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Research Article

Diversity and ecology of diatoms from Felent creek (Sakarya river basin), Turkey

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Abstract: Diatoms are an important group of aquatic ecosystems. To date, there have been many important algological studies in different river basins in Turkey. However, the use of diatoms in biomonitoring (according to diatom indices, Watanabe's or Van Dam's systems) is relatively new in Turkey. In the present study, 41 samples of epilithic diatoms were collected from 5 stations along Felent creek between June 2006 and February 2007 and a total of 117 diatom taxa were identified. The bio-indication (autoecology and abundance scores in the communities) of Felent creek was investigated and, as a result, the organic pollution indicators of Watanabe's classification (81 species, 69.2%) constituted 3 groups. The Sládečék's index calculated for each sampling station varied from 1.36 to 2.08 (from oligo- to betamesosaprobic) at stations, and the river pollution index was calculated for each defined environmental variable as well as for species richness and index of saprobity over stations in summer and winter. The river water was alkaline and temperate with low salinity, and there was organic pollution in summer. Species richness was mostly higher in winter than in summer.

Key words: Biomonitoring, diatom, ecological indices, Felent creek, saprobity

Felent çayı (Sakarya nehir havzası) diyatomelerinin çeşitliliği ve ekolojisi

Özet: Diyatomeler, sucul ekosistemlerin önemli bir grubudur. Diyatomelerin biyolojik izleme çalışmalarında kullanımı Türkiye için yenidir. Bu çalışmada, Felent çayı boyunca 5 istasyondan Haziran 2006 ve Şubat 2007 tarihleri arasında toplanan 41 epilitik diyatome örneği incelenmiş ve toplam 117 takson tespit edilmiştir. Felent çayındaki çevresel şartlar diyatomelere bağlı olarak incelenmiş ve organik kirlilik, Watanabe indeksine (81/117 takson, toplam türlerin % 69,2 si) göre üç grupta ele alınmıştır. Yine, Sládečék indeksi hesaplanmış ve indeks değeri 1,36 ile 2,08 arasında yani, oligo- ile betamesosaprobic arasında çıkmıştır. Sonuçta, zengin tür çeşitliliği görülebilir. Ayrıca, RPI (Nehir Kirlilik İndeksi) de hesaplanmıştır. Sonuçta, Felent çayı yaz döneminde alkali özellikte, orta seviyede sıcak, düşük tuzlu ve organik kirlilik yüküne maruz kalmaktadır. Tür çeşitliliği kış döneminde yaz dönemine oranla daha fazladır.

Anahtar sözcükler: Biyolojik izleme, diyatome, ekolojik indeksler, Felent çayı, saprob

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Introduction

Aquatic communities are the first element to be disturbed by modifications in the physical or chemical quality of rivers. The study of aquatic organisms is thus very useful to detect and assess human impacts. The use of several aquatic organisms integrating different time scale variations gives a precise idea of the ecosystem's health (Ector & Rimet, 2005). Diatoms are an important group in water ecosystems; they form a large part of the benthos (often 90%-95%) and that is why they could become an important part of water quality monitoring (Ács et al., 2004).

The diatom communities in similar climatic conditions were studied with respect to seasonal influences of environmental factors of the riverian systems in Greece (Ziller & Montesanto, 2004), Lebanon (Squires & Saoud, 1986), Iran (Atazadeh et al., 2007), Israel (Tavassi et al., 2004; Barinova et al., 2006a, 2006b; Tavassi et al., 2008; Barinova et al., 2010), Georgia (Barinova et al., 2011), Italy (Bona et al., 2007; Dell'Uomo & Torrisi, 2009), Portugal (Almeida, 2001; Feio et al., 2009; Resende et al., 2009), and Spain (Blanco et al., 2007, 2008; Urrea & Sabater, 2009). Bio-indicational approaches for river monitoring by using algal communities were developed in Israel during the last decade (Tavassi et al., 2004; Barinova et al., 2006a, 2006b; Tavassi et al., 2008; Barinova et al., 2010). Numerous phycological investigations have been performed in different Turkish river basins. However, the use of diatoms in biomonitoring (according to diatom indices by OMNIDIA and autoecological indices such as Watanabe's or Van Dam's systems) is relatively new in Turkey (Solak et al., 2011).

Kütahya, which is one of the most important locations in Turkey due to being the vanishing point of different phytogeographical regions (Irano-Turanian, Mediterranean, and European-Siberian), is located at the junction of the Sakarya river basin, in the Inner Anatolian part of the Aegean Region and extends between the south-western edge of an alluvial plain watered by Felent creek, a branch of the River Porsuk. The province is in a transitional zone between the continental climate of the Aegean Region and the temperate climate of the Marmara Region (Çevre & Orman Bakanlığı, 2004).

