



Using Epilithic Algae Assemblages to Assess Water Quality in Lake Kovada and Kovada Channel (Turkey), and in Relation to Environmental Factors

Nezire Lerzan Çiçek^{1,*}, Fatma Yamuç¹

¹ Süleyman Demirel University, Eğirdir Fisheries Faculty, Isparta-Turkey.

* Corresponding Author: Tel.: +90.530 3490063;
E-mail: lerzancicek@sdu.edu.tr

Received 27 September 2016
Accepted 02 January 2017

Abstract

In this study, distribution of epilithic algae assemblages in Lake Kovada and Kovada Channel, their relationships to environmental factors, and biological water quality were investigated. Epilithic algae and water samples were taken from four stations (one in the channel, others in the lake), between June 2012-May 2013 seasonally. Totally 51 taxa were observed belonging to the groups Bacillariophyta (37), Chlorophyta (8), Charophyta (4) and Cyanobacteria (2), respectively. The stations were clustered into main two groups based on UPGMA. The highest similarity value was determined between third and fourth station (94%). Saprobic Index (SI) was applied in order to determine biological water quality. Physicochemical parameters have been evaluated according to the Klee's method and Regulation on the Management of Surface Water Quality in Turkish (RMSWQ). According to the Klee's method, water quality was found unpolluted in Kovada Lake, and its channel while it was found as polluted based on RMSWQ. Biological water quality values indicated Lake Kovada as poorly polluted, but its channel as polluted. According to CCA, 84.6% of the variance was described by the first four axes of the relations of species and environmental variables ($r=0.963$), and pH, conductivity and Cl⁻ were found to be the most influential variables on distribution of dominant taxa.

Keywords: Lake Kovada, Saprobic Index, water quality, benthic algae, CCA.

Introduction

Freshwater systems are the most important natural resources for all living organisms. There are 1.4 billion km³ water in the world and 3% of this value is freshwater systems. Nowadays water resources are polluted with various reasons as rapid population growth, unplanned urbanization, industrialization, and agricultural activities. (Kocataş, 2006; Cirik & Cirik, 2008). Contamination of water resources leads to irreversible problems (Atalık, 2006). Thus water pollution issue has an increasing importance in the world (Palmer, 1980; Gönülol & Obalı, 1986). Lakes comprise an important part of natural ecosystems with a lot of features, such as biological diversity, fishery, recreation, and hydrologic cycle. Above mentioned various negative influences cause to pollution in lakes (Kristensen & Hansen, 1994; Dodson, Arnott, & Cottingham, 2000).

Generally, planktonic primary production is investigated in order to determine the productivity of trophic levels in lakes. However, recent studies showed that primary production exists in both planktonic and benthic habitats. Benthic algae have

significant effect to littoral zone and whole-lake in primary production (Vadeboncoeur, Peterson, Vander Zanden, & Kalff, 2008; Sadro, Melack, & MacIntyre, 2011; Althouse, Higgins, & Zanden, 2014). Water quality of freshwater systems should be designated according to physicochemical and biological data. Organisms are sensitive to fluctuations in their habitats. For this reason, physicochemical parameters are commented couple with biological approaches. Existence of some organisms or disappearance can show long-term changes in water quality, while chemical parameters reflect instantaneous water quality (Barlas, 1995; Kazancı, Girgin, Dügel & Oğuzkurt, 1997; Güler, 2003). Benthic diatoms are one of the most important organisms for determining water quality in freshwater systems (Garrido, Romo, & Villena, 2013). Several diatom-based indices were developed and these indices have been used in a number of countries (Whitton & Kelly, 1995; Kelly & Whitton, 1995; Lirika, Aleko, & Alqi, 2011; Bennion, Burgess, Juggins, Kelly, Reddihough, & Yallop, 2012; Lirika, Aleko, & Alqi, 2013). The Saprobic Index was used for the first time in Turkey in order to assess the water quality of the Isparta Stream by the

Kalyoncu and Barlas (1997). There are several studies about determine of water quality with Saprobi index in Turkey (Kalyoncu, Barlas, Ertan, & Gülboy, 2004; Kalyoncu 2006; Solak, Barinova, Ács, & Dayıoğlu, 2012; Kalyoncu & Şerbetçi, 2013). The aims of this study were to determine water quality based on benthic algae and physicochemical parameters, and to explain effects of some physicochemical variables on the dominant species occurring in Lake Kovada and its channel.

Materials and Methods

Study Area

Lake Kovada is one of the important surface waters of Turkey. The lake is located in the south of Eğirdir and the east of Isparta (Turkey). It forms natural extension of Lake Eğirdir. It was divided as a result in loading silty of narrow zone years ago, and actually has become a separate lake (Anonymus, 2016). The deepest point of Lake Kovada, a karst-tectonic lake, is about 7 m and the average width is about 2-3 km (Arslan & Şahin, 2006). The lake and its environment were declared as Natural Protected Area I in 1992. Kovada Channel, length 22 m, provides a link between Eğirdir and Lake Kovada. The water of Lake Eğirdir is transported by this channel to Lake Kovada (Figure 1).

Sampling Method

Physical and Chemical Sampling and Analysis

Water samples were taken from each stations seasonally (Jun 2012-May 2013), and analyzed within 24 hours after taken. Water temperature, pH, dissolved oxygen (DO) and conductivity were

measured with YSI 550A meter, YSI EcoSense pH110A pH meter, YSI EcoSense EC300A conductivity meter, during sampling in the study area. Mg^{+2} , Ca^{+2} , Cl^- , NH_4^+-N , NO_2^-N , NO_3^-N , $PO_4^{3-}P$, ΣP , and total hardness determined in the laboratory according to Standard methods (Greenberg, Connors, Jenkins, & Franson, 2005). Physicochemical variables were evaluated according to Klee's method (Klee, 1991) and Regulation on the Management of Surface Water Quality in Turkish (Anonymus, 2012).

Epilithic Algae Sampling and Evaluation

Epilithic algae were taken from the four stations seasonally (between June 2012-May 2013). Samples of benthic algae were collected by brushing or scraping the upper surface of stones (cobbles or small boulders) obtained from the littoral zones of lake (Anonymous, 2014). The samples, fixed with 4% formaldehyde. Samples were boiled with equal volume acid mixture ($H_2SO_4:HNO_3$) for identification of diatoms. The residue was washed vigorously with distilled and deionized water (DDW) to remove residual acid and then the diatom samples were fixed in Entella medium, at least 300 valves of epilithic diatom were counted (Round, 1953; Anonymous, 2014). Algae were identified under x100 Nikon microscope according to taxonomic keys (Pestalozzi, 1955; 1968; 1982; 1983; Prescott, 1973; 1978; Hustedt, 1985; Krammer & Lange-Bertaloth, 1986; 1988; 1991a,b; Bourrlly & Couté, 1991; Komárek, 2000; 2008; John, Whitton, & Brook, 2005). We use algaebase data base for algae list Guiry and Guiry (2016), and Gönülol (2016). Also, author names are given in abbreviated form according to Brummit and Powell (1992). Biological water quality was determined according to Saprobi index (Rott, Hofmann, Pall, Pfister, & Pipp, 1997; Vogel, 2004).



