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EVALUATION OF THE RELATIONSHIP BETWEEN EPIPHYTIC DIATOMS AND ENVIRONMENTAL PARAMETERS WITH THE CANONICAL CORRESPONDENCE ANALYSIS (CCA)

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Abstract

This study aimed to determine the relationship between environmental parameters and epiphytic diatoms. Four sampling sites were selected in the littoral region of Lake Egirdir. Macrophytes were taken seasonally from July 2012 to April 2013. Submerged samples (*Myriophyllum spicatum* L., *Potamogeton perfoliatus* L., *Ceratophylum* sp. and *Valisneria* sp.) were collected for the analysis of epiphytic algae. Twenty-four diatom species were identified in this study. *Cocconeis pediculus* Ehrenberg was identified as the most abundant epiphytic diatom on the *Myriophyllum spicatum* L., *Potamogeton perfoliatus* L., *Ceratophylum* sp. and *Valisneria* sp. Besides, physical and chemical parameters of lake water were determined. Water temperature, pH and conductivity varied from 6.9 - 26.3°C, 8.9-9.1, 276.1 – 388.1 µS/cm, dissolved oxygen values as 11.8 – 9.7 mg l^{-1}, respectively. Concentration of calcium, magnesium, silicon, nitrate and phosphate ranged 41.3-32.1, 36.5- 41.3, 5.7 -6.1, 1.1- 3.4 and 0.02- 0.43 mg l^{-1}, respectively. It was concluded that wave motions in aquatic environments and water quality parameters are primarily effective in the distribution of epiphytic diatoms, seasons are important in the development of some species, and macrophytes provide support for the species to attach to the surfaces according to their morphological differences, despite not being very determinative.

Key words: Water quality, Epiphytic, Diatom, Lake, Canonical correspondence analysis.

Introduction

Turkey has a 145,000 km-long water network and a large amount of life exist in inland waters. Among the variety of living things algae are important because they are the first part of the food chain. They ensure ecological balance and contain the species which are important indicator taxa in the determination of water pollution (Ertan and Morkoyunlu, 1998). Diatoms are the dominant group of algae in the wetlands of Turkey in terms of the species diversity. Therefore, findings obtained from studies on diatoms will reflect the characteristics of the diatom flora of the area studied and provide information on the characteristics of freshwater environments (Akbulut & Yildiz, 2002). The abundance and distribution of epiphytic diatoms in lakes exhibits spatial and temporal variation. Many allogenic factors (including light, temperature, and nutrients) and autogenic factors under biological control (such as competition, predation, and parasitism) interact to regulate spatial and temporal variations in lake ecosystems (Koçer & Şen, 2014).

Lake Egirdir, which is located in the Lakes Region of Turkey, is one of the important inland water resources in terms of its aquaculture potential. Also, several studies have been made about the Lake Eğirdir water quality (Ertan *et al*., 2001; Apaydın Yağcı *et al*., 2013). In addition to these studies on the Lake Eğirdir was reported to be oligotrophic in terms of water quality and mesotrophic in terms of algal flora (Turna *et al*., 1998). Recent studies report that Hoyran region, where the lake is rich in aquatic plants, is mesotrophic-eutrophic; the part in the Egirdir region is mesotrophic and when evaluated in terms of water quality parameters, it has 1st-2nd Class water quality in terms of sulfate, phosphate and nitrat according to Water Pollution Control Regulation (Apaydın *et al*., 2013).

In this study, we aimed to identify the environmental factors affecting the diversity of epiphytic diatoms living on submerged plants (*Myriophyllum spicatum* L., *Potamogeton perfoliatus* L., *Ceratophylum* sp. and *Valisneria* sp). Therefore, diatoms and their environmental relationships with water parameters were evaluated using the Canonical Correspondence Analysis (CCA) method.

Materials and Method

Study site: Lake Eğirdir, located within the borders of Isparta province is 917 m above the sea level. It is located between 37° 50' 41'' - 38° 16' 55'' north latitude and 030° 44' 39'' - 030° 57' 43'' east longitude. The drainage basin of the lake is 3321 km^2 and the average surface area is 475 km^2. The length of lake is 48 km in north-south direction and the widest section is 18 km, the narrowest section is 1.8 km. The average debth of the lake is 8-9 m and the deepest part is about 13 m. The area in the north of the narrowest part in the east-west direction of Lake Eğirdir is called "Hoyran Region" and the part in the south is called "Eğirdir Region". This study was seasonally (July and October 2012, January and April 2013) conducted at 4 sampling stations in Lake Egirdir (Fig. 1).

