovalis* (40.1 µg L^{-1} PO$_4$), *N. cryptocephala* (40.7 µg L^{-1} PO$_4$), *Navicula trivialis* (39.8 µg L^{-1} PO$_4$), *Nitzschia vermicularis* (43.2 µg L^{-1} PO$_4$), and *Nitzschia umbonata* (42.0 µg L^{-1} PO$_4$), preferred high PO$_4$ optima. A few diatom species were associated with relatively low PO$_4$ optima, e.g., *Cymbella affinis* (24.2 µg L^{-1} PO$_4$), *Encyonema silesiacum* (25.1 µg L^{-1} PO$_4$), and *Navicula radiosa* (25.4 µg L^{-1} PO$_4$).

3.3. Ecological status of sampling stations

The biological assessment of surface waters of the Araban-Yavuzeli catchment based on diatom indices is given in Table 4. The scores of diatom indices showed variations among the sampling stations (TIT ranged from 1.94 in Ardıl Creek1 to 2.61 in Gürpınar Creek, TI ranged from 1.45 in Balıklı Pond to 2.37 in Karapınar Pond, and EPI-D varied between 0.98 in Merzimen Creek2 and 1.61 in Fırat River). With regard to the characterization of the sampling stations by using diatom indices, TIT indicated a high ecological condition for Ardıl Creek1 and moderate ecological conditions for Gürpınar Creek and Merzimen Creek1. All studied stations had good ecological conditions except for Merzimen Creek2, which had a high ecological status due to EPI-D (Table 4).

4. Discussion

Physical and chemical variables of sampling stations varied from one station to another and changed temporarily. Bacalı Creek had the highest mean conductivity value, whereas Ardıl Creek1 had the lowest value, followed by the Fırat River. Conductivity values of studied sites were lower than those of the 11 Mediterranean stream tributaries from the lower part of the Ebro River in Spain (Tornés et al., 2018) and the Dalaman Stream in the western Mediterranean basin of Turkey, but higher than those of potential reference sites of the western

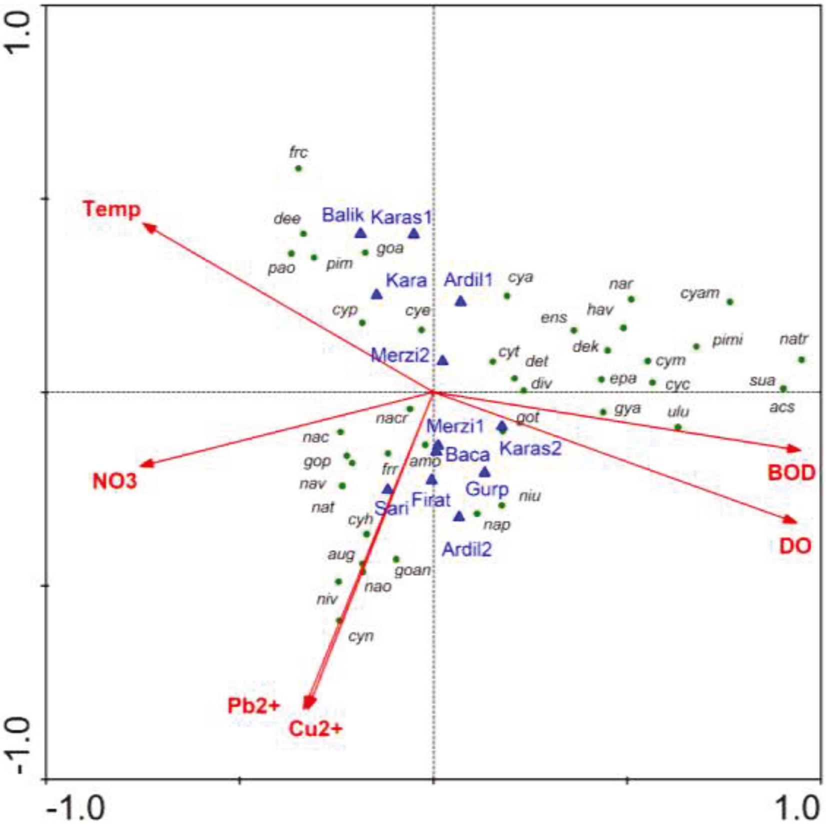

Figure 2. Ordination of diatom species (green circle) according to the effect of used environmental variables (red arrows) in the sampling sites (blue triangle) on CCA diagram. Abbreviations of sampling sites given in Table 1. Codes of species are given in Table 3. Temp: water temperature; Pb^{2+}: lead; Cu^{2+}: copper; BOD: biological oxygen demand; DO: dissolved oxygen; NO_3: nitrate.