Figure1. Study area and stations.

Physicochemical water quality was evaluated according to the Klee's method (1991) and Regulation on the Management of Surface Water Quality in Turkish (RMSWQ) (Anonymous, 2012). Biodiversity was determined with Shannon-Wiener and Simpson diversity indices, and a clustering analysis of unweighted pair group mean averages (UPGMA) was applied to determine the similarities between four stations, based on algae taxa using MVSP 3.1 (Multi Variate Statistical Package) (Kovach, 2002). Relationship between biodiversity values and individual numbers was determined with Spearman's correlation analysis using SPSS (16.0) package program. Algae assemblages and their relation with environmental variables were determined by Canonical Correspondence Analysis (CCA) using CANOCO 4.5 package (Ter Braak & Šmilauer, 2002).

Results

During the study period, physicochemical values changed according to seasons and stations in Lake Kovada and its channel. The water temperature varied between 3.2°C (in winter) and 23.7°C (in summer). The maximum dissolved oxygen was evaluated in winter as 13.45 mg L⁻¹ at station 4, and the minimum value 2.3 mg L⁻¹ in autumn at station 1 (Kovada Channel). pH values were measured between the

values 6.98 and 10.2 with minimum recorded in winter at station 4, and the maximum in autumn at station 2. The conductivity (25°C) ranged between 304.2 µS/cm in autumn at station 1, and 226.6 µS/cm in summer at station 2. The NH₄-N, NO₃-N, NO₂-N, PO₄-P and ΣP mg L⁻¹ values were measured in trace quantities generally. The maximum value evaluated for NH₄-N was 0.14 mg L⁻¹ at station 4 in winter; for NO₂-N 0.046 mg L⁻¹ at station 3 in winter; for NO₃-N 0.45 mg L⁻¹ at station 2 in summer; for PO₄-P 1.27 mg L⁻¹ and for ΣP 5.21 mg L⁻¹ at station 1 in winter. The level of Cl⁻ ranged from 6.2 mg L⁻¹ to 35.5 mg L⁻¹; Ca from 17.64 mg L⁻¹ to 38.49 mg L⁻¹, Mg from 8.74 mg L⁻¹ to 32.07 mg L⁻¹, total hardness from 94.52 mg L⁻¹ to 174.64 mg L⁻¹ at all stations (Table 1). As a result of samplings, total of 51 taxa belong to Bacillariophyta (37), Chlorophyta (8), Charophyta (4), Cyanobacteria (2) were identified in study area (Table 2). Bacillariophyta comprised 72.3% of total taxa, *Cymbella* and *Navicula* (five species) represented the most species number. *Diatoma vulgare*, *Encyonema minutum*, *Epithemia sorex*, *Ulnaria ulna* were observed constant in stations (Table 2). Dominant taxa changed according to seasons and stations. During this research *Epithemia sorex* Kütz., *Navicula capitatoradiata* H. Germ., *Nitzschia palea* (Kütz.) W.Sm., *Diatoma vulgare* Bory, *Gomphonema parvulum* (Kütz.) Kütz., *Diatoma tenuis* C.Agardh were detected as dominant species of

Table 1. Distributions of physicochemical variables according to stations in Lake Kovada and Kovada Channel

Physicochemical variables	St 1	St 2	St 3	St 4
	Mean±SD Min-Max	Mean±SD Min-Max	Mean±SD Min-Max	Mean±SD Min-Max
Temperature (oC)	13.80±7.87 3.2-21.7	15.15±8.60 3.2-23.7	15.42±8.11 3.7-22.4	14.10±7.40 3.2-19.6
O2 (mg/L)	9.29±4.62 2.9-12.96	12.36±0.90 11.22-13.4	11.83±1.28 9.95-12.85	11.63±2.57 7.8-13.45
pH	8.47±0.78 7.36-9.16	8.46±0.98 7.18-9.4	8.99±1.25 7.28-10.21	8.50±1.06 6.98-9.4
Conductivity (µS/cm)	264.77±29.87 231.4-298.8	268.48±24.21 251.3-304.2	265.68±30.21 226.6-291.5	264.73±25.36 244.5-301.2
Cl ⁻ (mg/L)	15.75±7.75 6.20-24.85	39.05±11.03 10.65-35.5	19.61±13.17 17.64-38.49	21.39±11.26 24.60-32.08
NH ₄ -N (mg/L)	0.067±0.01 BDL*-0.11	0.12±0.04 0.025-0.13	0.07±0.05 BDL*-0.13	0.06±0.04 BDL*-0.14
NO ₂ -N (mg/L)	0.0115±0.001 BDL*-0.016	0.014±0.001 BDL*-0.015	0.014±0.025 BDL*-0.04	0.041±0.026 BDL*-0.06
NO ₃ -N (mg/L)	BDL*	0.26±0.19 0.05-0.45	BDL*	BDL*
PO ₄ -P (mg/L)	0.46±0.70 BDL*-1.27	BDL*	0.11±0.07 BDL*-0.16	0.035±0.04 BDL*-0.1
ΣP(mg/L)	2.04±2.32 0.28-5.21	1.64±0.54 0.3-1.38	0.42±0.26 0.13-0.69	0.32±0.16 0.15-0.5
Ca (mg/L)	29.27±4.01 24.06-33.68	56.13±8.73 17.64-38.49	29.007±3.71 24.6-32.08	31.27±4.62 27.27-35.28
Mg (mg/L)	21.14±4.44 15.55-26.24	34.98±6.49 8.74-23.23	21.38±5.32 14.58-27.21	23.81±7.54 14.58-32.07
Total Hardn.	135.33±23.37 113-167.25	261.76±38.48 94.52-170.44	146.38±25.93 118.76-174.64	152.39±22.47 118.76-165.80