Station 1: There are spoardic reeds at the station located in the bridge area of Lake Eğirdir. The littoral zone is gritty and partly stony. *Valisneria* sp. and *Myriophyllum spicatum* population shows the distribution in the area.

Station 2: There is *Potamogeton perfoliatus and Valisneria sp.* distribution at the station selected opposite Eğirdir Osteopathic Hospital.

Station 3: It is the region used as a public beach. *Myriophllum spicatum and Valisneria* sp.,*Ceratophyllum* sp. samplings were taken from this station.

Station 4: There is *Myriophllum spicatum, Potamogeton perfoliatus and Ceratophyllum* sp. distribution in the region known as Altınkum Public Beach.

Fig. 1. Geographical location of Lake Eğirdir and sampling stations.

Sampling and analysis: Samples of *Myriophyllum spicatum* L.*, Potamogeton perfoliatus* L., *Ceratophylum* sp. and *Valisneria* sp. were collected for the analysis of epiphytic algae. The epiphytic diatoms were collected by brushing off the plants. Permanent slides were prepared after boiling the diatom samples with acidic solution and than the diatom samples were fixed in Entellan medium (Wetzel & Likens 1991; Anon., 1995). Taxonomic identifications were made according to Hustedt (1985); Patrick & Reimer (1966, 1975); Gönülol*et al*. (1996); Aysel *et al*. (2005); Gönülol (2016); Guiry & Guiry, (2016). In addition, percentages of occurrence of diatoms on the surface of macrophytes were calculated. Seasonal measurements (water temperature, conductivity, pH, dissolved oxygen) were analyzed to determine the water quality values of the stations in the field, and the other parameters (Calcium, Magnesium, Silisyum, Nitrate and Phosphate) were analyzed spectrophometrically (Apaydın *et al*., 2013).

Seasonal differences in periphytic biomass among the stations were evaluated with Duncan's Post Hoc Tests within the analysis of variance (ANOVA) design of SPSS 9.0® for Windows (Anon., 2004). The significance was evaluated at the $p<0.05$ level for the analysis. For species that occurred three or more times from different sites, the canonical correspondence analysis (CCA) was used to assess species-specific responses to five environmental variables (ter Braak & Barendregt, 1986; ter Braak & Verdonschot, 1995). In order to reduce an arc-effect and/or eliminate the effects of multicolinearity among the variables, the number of environmental variables was kept lower than the number of species (Ter Braak & Barendregt 1986). The significance was assessed using Monte Carlo permutation tests (499 permutations). As suggested by Ter

Braak & Barendregt (1986), the data used for CCA were log-transformed, and rare species were down-weighted after being tested with the Detrended Correspondence Analyses (DCA). According to DCA analyses, gradient lengths of three or higher values support suitability of the data for CCA application. Multivariate analyses and the GLM were performed using CANOCO version 5.0.

Results

In the study, water temperature values were determined as 6.9-26.3°C, conductivity values as 276.1 – 388.1 µS/cm, pH values as 8.9-9.1, dissolved oxygen values as 11,8 – 9.7 mg l^{-1}, calcium values as 41.3-32.1 mg l^{-1}, magnesium values as 36.5- 41.3 mg l^{-1}, silicon values as 5.7 - 6.1 mg l^{-1}, nitrate values as 1.1- 3.4 mg l^{-1} and phosphate values as 0.02-0.43 mg l^{-1}. It was determined that some seasonally measured physical and chemical parameters were low in winter months; calcium and magnesium values showed an inverse proportion; conductivity values were represented with low values in winter and with values similar to each other in the other seasons (Fig. 2).

Twenty four epiphytic taxa belonging to Bacillariophyta living on *Myriophyllum spicatum* L., *Potamogeton perfoliatus* L., *Ceratophylum sp.* and *Valisneria sp*. macrophytes' taken from four different stations selected in the littoral zone of Lake Eğirdir were identified. The list for the identified taxa and their occurrence percentages are given in Table 1.