It is important to know the taxonomic composition of the diatoms of Felent creek, not only because it is one of the most important branches of the Porsuk River, but also because it crosses Kütahya Province. Regarding the algological studies, the Sakarya river basin and other river basins were previously studied by different authors (Yıldız, 1987; Gezerler-Sipal et al., 1994; Yıldız & Özkıran, 1994; Atıcı & Yıldız, 1996; Yıldız & Atıcı, 1996; Atıcı, 1997; Atıcı & Ahıska, 2005; Bingöl et al., 2007; Baykal et al., 2009; Atıcı & Obalı, 2010; Ongun-Sevindik et al., 2010; Solak, 2011). Moreover, the algae and their relationship with some extreme conditions were investigated by different authors (Atıcı et al., 2001; Akbulut & Dügel, 2008). The aim of the present study was to reveal diatom diversity and its relationship to environmental variables in the creek.

Description of the study site

The creek runs for about 35 km from the north-east of Kütahya plain across cultivated areas and through Kütahya Province to the Porsuk River. Industrial and domestic effluents were discharged into the creek. These have affected the river ecosystem and decreased water quality. Felent creek flows through agricultural lands before reaching the province. Domestic, agricultural, and industrial pollutants were the most important problem in the creek.

Materials and methods

Forty-one samples of epilithic diatoms were collected from 5 stations along Felent creek between June 2006 and February 2007. The environmental variables, (temperature, conductivity, and pH) were measured by Lange Hach 40d multi-parameter measurement. Diatoms were collected by scraping from 20 cm^2 area stones and were cleaned by H_2O_2-HCl (Swift, 1967) and then mounted for microscopic observation at a magnification of 1000×. After the slides were prepared, the diatoms were identified according to Krammer and Lange-Bertalot (1986-1991b). Approximately 300 valves were enumerated in each slide to determine the relative abundance of each taxon.

Taxonomy of our research along with the data list published for the last century was adopted under a modern classification system (Guiry & Guiry, 2009). The ecological data analysis of algal species diversity that was performed revealed the grouping of freshwater algae in respect to variables that were taken from the database compiled for freshwater algae (Barinova et al., 2006b). Each group was separately assessed in respect to its bio-indication significance.

The integral river pollution index (RPI) (Sumita, 1986) is based on the pollution estimates for all the sampling stations. The integral indices were calculated according to several environmental variables (Barinova et al., 2006b) as follows:

$$RPI_d = \Sigma\ (Di + Dj) \times l/2L \qquad \text{(Eq. 1)}$$

where Di, Dj are the environmental variables for each of the stations, l is the distance between 2 adjacent stations (km), and L is the total length of the river.

The diatom abundances were assessed on the basis of a 6-score scale (Korde, 1956; Barinova et al., 2006b) (Table 1).

Of several currently used estimates of saprobity, it is the one by Pantle and Buck (1955) modified by Sládečék (1973, 1986) that proved the most suitable for the present analysis because this model covered all possible existing aquatic ecosystems variables and built up a whole system with biological variables. The indicators of saprobity were assigned to 4 groups according to their saprobity index values (S), ranging from polysaprobes (S = 3.5-4.0) to xenosaprobes (S = 0-0.5). Saprobity indices were obtained for each algal community as a function of the number of saprobic species and their relative abundances:

$$S = \Sigma sh\ /\ \Sigma h \qquad \text{(Eq. 2)}$$

Table 1. Species frequency according to the 6-score scale.

Score	Visual estimate	Cell numbers per slide
1	Occasional	1-5
2	Rare	10-15
3	Common	25-30
4	Frequent	1 cell over a slide transect
5	Very frequent	Several cells over a slide transect
6	Abundant	One or more cells in each field of view

where S is index of saprobity for algal community (unitless), s is species-specific saprobity level, and h is the density score of a 5-score scale (Whitton et al., 1991).

The water quality and self-purification zone assessments are based on the ecological classification widely used in European and Asian countries (Romanenko et al., 1990; Whitton et al., 1991; Barinova et al., 2006a). The saprobity was investigated according to Watanabe's system, which described 3 indicator groups: "saproxenes (unpolluted water)", "eurysaprobes (moderately polluted water)", and "polysaprobes (polluted water)" in this system (Watanabe et al., 1986).

Statistical analysis of the relationships of species diversity in algal communities and their environmental variables was performed by Canonical Correspondence Analysis (CCA) with CANOCO for Windows 4.5 package. Statistical significance of each variable was assessed using the Monte Carlo unrestricted permutation test involving 499 permutations (ter Braak, 1990). The CCA biplot represents the overlap of species in relation to a given combination of environmental variables. Arrows represent environmental variables, with the maximal value for each variable located at the tip of the arrow (ter Braak, 1987).