Table 2. Species frequency (%) and distributions according to stations

	Sta 1	Sta 2	Sta 3	Sta 4
Bacillariophyta				
Bacillariophyceae				
<i>Amphora ovalis</i> (Kütz.) Kütz.	50	75	75	75
<i>Cocconeis placentula</i> Ehrenb.	50	50	25	50
<i>Cocconeis placentula</i> var. <i>euglypta</i> (Ehrenb.) Grunov	50	25	-	-
<i>Cymatopleura elliptica</i> (Bréb.) W. Sm.	25	-	25	25
<i>Cymatopleura solea</i> (Bréb.) W. Sm.	-	-	50	-
<i>Cymbella affinis</i> Kütz.	25	100	75	75
<i>Cymbella aspera</i> (Ehrenb.) Cleve	50	25	50	25
<i>Cymbella cistula</i> (Ehrenb.) O. Kirchn.	50	100	50	50
<i>Cymbella helvetica</i> Kütz.	25	25	75	25
<i>Cymbella lanceolata</i> (C. Agardh) C. Agardh	25	50	75	75
<i>Diatoma tenuis</i> C. Agardh	-	-	25	25
<i>Diatoma vulgare</i> Bory	100	100	100	75
<i>Diploneis ovalis</i> (Hilse) Cleve	25	25	25	25
<i>Encyonema leibleinii</i> (C. Agardh) W. J. Silva <i>et al.</i>	25	50	-	-
<i>Encyonema minutum</i> (Hilse) D. G. Mann	100	75	100	100
<i>Encyonema silesiacum</i> (Bleisch) D. G. Mann	25	75	50	50
<i>Epithemia adnata</i> (Kütz.) Bréb.	50	50	50	75
<i>Epithemia sorex</i> Kütz.	50	100	75	100
<i>Fragilaria acus</i> (Kütz.) Lange-Bert.	25	25	-	-
<i>Gomphonema acuminatum</i> Ehrenb.	-	25	-	-
<i>Gomphonema parvulum</i> (Kütz.) Kütz.	25	75	50	50
<i>Gomphonema truncatum</i> Ehrenb.	25	50	-	25
<i>Gyrosigma acuminatum</i> (Kütz.) Rabenh.	25	-	-	-
<i>Gyrosigma attenuatum</i> (Kütz.) Rabenh.	50	25	25	25
<i>Halamphora venata</i> (Kütz.) Levkov	50	25	-	-
<i>Navicula</i> sp.	25	-	-	-
<i>Navicula capitatoradiata</i> H. Germ.	50	75	75	75
<i>Navicula cari</i> Ehrenb.	75	75	75	100
<i>Navicula cincta</i> (Ehrenb.) Ralfs	25	25	-	-
<i>Navicula radiosa</i> Kütz.	25	75	25	75
<i>Nitzschia palea</i> (Kütz.) W. Sm.	50	100	75	25
<i>Nitzschia sigmoidea</i> (Nitzsch) W. Sm.	-	25	-	-
<i>Rhicosphenia abbreviata</i> (C. Agardh) Lange-Bert.	50	25	50	75
<i>Rhopalodia gibba</i> (Ehrenberg) O. Müll.	-	50	75	75
<i>Rhopalodia gibba</i> var. <i>minuta</i> Kramm.	-	50	75	25
<i>Ulnaria ulna</i> (Nitzsch) Compère	100	100	100	75
Coscinodiscophyceae				
<i>Melosira varians</i> C. Agardh	-	50	25	-
Charophyta				
Conjugatophyceae				
<i>Closterium</i> sp.	-	-	25	-
<i>Cosmarium obtusatum</i> (Schmidle) Schmidle	25	25	-	-
<i>Spirogyra</i> sp.	25	-	-	0
<i>Staurastrum</i> sp.	-	25	-	0
Chlorophyta				
Chlorophyceae				
<i>Acutodesmus acuminatus</i> (Lagerh.) Tseranko	25	25	-	-
<i>Desmodesmus communis</i> (E.H. Hegew.) E.H. Hegew.	75	75	50	50
<i>Monactinus simplex</i> (Meyen) Corda	-	25	25	-
<i>Monactinus simplex</i> var. <i>echinulatum</i> (Wittr.) Pérez <i>et al.</i>	-	25	-	-
<i>Pseudopediastrum boryanum</i> (Turpin) E.H. Hegew.	25	50	25	25
<i>Pseudopediastrum boryanum</i> var. <i>longicorne</i> (Reinsch)	25	-	50	25
<i>Scenedesmus obtusus</i> Meyen	25	-	-	-
<i>Stauridium tetras</i> (Ehrenb.) E. H. Hegew.	50	-	25	50
Cyanobacteria (Cyanophyta)				
Cyanophyceae				
<i>Merismopedia tenuissima</i> Lemmerm.	-	25	25	25
<i>Oscillatoria tenuis</i> C. Agardh ex Gomont		25		

the study region (Figure 2).

According to Shannon Wiener (H') and Simpson (D) diversity indices, biological diversity values were determined in the channel and lake. The lowest

diversity (H': 2.4 and D: 0.75) was observed in winter season while the highest diversity (H':4.1 and D:0.93) was determined in summer season in the channel. Biological diversity values were not found

seriously different among stations in the lake. However the highest biodiversity (H' : 3.85 and D :0.89) was determined in the summer and the lowest biodiversity (H' : 2.15 and D :0.57) was detected in the spring season in the lake (Table 3). Negative important correlation were found between biodiversity and individual numbers ($r_s = -0.594$ $P < 0.05$ for Shannon Wiener; $r_s = -0.545$ $P < 0.05$ for Simpson). Similarity between the stations was investigated by using Sorensen's similarity index, and the highest similarity was determined between stations 3 and 4 (94%) for dynamics of epilithic algae (Figure 3).

The water quality of Lake Kovada and Kovada Channel was found to be unpolluted (class I) based on Klee's (1991) method. According to Regulation on the Management of Surface Water Quality in Turkish station 3 and station 4 are polluted (class III) in all seasons while station 1 in spring

and in autumn, station 2 in summer and in autumn. Saprobi Index values showed variation among the stations and seasons (Table 4). The water quality class of Kovada Channel was found to be moderate pollution in the autumn while slightly polluted in other seasons. Biological water quality of Lake Kovada was found slightly polluted (class I-II) in spring (in the stations 2 and 3), in winter (in the stations 2 and 4) and in autumn (station 4) seasons, while moderate polluted (class II) in summer (station 2), and autumn (stations 2 and 3). When the Saprobi Index values of the channel increased, similarly an increase also detected in the lake (Figure 4).