Figure 2 displays the seasonal variations of the diatoms showing distribution on *Myriophyllum spicatum* in this study. Although *Cocconeis pediculus* was available in all seasons, it showed increase in the spring and autumn (Fig. 3).

Result

The diatoms showing distribution on *Ceratophyllum sp., Cocconeis pediculus* was determined to show an increase in spring and reach the highest rate in autumn (Fig. 4).

Of the diatoms showing distribution on *Valisneria* sp., *Cocconeis pediculus* was determined to reach the highest rate in the spring period (Fig. 5).

Of the diatoms showing distribution on *Potamogeton perfoliatus, Cocconeis pediculus* was determined to show a gradual increase during the year and reach the highest increase in autumn (Fig. 6).

Seasonal distribution of *Cocconeis pediculus,* identified as the most abundant epiphytic species in the study, was determined to show similarity to *Myriophyllum spicatum* L., *Potamogeton perfoliatus* L., *Ceratophylum* sp. and *Valisneria* sp. The relationship between the identified diatom species and the environmental parameters (electrical conductivity, water temperature, dissolved oxygen, pH, calcium, magnesium, silicon, nitrate and phosphate) which were determined using the Canonical Correspondence Analysis (CCA) method are given in Table 2. The total variance explained with CCA total variation is 0.78783 and explanatory variables account for 72.6% (adjusted explained variation is 31.6%) (Table 2).

The fact that temperature and nitrate are located close to the origin of both axes in the graph of water quality parameters demonstrate that spatial and temporal variation in the data set is very low, and its effect on the total variation is insignificant. Magnesium, electrical conductivity and dissolved oxygen were also determined to have weak correlations with Axis 1 and Axis 2. Calcium, silicon and pH were important in the slope of Axis 1 explaining the larger proportion of the total variance; however, they showed weak correlations. Orthophosphate was important in the slope of Axis 2 with a weak correlation (Fig. 7).

Table 1. Identified diatoms and their occurrence percentages in Lake Eğirdir.

Taxa	*Ceratophyllum* sp. (%)	*Valisneria* sp. (%)	*Myriopyllum spicatum* (%)	*Potamogeton perfoliatus* (%)
Amphora ovalis (Kütz.) Kütz.	3	4	4	2
Brebissonia lanceolata (C.Ag.) Mahoney & Reimer	6	2	7	-
Cocconeis pediculus Ehr.	50	45	45	49
Cocconeis placentula Ehr.	7	3	11	17
Craticula cuspidata (Kütz.)	1	1	-	-
Cymatopleura elliptica (Bréb.) W.Smith	-	1	-	6
Cymatopleura solea (Bréb.) W.Smith	1	-	-	1
Cymbella affinis Kütz.	-	-	1	-
Cymbella cymbiformis C.Agardh	13	8	10	5
Cymbella lanceolata (C.Agardh) C.Agardh	-	-	-	1
Cymbella tumida (Brébisson) van Heurck	3	-	-	-
Denticula tenuis Kütz.	1	7	5	-
Diatoma vulgaris Bory var. *brevis* Grunow	1	3	-	-
Encyonema ventricosum (C.Agardh) Grunow	-	1	1	-
Epithemia adnata (Kützing) Brébisson	3	5	-	-
Epithemia argus (Ehr.) Kütz.	1	4	-	-
Epithemia muelleri Fricke	-	3	3	5
Epithemia turgida (Ehr.) Kütz.	-	4	-	-
Gomphonema intricatum Kütz.	1	-	-	-
Gomphonema olivaceum (Hornemann) Brébisson.	-	-	5	10
Gyrosigma attenuatum (Küt.) Rabenhorst	-	-	2	-
Navicula radiosa Kützing	1	3	-	-
Rhoicosphenia abbreviata (C.Agardh) L-Bertalot	-	1	-	4
Ulnaria ulna (Nitzsch) Compère	2	5	4	3

Table 2. Total variance explained with CCA total variation is 0.78783 and explanatoryvariables account for 72.6% (adjusted explained variation is 31.6%).