Mediterranean basin of Turkey (Toudjani et al., 2017). The increase in conductivity herein could be associated with the addition of nutrient salts and other ions. This could be a consequence of a greater contribution of sediment from erosion processes intensified by deforestation in the Araban-Yavuzeli catchment. The high erosion rate in the catchment is caused by urban runoff, expansion of agricultural activity in some areas, and discharge of domestic wastes.

Relatively high nutrient values in the studied sampling stations in the Araban-Yavuzeli catchment were a consequence of the pressure of agricultural activities, discharge of domestic wastewaters with insufficient treatment facilities, and runoff from fertilized agricultural soils. This kind of pollution problem was also proposed in different ecoregions (Delgado and Pardo, 2014; Mangadze et al., 2015; Toudjani et al., 2017). Another important pollution source was manure thrown into agricultural lands that leaked into receiving water bodies via irrigation and was transferred with soil erosion. Unfortunately, the Araban-Yavuzeli catchment is poor in terms of the percentage of forest and thus mostly includes bare mountains and agricultural areas. The region has excessive evaporation that not only affects the flow regime but also the water quality of water bodies. The intense usage of agricultural land with manure and fertilizer could increase the amount of dissolved inorganic nitrogen in water bodies in the Araban-Yavuzeli catchment.

Ardıl Creek1 had low nutrient contents, except for nitrate. This is due to this station being located near a water resource supply and the Köklüce village and thus under pressure of the villagers' domestic wastewater. Besides, the Ardıl Dam was built at the upper section of this station in 2015. Water collection at this dam, along with a landscape ecological component, can affect the flow regime and the resultant water quality of Ardıl Creek1

Table 4. Characterization of the sampling stations in the Araban-Yavuzeli catchment by the TIT (trophic index-Turkey), EQR (ecological quality ratio), EPI-D (eutrophication and/or pollution index-diatom), and TI (trophic index).

Station	TIT	EQR	Status	TI	Status	EPI-D	Status
Bacalı Creek	2.50	0.62	Good	1.60	Good	1.29	Good
Sarıbuğday Creek	2.53	0.61	Good	1.62	Good	1.33	Good
Karapınar Pond	2.41	0.64	Good	2.37	Moderate	1.51	Good
Ardıl Creek1	1.94	0.83	High	1.62	Good	1.18	Good
Ardıl Creek2	2.32	0.68	Good	1.77	Good	1.44	Good
Karasu Creek1	2.45	0.63	Good	1.79	Good	1.48	Good
Karasu Creek2	2.46	0.63	Good	1.92	Good	1.23	Good
Gürpınar Creek	2.61	0.57	Moderate	1.89	Good	1.47	Good
Fırat River	2.45	0.63	Good	2.28	Moderate	1.61	Good
Merzimen Creek1	2.55	0.58	Moderate	2.04	Moderate	1.60	Good
Merzimen Creek2	2.30	0.69	Good	1.57	Good	0.98	High
Balıklı Pond	2.30	0.69	Good	1.45	Good	1.01	Good

and the downstream ecosystems. Higher metal values, especially Cr^{2+} and Ni^{2+}, were found in Ardıl Creek1 when compared with other sampling stations. This could be a consequence of the transfer of these metals from mining areas via precipitation. The concentration of metal ions in Ardıl Creek1 was higher than in the Yangtze River in the Nanjing section, China (Wu et al., 2009), watercourses in the Manyame catchment area of Zimbabwe (Mangadze et al., 2015), and surface water of an urban river in Bangladesh (Islam et al., 2015), but lower than in the Yamaçoba Reservoir output near a mining region in the southeast of Anatolia (Çelekli et al., 2016).