The relationships between water temperature, pH, dissolved oxygen, nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), total phosphorus (TP), orthophosphate (PO_4-P), and the abundance of dominant species were explored using the statistical method of Canonical Correspondence Analysis

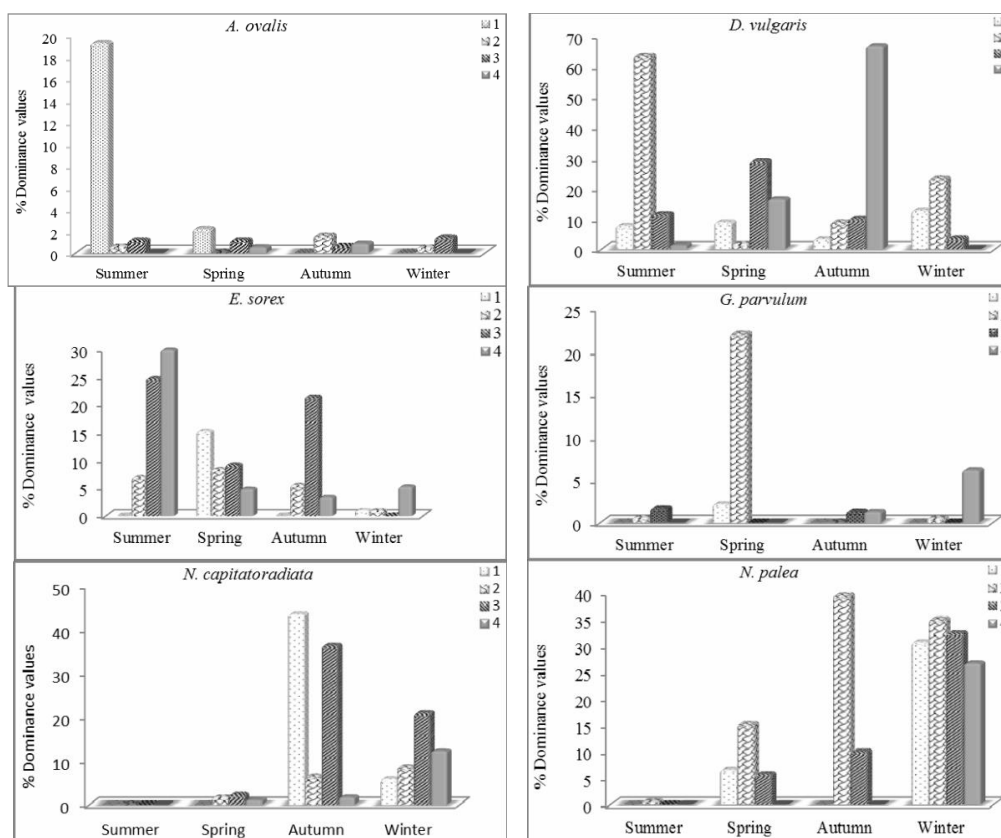


Figure 2. Distributions of some dominant taxa according to seasons.

Table 3. Shannon Wiener (H') and Simpson (D) Diversity Index values of the stations

Seasons	St 1		St 2		St 3		St 4	
	H'	D	H'	D	H'	D	H'	D
Summer	4,16	0,93	2,66	0,62	3,85	0,89	3,59	0,87
Autumn	2,68	0,76	3,45	0,81	2,97	0,80	2,51	0,62
Winter	2,45	0,75	2,87	0,82	2,51	0,78	3,06	0,84
Spring	4,07	0,92	3,52	0,88	2,15	0,57	2,23	0,63

(CCA). According to CCA, the first and second axis were explained %64.9 of total variance (Table 5). Dissolved oxygen, $\text{NO}_3\text{-N}$, total hardness, water temperature, pH, conductivity and Cl^- parameters positively correlated with first axis while $\text{PO}_4\text{-P}$ and $\text{NH}_4\text{-N}$ were negatively correlated. Distribution of *D. vulgare*, *E. adnata*, *E. sorex*, *R. abbreviata*, *C. cistula*, *S. quadricauda* and *R. gibba* were positively related with temperature, total hardness, dissolved oxygen, conductivity, pH, $\text{NO}_3\text{-N}$, Cl^- . However $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$ negative affected to distribution of these species. *C. cistula* and *R. abbreviata* were positively correlated with temperature and total hardness yet negatively correlated with $\text{PO}_4\text{-P}$ and $\text{NH}_4\text{-N}$. Temperature was determined as the most effective factor for these taxa. *D. vulgare* was positively

correlated with dissolved oxygen, temperature, total hardness and $\text{NO}_3\text{-N}$ and the most effective parameters were dissolved oxygen and total hardness. *E. sorex* was positively affected with pH, furthermore *S. communis* closely related to this parameter. According to secondary axes, $\text{PO}_4\text{-P}$ was positively related to distributions of *U. ulna* and *N. cari* whereas temperature, total hardness were negatively related to these taxa (Figure 5).

Discussion

In this study, water temperature ranged between 3.2°C and 23.7°C at the stations as mentioned above. Water temperature is one of the important parameters affecting distribution of organisms in

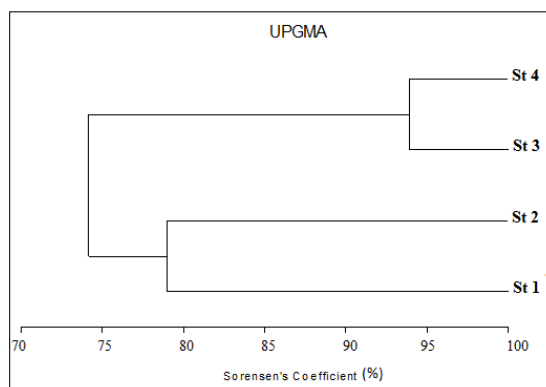


Figure 3. UPGMA dendrogram for four stations.

Table 4. Physicochemical and biological water quality classes according to seasons and stations

	St 1			St 2			St 3			St 4		
	SI	Kle e	WPC R	SI	Kle e	WPC R	SI	Kle e	WPC R	SI	Kle e	WPC R
Summer	I-II	I	II	II	I	III	I	I	III	I	I	III
Autumn	II	I-II	III	II	I	III	II	I	III	I-II	I	III
Winter	I-II	I-II	II	I-II	I	II	II	I	III	I-II	I	III
Spring	I-II	I	III	I-II	I	III	I-II	I	III	I	I	III
Mean	II	I	III	I-II	I	III	I-II	I	III	I	I	III

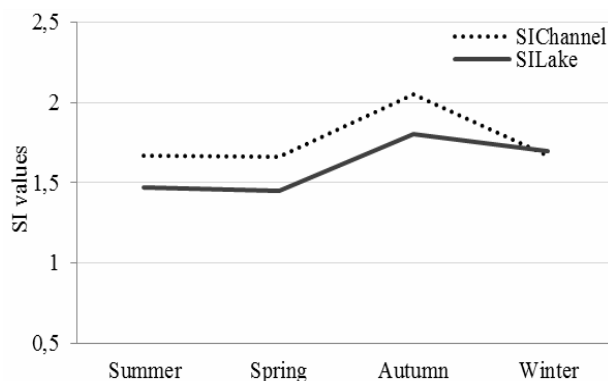


Figure 4. Saprobi Index values in Lake Kovada and its channel.