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.2704	0.1165	0.0634	0.0516
Explained variation (cumulative)	34.33	49.11	57.16	63.71
Pseudo-canonical correlation	0.9775	0.8776	0.9100	0.9371
Explained fitted variation (cumulative)	47.26	67.61	78.69	87.71

Permutation test results:
On all axes: Pseudo-F=1.8, P=0.026

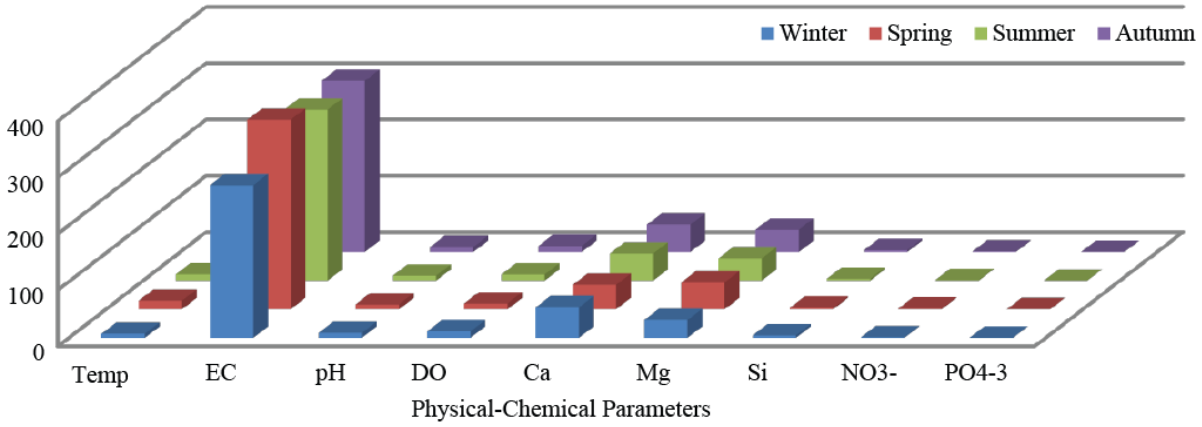

Fig. 2. Seasonal variation of physico-chemical parameters from July 2012 - April 2013.

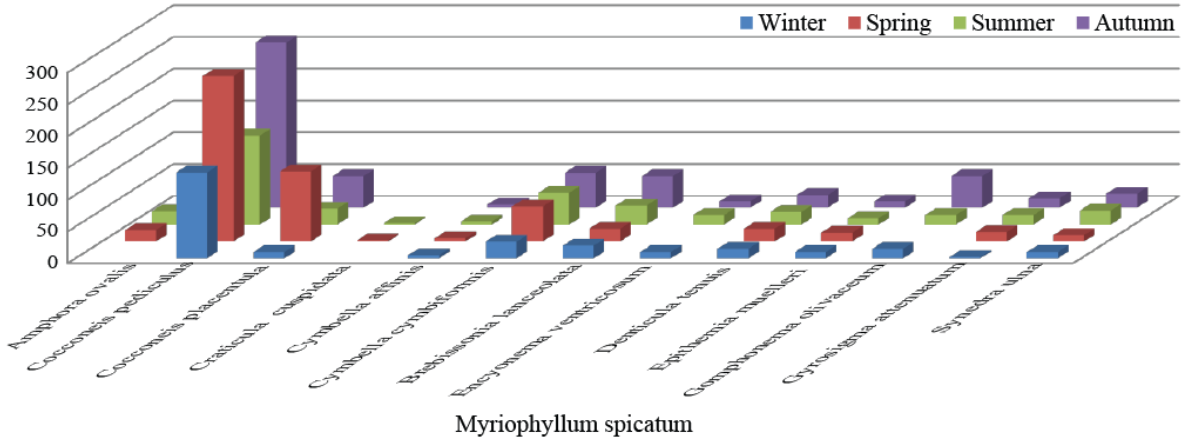

Fig. 3. Seasonal variation of epiphytic algae on *Myriophyllum spicatum* L.