Changes in physical and chemical variables (especially the concentration and ratio of nitrogen and phosphorus) directly influence the distribution of diatom assemblages and their abundance in the ecosystems (Pipp, 2002; Rott et al., 2003; Rimet, 2012; Çelekli et al., 2019). Complex relationships between predictor factors and response variables in the water bodies of the Araban-Yavuzeli catchment were elucidated by CCA (Figure 2). This is the case in the present study since water temperature, nitrate, copper, lead, DO, and BOD_5 significantly affect the distribution of diatom assemblages (Figure 2). The most frequently observed taxa here (e.g., *A. ovalis*, *G. parvulum*, *N. cryptocephala*) were also reported in other ecoregions (Van Dam et al., 1994; Sakai et al., 2013; Oeding and Taffs, 2017; Vasiljevic et al., 2017; Tornés et al., 2018). Of common species, *A. ovalis* commonly occurs in different kinds of freshwater bodies and has wide tolerance levels to environmental factors (Oeding and Taffs, 2017; Toudjani et al., 2017; Vasiljevic et al., 2017; Tornés et al., 2018). The presence of *A. ovalis* in slow-flowing rivers herein strengthened the suggestion of Levkov (2009). *Gomphonema parvulum* is a widely distributed species throughout the world, including the surface waters of Italy (Dell'Uomo, 2004), mountain rivers of the Segre basin of Catalonia (Goma et al., 2005), a karstic limnocrene spring of Turkey (Çelekli and Külköyl*üoğlu*, 2007), running waters of the United Kingdom (Kelly et al., 2008), subtropical temperate Brazilian aquatic ecosystems (Lobo et al., 2010), the Eastern Highlands of Zimbabwe (Bere, 2016), the western Mediterranean river basin of Turkey (Toudjani et al., 2017), the Richmond River Catchment of Australia (Oeding and Taffs, 2017), and the Mediterranean streams tributaries from the lower part of the Ebro River in Spain (Tornés et al., 2018). This wide distribution could be due to strong resistance to environmental factors (Delgado et al., 2012; Toudjani et al., 2017), also indicated in the present study by CCA (Figure 2). In the present study, *N. cryptocephala* is associated with polluted sites having relatively high amounts of nutrients and conductivity optima. *Navicula cryptocephala* has been described as a nutrient-tolerant diatom species in freshwater courses in Austria (Rott et al., 1999), Brazil (Lobo et al., 2010), the United Kingdom (Kelly et al., 2008), Argentina (Cochero et al., 2015), Beijing (Chen et al., 2016), the Bloukrans River system in the Eastern Cape province of South Africa (Dalu et al., 2017), Australia (Oeding and Taffs, 2017), and Turkey (Toudjani et al., 2017; Çelekli et al., 2019).

The results of the TIT indicated that Ardıl Creek1 had a very good ecological condition, while it had good ecological condition according to results of the TI and

EPI-D. This sampling station was associated with low nutrient values and was characterized by the occurrence of pollution-sensitive diatom species (e.g., *C. affinis*, *E. silesiacum*, and *N. radiosa*), considered to be dominant in less polluted ecosystems (Gómez and Licursi, 2001; Delgado et al., 2012; Wang et al., 2014; Çelekli et al., 2019). In the future, water collection at the Ardıl Dam and other factors can affect the flow regime, which will result in the deterioration of the ecological status of Ardıl Creek1. Ecological preferences of the aforementioned species and physicochemical variables confirmed the different ecological status of the sampling stations and the suitable applicability of the TIT in an ecoregion approach. To assess the ecological quality of aquatic ecosystems, the TIT gave better results in the Western Anatolia basin (Toudjani et al., 2017) when compared to the EPI-D (Dell'Uomo, 2004). The TIT was also found to be more competitive in the North Aegean catchment compared to the TI (Rott et al., 1999). P-PO_4 as a main environmental variable for primary producers had a significant positive correlation with TIT ($P < 0.01$, $r = 0.789$), but aremarkable correlation was not found for TI and EPI-D. This study suggested that diatom metrics can be effectively used for running water quality assessment. Development of ecoregionally specific diatom metrics is warranted since climate, geology, anthropogenic activities, and land use may affect the preferences of diatom assemblages and their trophic weight (Gomá et al., 2004; Lobo et al., 2004; Soininen, 2007; Çelekli et al., 2019).

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