aquatic ecosystems. Lake temperature changes according to lake surface area, depth, absorbed solar energy, and seasons (Tanyolaç, 2011; Egemen, 2000; Cirik & Cirik, 2008). Zeybek (2012) reported that water temperature showed an alteration seasonally in the Lake Kovada and its channel. The maximum pH value was 10.21 in autumn while the minimum was 6.98 in winter. In aquatic systems pH is closely associated with especially dissolved CO₂ level in water. pH of freshwater lakes is generally ranging between 6 and 9 (Tanyolaç, 2011; Wetzel & Likens, 2000). According to the pH values, Lake Kovada and its channel have alkaline characteristic. Similar results emphasized in other studies related to Lake Kovada (Gülle, 1999; Zeybek, Kalyoncu, & Ertan, 2013). The minimum dissolved oxygen value was determined in autumn while the maximum value was in winter. The maximum dissolved oxygen was measured as 13.45 mg L⁻¹ at station 4, and the minimum value as 2.3 mg L⁻¹ at station 1. Yüce and Ertan (2014) reported that value of dissolved oxygen was ranged from 1.8 to 25.7 mg/l in the channel while Zeybek *et al.* (2013) stated that the lowest dissolved oxygen was determined as 2.63 mg/l. The highest conductivity (304.2 µS/cm) was determined at station 2, in the connection area of the water of channel and lake, in autumn. Zeybek *et al.* (2013) reported that the highest conductivity was detected in Kovada Channel. Cl⁻ values were determined between 6.2 in autumn, and 35.5 mg L⁻¹ in

summer. The highest value was detected in the lake. Yüce (1999) mentioned that mean value of Cl⁻ was 22.69 mg/l in Lake Kovada. The NH₄-N, NO₃-N, NO₂-N, PO₄-P and ΣP mg L⁻¹ values were measured trace quantities generally. PO₄-P and ΣP values increase in channel while the others in lake. Total phosphor determines productivity in aquatic systems (Wetzel, 2001). In water body 0.1 mg L⁻¹ phosphor concentration is measure of water quality for eutrophication (Egemen, 2000). This result showed that the channel was affected by organic pollution. This situation probably arised from waste of cold storage depots and cultivated areas. A study related to determination of trophic status was informed that the channel was hypereutrophic according to total phosphor (Zeybek, Kalyoncu, & Ertan, 2012). In the clean waters NO₂-N is found in trace quantities or is absent while in polluted waters with organic matter reaches high concentrations (Girgin & Kazancı, 1994). The highest NO₂-N was determined between BDL-0.046 mg L⁻¹ in winter. NO₃-N should be less from 1 mg L⁻¹ (Anonymous, 1997). During the research period the highest NO₃-N was determined as 0.19 mg L⁻¹.

Bacillariophyta comprised the predominant group in the epilithic community. In the studies related to benthic algae in lakes similar results were notified (Şahin & Akar, 2005; Pala & Aker 2014; Yüce & Gönülol 2016). *Epithemia sorex* Kütz., *Navicula capitatoradiata* H. Germ., *Nitzschia palea*

Table 5. The results of canonical correspondence analysis

Axes	1	2	3	4	Total inertia
Eigenvalues :	0.249	0.097	0.065	0.041	0.693
Species-environment correlations :	0.955	0.988	0.953	0.963	
Cumulative percentage variance of species data :	35.9	50.0	59.4	65.4	
of species-environment relation:	46.7	64.9	77.2	84.6	
Sum of all eigenvalues			0.693		
Sum of all canonical eigenvalues			0.534		

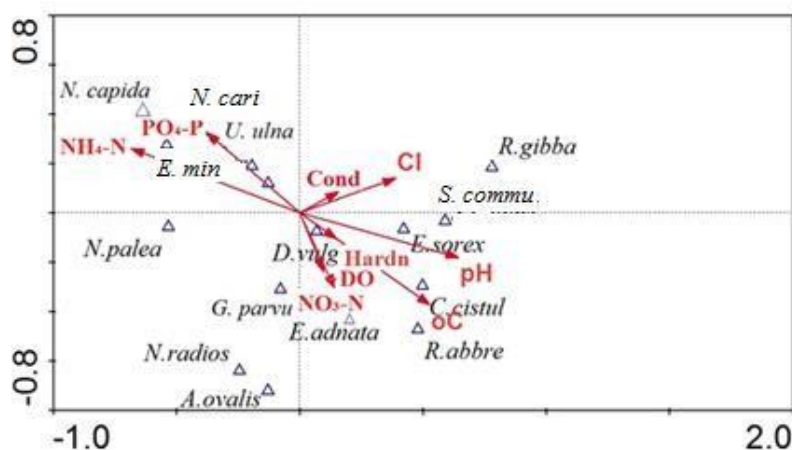


Figure 5. Ordination diagram of the CCA analysis.

(Kütz.) W. Sm., *Diatoma vulgare* Bory, *Gomphonema parvulum* (Kütz.) Kütz., *Diatoma tenuis* C. Agardh were determined as dominant taxa. Şahin (2002) reported that *C. minuta* (*E. minutum*) was the most common taxa in Yedigöller. In a study conducted in Palandöken Pond *Nitzschia palea*, *Synedra ulna* (*U. ulna*), *Epithemia sorex*, *Cymbella minuta*, *Gomphonema parvulum* were reported as dominant and constant taxa of epilithic flora (Gürbüz, 2000). Mean values of Shannon Wiener and Simpson diversity indices were lowest in winter. The highest epilithic algae density was determined in this season which was caused by the increase of *N. palea*. This taxa was dominant in all stations in winter season. Negative important correlation was found between biodiversity and individual numbers ($r_s = -0.594$ $P < 0.05$ for Shannon Wiener; $r_s = -0.545$ $P < 0.05$ for Simpson). When total cell number increase, caused by dominant taxa, diversity index values decrease (Coelho, Gamito, & Pe' rez-Ruzafa, 2007; Sevindik, Altunal, & Küçük, 2015). The highest diversity values (Shannon Wiener and Simpson diversity index) were found in station 1 (Kovada Channel). Zeybek *et al.* (2013) reported that the highest biodiversity values based on oligochaetes and chironomids was determined in also Kovada Channel. According to Sørensen's similarity index, the highest similarity was detected between station 3 and station 4 (%94), and the lowest similarity (0.73 %) between station 2 and station 4. According to Klee's method (1991), physicochemical water quality was determined unpolluted (class I) in Lake Kovada and its channel while according to Regulation on the Management of Surface Water Quality in Turkish polluted (class III). Biological water quality was found moderately polluted (class II) in Kovada Channel, and slightly polluted (class I-II) in Lake Kovada. In Lake Kovada and its channel Saprobic Index values increased in autumn.