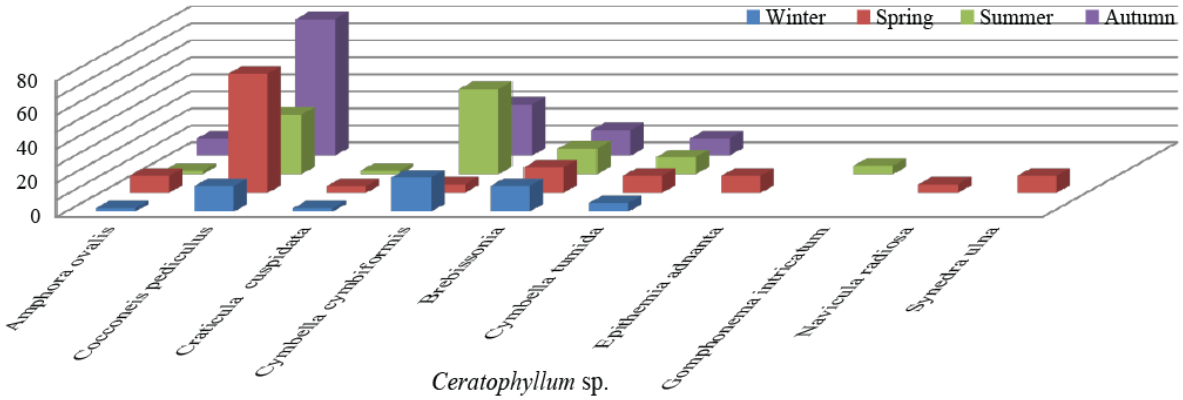

Fig. 4. Seasonal variation of epiphytic algae on *Ceratophyllum* sp .

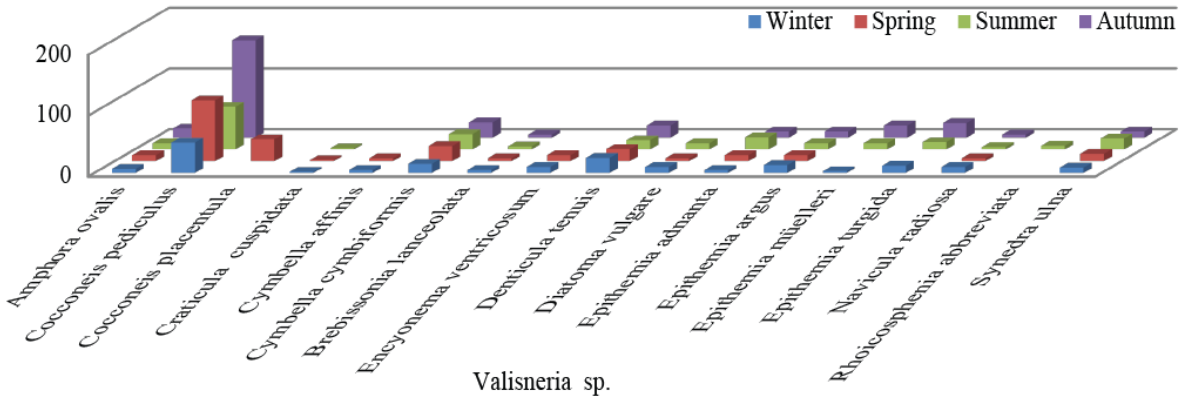

Fig. 5. Seasonal variation of epiphytic algea on *Valisneria* sp.