In the CCA diagram *E. sorex* occurred near the pH vector. When pH values were high, individuals of this taxa were dominant. *E. adnata* positively correlated with the $\text{NO}_3\text{-N}$, dissolved oxygen, temperature, pH. Yüce and Gönülol (2016) reported that *E. adnata* become dominant taxa when pH values increased. *R. abbreviata* positively correlated with the total hardness and temperature, while showed negative correlation with $\text{PO}_4\text{-P}$ and $\text{NH}_4\text{-N}$. Veraat, Romani, Tornés and Sabater (2008) mentioned that nutrient enrichment caused increase of these taxa. *D. vulgare* occurred near the dissolved oxygen, temperature, total hardness and $\text{NO}_3\text{-N}$. *D. vulgare* was dominant in summer and autumn. It was reported that this species is able to grow fastly better light and nutrient conditions (Snoeijs, 1990). Dönmez and Maraşlıoğlu (2016) emphasized that temperature affected the seasonal variations and the density of epilithic diatoms. *U. ulna* and *N. capitatoradiata* positively correlated with $\text{PO}_4\text{-P}$ and $\text{NH}_4\text{-N}$. Palmer (1969) reported that *Navicula* was

tolerant to organic pollution and includes pollution-resistant diatom. *U. ulna* was the most tolerant taxa to organic matter concentration increase (Lange-Bertalot, 1979; Gómez, 1998). Consequently we can say that Kovada Channel and Lake Kovada were under the pollution effect, and especially Lake Kovada was negatively influenced from the pollution of the channel. As a result of CCA analysis, the distribution of the benthic algae were closely correlated particularly with variations in dissolved oxygen, total hardness, temperature, pH, $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, and $\text{PO}_4\text{-P}$.

Acknowledgements

This research has been supported by The Scientific and Technological Research Council of Turkey (TUBITAK-2209-A). We are deeply grateful to them for their financial support.

References

- Althouse, B., Higgins, S. & Vander Zanden, M.J. (2014). Benthic and planktonic primary production along a nutrient gradient in Green Bay, Lake Michigan, USA. *Freshwater Science*, 33(2), 487-498. <http://dx.doi.org/10.1086/676314>
- Anonymous (1997). EPA (United States Environmental Protection Agency), Volunteer stream monitoring: a methods manual. Retrieved from <https://www.epa.gov/aboutepa/about-office-water#wetlands>.
- Anonymous (2012). Regulation on the Management of Surface Water Quality in Turkish. Ministry of Environment and Forestry (Turkey) Official Gazette 28483, Ankara.
- Anonymous (2014). Lake Assessment Method Macrophytes and Phytobenthos-Diatoms for Assessing River and Lake Ecological Quality (Lake DARLEQ2). Water Framework Directive-United Kingdom Technical Advisory Group (WFD-UKTAG), Scotland, 20 p.
- Anonymous (2016). Ministry of Environment and Forestry Turkey. Retrieved from <http://www.milliparklar.gov.tr/mp/kovadagolu/index.htm>
- Arslan, N. & Şahin, Y. (2006). A Preliminary Study on the Identification of the Littoral Oligochaete (annelida) and Chironomidae (diptera) Fauna of Lake Kovada, a National Park in Turkey. *Turkish Journal of Zoology* 30, 67-72.
- Atalık, A. (2006). Küresel Isınmanın Su Kaynakları ve Tarım Üzerine Etkileri. *Bilim ve Ütopya*, 139, 18-21.
- Barlas, M. (1995). Akarsu Kirlenmesinin Biyolojik ve Kimyasal Yönden Değerlendirilmesi ve Kriterleri. Doğu Anadolu Bölgesi I. ve II. Su Ürünleri Sempozyumu (pp 465-479), Erzurum, Turkey.
- Bennion, H., Burgess, A., Juggins, S., Kelly, M., Reddihough, G., & Yallop, M. (2012). Assessment of Ecological Status in UK Lakes Using Diatoms. Bristol, UK, *Environment Agency Press*, 36 pp.
- Bourlily, P. & Couté, A. (1991). Desmidiées de Madagascar (Chlorophyta, Zygothryceae). *Bibliotheca Phycologica*, Band 86, Berlin-Stuttgart, 348 pp.
- Brummitt R. K. & Powell C. E. (1992). Authors of Plant Names. A list of authors of scientific names of Plants, with recommended standard forms of their names,

- including abbreviations. Royal Botanic Gardens, Kew, Archives of Natural History Press, 732 pp.
- Cirik, S. & Cirik, Ş. (2008). Limnoloji (Ders Kitabı). İzmir, Türkiye, Ege Üniversitesi Su Ürünleri Fakültesi Yayınları, 166 pp.
- Coelho, S., Gamito, S. & Pe' rez-Ruzafa, A. (2007). Trophic state of Foz de Almargem Coastal Lagoon (Algarve, South Portugal) Based on the Water Quality and the Phytoplankton Community. *Estuarine, Coastal and Shelf Science*, 71, 218-231.
- Dodson, S.I., Arnott, S.E. & Cottingham, K.L. (2000). The Relationship in Lake Communities Between Primary Productivity and Species Richness. *Ecology*, 81(10), 2662-2679. <http://dx.doi.org/10.2307/177332>
- Dönmez, M. A. & Maraşlıoğlu, F. (2016). Littoral Epilithic Algae of the Ondokuz Mayıs University Pond I (Samsun/Turkey). *Ekoloji*, 25, (98), 61-64. <http://dx.doi.org/10.5053/ekoloji.2015.26>
- Egemen, Ö. (2000). Environment and Water Pollution. İzmir, Turkey, E.Ü. Faculty of Fisheries Journals Press, 120 pp.
- Garrido A.B., Romo, S. & Villena, M.J. (2013). Diatom Species Composition and Indices for Determining the Ecological Status of Coastal Mediterranean Spanish Lakes. *Anales Der Jardín Botánico de Madrid*, 70(2),122-135. <http://dx.doi.org/10.3989/ajbm.2373>
- Girgin, S., & Kazancı, N. (1994). Ankara Çayı'nda Su Kalitesinin Fiziko-kimyasal ve Biyolojik Yöntemlerle Belirlenmesi, Türkiye İç Suları Araştırma Dizisi I. Ankara, Türkiye. Özyurt Matbaası, 184s.
- Gómez, N. (1998). Use of Epipellic Diatoms for Evaluation of Water Quality in the Matanza-Riachuelo (Argentina), a Pampean Plain River. *Water Research*, 32 (7):2029-2034 pp.
- Gönüloğlu, A., & Obalı, O. (1986). Phytoplankton of Karamık Lake (Afyon), Turkey. Communications Faculty of Sciences University Series V, Ankara, 4, 105-128.
- Gönüloğlu A. (2016). Turkishalgae Electronic Publication, Samsun, Turkey. Retrieved from <http://turkiyealgleri.omu.edu.tr>
- Greenberg A.E., Connors, J.J., Jenkins, D., & Franson, M.A.H. (2005). Standard Methods for the Examination of Water and Wastewater, APHA, AWWA, WPCF. Washington, ABD. American Public Health Association press, 1134 p.
- Guiry, M.D., Guiry, G.M. (2016). AlgaeBase. World-Wide Electronic Publication, National University of Ireland, Galway. Retrieved from <http://www.algaebase.org>
- Güler, D. (2003). Su kalitesi araştırmalarında hidrobiyolojik ve mikrobiyolojik metodlar. Türkiye'nin kıta içi su kaynaklarında kirlilik etkileri ve çözüm önerileri bildiriler. İçme Suyu ve Kanalizasyon Dairesi Başkanlığı. Ankara, Türkiye, 263 pp.
- Gülle, İ. (1999). Kovada Gölü Zooplanktonunun Sistematik ve Ekolojik Yönden Araştırılması. (Master's thesis). Süleyman Demirel Üniversitesi, Isparta, Türkiye
- Gürbüz, H. (2000). A Quantitative and Qualitative Study on the Benthic Algal Flora of Palandöken Pond. *Turkish Journal Biology*, 24,31-48.
- Hustedt, F. (1985). The Pennet Diatoms. Koenigstein, Germany, Koeltz Scientific Books, 905s.
- John, D.M., Whitton, B.A., & Brook, A.J. (2005). The Freshwater Algal Flora of the British Isles, An Identification Guide to Freshwater and Terrestrial Algae. Cambridge, UK, *Cambridge University Press*, 694 pp.
- Kalyoncu, H. & Barlas, M. (1997). Isparta Deresi'nde Yoğun Olarak Belirlenen Epilithic Diatomların Su Kalitesine Bağlı Olarak Mevsimsel Gelişimleri. IX. Ulusal Su Ürünleri Sempozyumu (pp. 310-324), Eğirdir, Isparta, 474 pp.
- Kalyoncu H., Barlas M., Ertan O.Ö. & Gülboy H. (2004). Ağlasun Deresi'nin Su Kalitesinin Fizikokimyasal Parametrelere ve Epilithic Algelerine Göre Belirlenmesi. Eğirdir Su Ürünleri Fakültesi Dergisi, 2(7),7-14.
- Kalyoncu, H. (2006). Determination of Water Quality in Isparta Stream According to Physiochemical Parameters and Epilithic Diatoms. Süleyman Demirel University Journal of Natural and Applied Sciences, 1(1),14-25.
- Kalyoncu, H. & Şerbetçi, B. (2013). Applicability of Diatom-Based Water Quality Assessment Indices in Dari Stream, Isparta/Turkey. *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering*, 7(6), 386-394
- Kazancı, N., Girgin, S., Dügel, M. & Oğuzkurt, D. (1997). Akarsuların Çevre Kalitesi Yönünden Değerlendirilmesinde ve İzlenmesinde Biyolojik İndeks Yöntemi. Türkiye İç Suları Araştırma Dizisi:II. Ankara, Türkiye, İmaj yayınevi, 100 s.
- Kelly, M. & Whitton B. A., (1995). The Trophic Diatom Index: a new index for monitoring eutrophication in rivers. *Journal of Applied Phycology*, 7(4), 433-444.
- Klee, O. (1991). *Angewandte Hydrobiologie*. 2. neubearbeitete und erweiterte Auflage, G. Theieme Verlag, Stuttgart-New York, 272 pp.
- Kocataş, A. (2006). Ekoloji ve Çevre Biyolojisi. İzmir, Türkiye, Ege Üniversitesi Su Ürünleri Fakültesi Yayınları, 597 pp.
- Komárek, J. (2008). Cyanoprokaryota 2. Teil: Oscillatoriales. Germany, Spectrum Akademischer Verlag Heidelberg, 759 pp.
- Komárek, J. (2000). Cyanoprokaryota 1. Teil: Chroococcales Süßwasserflora Von Mitteleuropa Band 19/1, Cyanoprokaryota 1. Teil: Chroococcales. Berlin, Spectrum Akademischer Verlag Heidelberg, 548 pp.
- Kovach, W.L. (2002). MVSP-a Multivariate Statistical Package for Windows, ver. 3.21., Wales UK.
- Krammer, K. & Lange-Bertaloth, H. (1986). Bacillariophyceae. 1. Teil: Naviculaceae. In: Ettl H., Gerloff J., Heynig H. & Mollenha Uer d. (Eds.) Süßwasser flora von Mitteleuropa, Band 2/1. Gustav Fischer Verlag: Stuttgart, New York, 876 pp.
- Krammer, K. & Lange-Bertaloth, H. (1988). Bacillariophyceae. 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. In: Ettl H., Gerloff J., Heynig H. & Mollenha Uer d. (Eds.) Süßwasserflora von Mitteleuropa, Band 2/2. VEB Gustav Fischer Verlag: Jena, 596 pp.
- Krammer, K. & Lange-Bertaloth, H. (1991a). Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. In:Ettl H., Gerloff J., Heynig H. & Mollenha Uer d. (Eds.) Süßwasserflora von Mitteleuropa, Band 2/3. Gustav Fischer Verlag: Stuttgart, Jena, 576 pp.
- Krammer, K. & Lange-Bertaloth, H. (1991b). Bacillariophyceae. 4. Teil: Achnantheaceae, Kritische Ergänzungen zu Navicula (Lineolatae) und Gomphonema, Gesamtliteraturverzeichnis Teil1-4. In: Ettl H., Gerloff J., Heynig H. & Mollenha Uerd. (Eds.) Süßwasserflora von Mitteleuropa, Band 2/4. Gustav Fischer Verlag: Stuttgart, Jena, 437 pp.