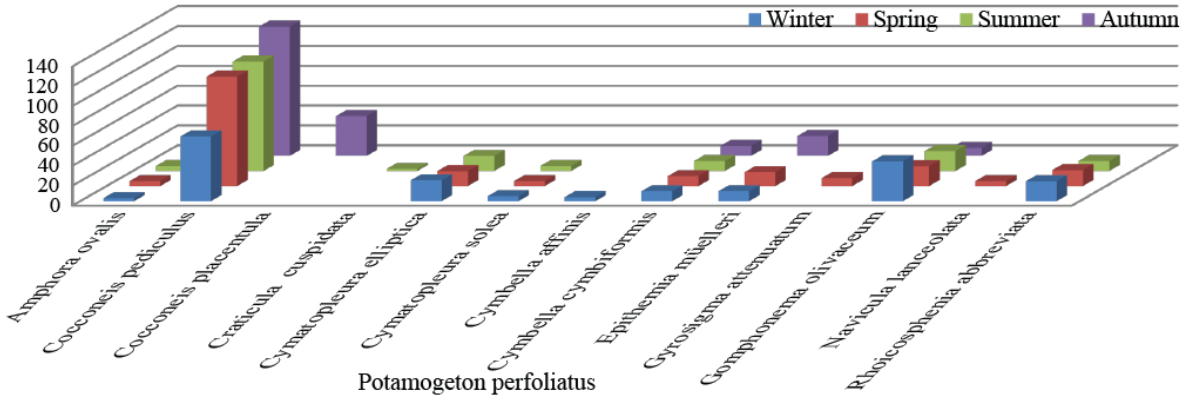

Fig. 6. Seasonal variation of epiphytic algea on *Potamogeton perfoliatus* L.

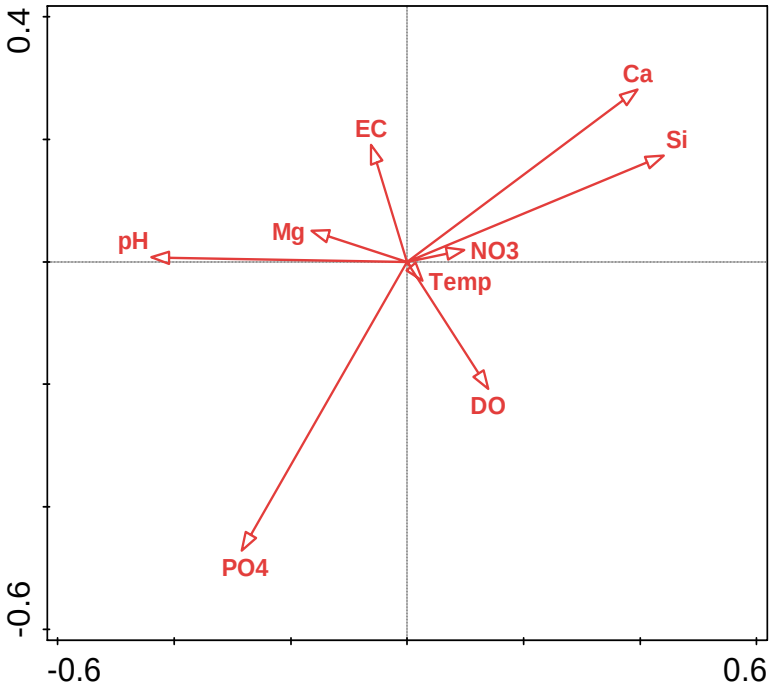

Fig. 7. Correlations between water quality parameters.

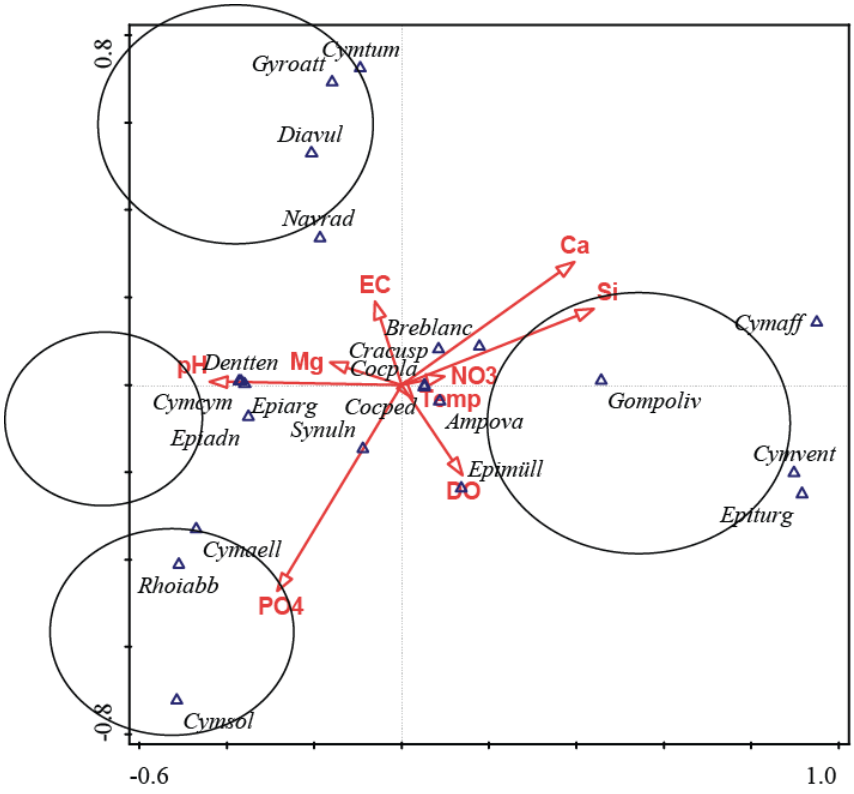

Fig. 8. Correlations between water quality parameters and epiphytic diatoms according to Canonical Correspondence Analysis (CCA). Cymaff: *Cymbella affinis*; Gompoliv: *Gomphonema olivaceum*; Cymvent:*Cymbella ventricosa*; Epitur: *Epithemia turgida*; Cymtum:*Cymbella tumida*; Gyroatt:*Gyrosigma attenuatum*; Diavul: *Diatoma vulgaris;* Navrad: *Navicula radiosa*; Denten: *Denticula tenuis*; Cymcym:*Cymbella cymbiformis*; Epiadn:*Epithemia adnanta;* Epiarg: *Epithemia argus;* Cymaell: *Cymatopleura elliptica;* Rhoiabb: *Rhoicosphenia abbreviata;* Cymsol:*Cymatopleura solea.*

Correlations between water quality parameters and epiphytic diatoms according to the Canonical Correspondence Analysis (CCA), the species in group C are located in the negative part of Axis 1, explaining the total variation in a larger proportion in the same direction as pH as they are species showing alkaliphilic or alkalibiontic properties (Fig. 8). On the contrary, the species in group A are located in the positive part of the first axis in reverse direction with pH as they are neutral and acidophilic. This relationship can also be evaluated as an indicator of spatial and temporal variation showing that the species in group A became dominant and increased in abundance in the periods and regions in which pH value decreased, and the species in group C became dominant and increased in abundance in the periods and regions in which pH value increased. In addition, the species in group D showed a weak but significant relationship with the dissolved reactive phophorus change and this relationship can be evaluated as 'the species became dominant in the months and regions in which the dissolved reactive phophorus concentration increased.

Discussion

Average physicochemical parameters in Lake Eğirdir have been determined as follows: water temperature: 15.5°C, conductivity: 356,3 µS/cm and dissolved oxygen: 9.7 mg l^{-1}, pH 8.7. In previous studies, these values were reported to be, respectively 14.6°C, and 15.9°C, 343.3 µS/cm and 377 µS/cm, 9.1 mg l^{-1} and 8.1 mg l^{-1}, 8.4 and 8.6 (Aksoylar & Erten., 2002; Atay & Bulut, 2005). Factors such as location of the research stations, sampling times, years, seasonal changes and wave motions can cause differences in physicochemical values of aquatic systems. Similar results have also been obtained in this study. In Lake Eğirdir, which has moderately hard water, the average of calcium has been determined as 39.3 mg l^{-1} and the average of magnesium as 42 mg l^{-1}. However, in the other studies, calcium averages were reported as 44.9 mg l^{-1},41.9 mg l^{-1} ^{1}, and magnesium averages as 79.5 mg l^{-1}, 40.7 mg l^{-1} (Aksoylar & Erten, 2002; Atay & Bulut, 2005). Calcium and magnesium values showed a decrease in time. The value average of silicon, which is effective in the development of diatoms in particular, was identified as 4.3 mg l^{-1}. Nitrate average, which is important for photosynthesis, was determined as 1.5 mg l^{-1} and phosphate average value as 0.1 mg l^{-1}. Our findings of physicochemical parameters of Lake Eğirdir show similarity with the findings of other studies carried out in the lake (Aksoylar & Erten, 2002; Atay & Bulut, 2005).

In the present study, 24 diatom species of epiphytic algae were identified on the species of Ceratophyllum sp. *Valisneria* sp. *Myriopyllum spicatum, Potamogeton perfoliatus,* which showed distribution in Lake Eğirdir.