- Kristensen, P. & Hansen, H.O. 1994. European Rivers and Lakes, A sssessment of their Environmental State. EEA Environmental Monographs 1. Silkeborg, Denmark, European Environment Agency, *Silkeborg Bogtryk Press*, 124 pp.
- Lange-Bertalot, H. (1979). Pollution and tolerance of diatoms as criterion of water quality estimation. *Nova Hedwigia*, 64, 285-304.
- Lirika, K., Aleko M., & Alqi Ç. (2011). Evaluation of Trophic and Saprobic Diatom Index in Albanian Rivers. *Journal International Environmental Application & Science*, 6(5), 692-698.
- Lirika K., Alma, I., Magdalena, C. & Dashnor K. (2013). Use of Diatom and Macrophyte Index to Evaluate the Water Quality in Ohrid Lake. *Journal of the Faculty of Engineering and Architecture of Gazi University*, 28(2), 393-400.
- Pala, G. & Aker, Y.E. (2014). Pınarbaşı Göleti (Elbistan, Kahramanmaraş)'nin Planktonik ve Bentik Alglerinin Araştırılması. *Fırat Üniv. Fen Bilimleri Dergisi*, 26(2), 105-113.
- Palmer, M.C. (1969). A Composite Reating of Algae Toleranting Organic Pollution. *Journal of Phycology*. 5(1), 78-82. <http://dx.doi.org/10.1111/j.1529-8817.1969.tb02581.x>
- Palmer, C.M. (1980). *Algae and Water Pollution*. England, TonbridgePrinters, 123 pp.
- Pestalozzi, H.G. (1955). *Das Phytoplankton Des Süßwassers Band XVI, 4. Teil; Euglenophyceen*, 606p.
- Pestalozzi, H.G. 1968. *Das Phytoplankton Des Süßwassers, Band XVI, 1. Teil, Cyanophyta*, Germany. 251 pp.
- Pestalozzi, H.G. (1982). *Das Phytoplankton Des Sußwassers 8. Teil, 1. Hälfte, Conjugatophyceae; Zygnematales und Desmidiales*, Germany, 542 pp.
- Pestalozzi, H.G. (1983). *Das Phytoplankton Des Süßwassers 7. Teil: 1. Hälfte, Chlorophyceae; Chlorococcales*, Germany.513 pp.
- Prescott, G.W. (1973). *Algae of Western Great Lake Area*. Fifth printing. Germany, 965 pp.
- Prescott, G.W. (1978). *How to know the freshwater algae*. Third Edition. United States of America, 293 pp.
- Rott, E., Hofmann, G., Pall, K., Pfister, P. & Pipp, E. (1997). *Indikations listen für Aufwuchsalgen. Teil 1: Saprobielle Indikation*. Bundesministerium für Land- und Forstwirtschaft (Hrsg. u. Verlag), *Wasserwirtschaftskataster*, Wien.
- Round, F.E. (1953). An Investigation of Two Benthic Algal Communities in Malharm Tarn, Yorkshire. *J. Ecol.*, 41,174-197. <http://dx.doi.org/10.2307/2257108>
- Sadro, S., J., Melack M. S., & MacIntyre, S. (2011). Spatial and temporal variability in the ecosystem metabolism of a highelevation lake: integrating benthic and pelagic habitats. *Ecosystems*, 14, 1123–1140. <http://dx.doi.org/10.1007/s10021-011-9471-5>
- Sevindik, T.O., Altunal, E. & Küçük, F. (2015). The Seasonal and Spatial Distribution of the Phytoplankton of a Mesotrophic Lake Related to Certain Physical and Chemical Parameters. *Ekoloji*, 24(97),14-23. <http://dx.doi.org/10.5053/ekoloji.2015.09>
- Snoeijs, P.J.M. (1990). Effects of Temperature on Spring Bloom Dynamics of Epilithic Diatom Communities in the Gulf of Bothnia. *Journal of Vegetation Science*, 1,599-608.
- Solak, C.N., Barinova, S., Ács, É. & Dayioğlu H. (2012). Diversity and Ecology of Diatoms from Felent Creek (Sakarya river basin), Turkey. *Turk. J. Bot.*, 36,191-203. <http://dx.doi.org/10.3906/bot-1102-16>
- Şahin, B. (2002). Epipellic and Epilithic Algae of the Yedigöller Lakes (Erzurum-Turkey). *Turkish Journal of Biology*, 26,221-228.
- Şahin, B. & Akar, B. (2005). Epipellic and Epilithic Algae of Küçükgöl Lake (Gümüşhane-Turkey). *Turkish Journal Biology*, 29, 57-63.
- Tanyolaç, J. (2011). *Limnoloji*. Ankara, Türkiye, Hatiboğlu Yayınları, 290 pp.
- Ter Braak & Šmilauer, P. (2002). *CANOCO refence manual and CanocoDraw for Windows user's guide:software to canonical community ordination (version 4,5)*. Microcomputer Power, New York.
- Vadeboncoeur, Y., Peterson, G., Vander Zanden, M.J. & Kalff, J. (2008). Benthic Algal Production Across Lake Size Gradients: Interactions Among Morphometry, Nutrients, and Light. *Ecology*, 89, 2542–2552.
- Veraat, A.J., Romani A.M., Tornés E. & Sabater S. (2008). Algal response to Nutrient enrichment in forested oligotrophic stream. *Journal of Phycology* 44, 564–572. <http://dx.doi.org/10.1111/j.1529-8817.2008.00503.x>
- Vogel, A. (2004). *Diatomeenaufwuchs Auf Historischen Herbarbelegen Als Indikator Der Ehemaligen Wasserqualität Von Fließgewässern (PhD Thesis)*, München, Germany
- Wetzel, R.G. & Likens, G.E. (2000). *Limnological Analyses, Third Edition*. New York, *Springer-Verlag Inc.*, 429 pp.
- Wetzel, R.G. (2001). *Limnology. Lake and River Ecosystems*. 3rd. Ed. San Diego, Academic Press, 1006p.
- Whitton, B.A. & Kelly, M.G. (1995). Use of algae and other plants for monitoring rivers. *Aust. J. Ecol.*, 20, 45-56.
- Yüce, A. (1999). *Kovada Gölü ve Kanalı Alglerinin Taksonomik ve Ekolojik Yönden İncelenmesi*, PhD thesis, Süleyman Demirel Üniversitesi, Isparta, Turkey
- Yüce, M.A. & Ertan, Ö.O. (2014). *Kovada Channel Phytoplankton (Isparta- Turkey)*. *Journal of Biological and Environmental Sciences*, 8(24), 165-171.
- Yüce M.A. & Gönüloğlu A. (2016). Evaluation of the Relationship Between Epiphytic Diatoms and Environmental Parameters with the Canonical Correspondence Analysis (CCA). *Pakistan Journal Botany*, 48(4),1723-1730.
- Zeybek, M. 2012. *Kovada Kanalı ve Bağlantılı Olduğu Göl Sularında Su Niteliğinin Belirlenmesi*, PhD thesis, Süleyman Demirel Üniversitesi, Isparta, Turkey
- Zeybek, M., Kalyoncu, H. & Ertan, Ö O. (2012). The Determination of Trophic Status in Kovada Channel that Connects Lake Eğirdir and Lake Kovada, and in the Region of the Lakes Adjacent to the Channel. *Ege Journal of Fisheries and Aquatic Sciences*. 29(3), 137-141. <http://dx.doi.org/10.12714/egejfas.2012.29.3.06>
- Zeybek, M., Kalyoncu, H. & Ertan, Ö O. (2013). The Effects of Environmental Variables on Distribution of Aquatic Oligochaeta and Chironomide at Kovada Channel and the Linked Lakes (Isparta/Turkey). *Fresenius Environmental Bullutein*. 22(11), 3160-3169.