Diatoms species belonged to genera Amphora*, Brebissonia, Cocconeis, Craticula, Cymatopleura, Cymbella, Denticula, Diatoma, Encyonema, Epithemia, Gomphonema, Gyrosigma, Navicula, Rhoicosphenia* and *Synedra*. The dominance of *Cocconeis pediculus* Ehr. (50%, 49%, 45%, and 45% respectively) was observed on *Ceratophyllum* sp. *Valisneria* sp. *Myriopyllum spicatum Potamogeton perfoliatus* (Table 1). The fact that *Coccones pediculus* is a real epiphytic species quite frequently encountered in aquatic systems can be explained with its preference of high nutrient concentrations and ecological tolerance to organic pollution. In this research, although the percentage values of the *Amphora ovalis, Cocconeis placentula, Craticula cuspidata* and *Ulnaria ulna* species varied, they were identifed to be distributed in all macrophytes. When the stations and the seasons in which the species showed distribution were statistically evaluated, the differences between the seasons and the stations in the distribution of *Amphora ovalis, Cocconeis placentula, Craticula cuspidate* were found insignificant ($p>0.05$). A significant difference was found when spring and summer were compared to other seasons in the quantitative increase of *Cocconeis pediculus,* and when autumn was compared to other seasons in term of *Ulnaria ulna* ($p<0.05$).

Diatom species have epilitic, epiphytic, epipelic and planktonic distribution in many lakes and ponds due to their broad ecological tolerance capabilities. This situation has been observed in many lentic and lotic ecosystems in Turkey (Gönülol *et al*., 1996; Aysel, 2005; Gönülol, 2016). In all the research in Lake Egirdir, diatom members was found dominant (Timur *et al*., 1988; Conk & Cirik, 1995; Savaş & Cirik, 1997). In the studies conducted on the same lake, different species belonging to the same group were also encountered. This difference is thought to have resulted from the performance of the studies in different years, sampling stations, time-dependant changing ecological properties, allochtonous and anthropogenic factors. The effect of physical and chemical factors on the diatom composition in a lake, its density and seasonal distribution is large. In our study, diatom members which had wide- range of tolerance especially were identified abundancly in each season.

The epiphytic diatoms in Lake Egirdir are evaluated according to the Canonical Correspondence Analysis (CCA). The temperature and nitrate are located close to the origin of both axes in the graph of water quality parameters indicate that spatial and temporal variation in the data set is very low and its effect on the total variation is insignificant. Magnesium, electrical conductivity and dissolved oxygen were also determined to have weak correlations with Axis 1 and Axis 2. Calcium, silicon and pH are more significant in the slope of Axis 1 explaining the larger proportion of the total variation but show weak correlations. Orthophosphate is more significant in the slope of Axis 2 with a weak correlation. *Denticula tenuis, Cymbella cymbiformis, Epithemia adnanta, Epithemia argus* and *Ulnaria ulna* in group C were located in the same direction as pH showing alkaliphilic or alkalibiontic properties. *Cymbella affinis, Gomphonema olivaceum, Cymbella ventricosa* and *Epithemia turgida* species in group A are located in reverse direction with pH showing neutral or acidophilic properties. Similar results have also been obtained in algological studies conducted in the freshwaters of Turkey (Akbulut & Yıldız, 2002; Çelekli & Köylüoğlu, 2006; Atıcı & Obalı, 2010; Koçer & Şen, 2012, 2014).

These findings show that, during the research time the species in group A (*Gomphonema ovalis, Cymbella affinis, Cymbella ventricosa, Epithemia turgida*) became dominant and increased abundantly in regions which pH value decreased, and the species in group C *(Denticula tenuis, Cymbella cymbiformis, Epithemia adnanta, Epithemia argus)* became dominant and increased abundantly in regions which pH value increased. These species can be evaluated as an indicator of spatial and temporal variation. In addition, *Cymatopleura elliptica, Rhoicosphenia abbreviata, Cymatopleura solea* showed a weak but significant relationship with the dissolved reactive phophorus change, and this relationship was thought to be effective in the dominant occurrence of the species in the months and regions in which the dissolved reactive phophorus concentration increased.

In the current study, it is concluded that wave motions in aquatic environments and water quality parameters are primarily effective in the distribution of epiphytic diatoms. Seasons are important in the development of some diatom species. Also, macrophytes provide support for the species which are attached to their surfaces according to their morphological differences, despite not being very determinative.

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