Results and discussion

Regarding the environmental variables, temperature, conductivity, and pH values were measured at the sampling stations. pH values did not show a large fluctuation at each station (Table 2), but temperature and conductivity (E) values were the highest at station F4. This station was especially affected by domestic sewage because of thermal tourism in the summer and also the values were higher at F5 in comparison to the other stations because of the discharge of domestic and industrial wastes in Kütahya Province (Figure 1).

A total of 117 taxa were identified in Felent creek and *Nitzschia* (13) constituted the highest number in the community. This genus was followed by *Navicula* (9), *Cymbella*, and *Gomphonema* (6) (Table 3). Regarding the distribution of taxa at the stations, F5 had the highest number of species, while the other stations had similar numbers (Figure 2).

Table 2. Environmental conditions of Felent creek.

Env. variable	Stations	Distance from the spring (km)	Min	Max	Mean	SD
T (°C)	F1	0	5.6	16.7	12.1	3.9
	F2	5	9.8	16.2	13.0	2.4
	F3	8	10.1	19.7	14.3	3.3
	F4	11	15.9	32.9	24.3	5.8
	F5	34	10.3	22.5	16.2	4.4
pH	F1	0	6.97	8.14	7.38	0.39
	F2	5	6.98	7.63	7.39	0.24
	F3	8	7.22	8.01	7.79	0.19
	F4	11	7.27	8.08	7.53	0.32
	F5	34	7.04	7.51	7.45	0.25
E (μS/cm)	F1	0	539	912	660	132
	F2	5	630	1135	770	160
	F3	8	531	1080	674	172
	F4	11	758	1213	938	152
	F5	34	628	917	814	144

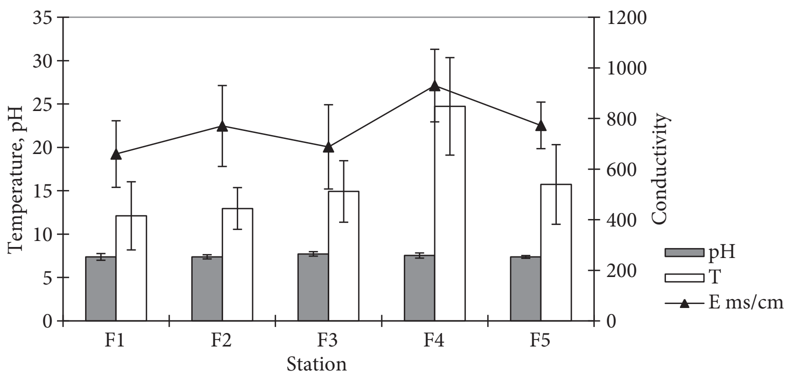


Figure 1. The environmental variables of the stations in Felent creek.

Table 3. Diatom indicators of environments in Felent creek with their autoecology and abundance scores in the communities.

Taxa	Code	F1	F2	F3	F4	F5	Hab	T	Reo	D	Sal	pH	Sap	Htr	Tro
Achnanthes lanceolata var. *rostratiformis* Lange-Bertalot	ACHlan	1	1-2	1-2	1	0	B								
Achnanthidium affine (Grunow) Czarnecki	ACHaff	1	1	1	0	1	B		str	es	i	alf	b		
Achnanthidium exiguum (Grunow) D.B.Czarnecki	ACHexi	0	0	1-5	1-5	0	B	eterm	st-str	sp	i	alf	b	ate	o-e
Achnanthidium minutissimum (Kützing) Czarnecki	ACHmin	3-6	1-5	2	1-2	1-3	B					neu	o-b		
Amphipleura pellucida (Kützing) Kützing	AP001A	1-2	0	0	2	1	B		st		i	alf	a-b	ate	o-m
Amphora ovalis (Kützing) Kützing	AM001A	1-2	1	1-2	1	1-2	B	temp	st-str	sx	i	alf	a-b	ate	e
Amphora pediculus (Kützing) Grunow ex A.Schmidt	XXG982	1-3	1-6	1-4	1-3	1	B	temp	st	sx	i	alf	o-a	ate	e
Anomoeoneis sphaerophora E.Pfitzer	AN009A	0	0	2	1	0	P-B	warm	st-str		hl	alb	x-b	ate	e
Caloneis amphisbaena (Bory de Saint Vincent) Cleve	CLA01Y	0	0	1	1	0	B		st-str		hl	alf	o	ate	e
Caloneis silicula (Ehrenberg) Cleve	CA003A	0	0	1	1	1	B		st	sp	i	alf	x	ats	me
Cocconeis pediculus Ehrenberg	CO005A	1-2	1-2	2-4	1	0	B		st-str	sx	i	alf	o-a	ate	e
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow	CO001B	1	1	1-2	2	2	P-B	temp	st-str	sx	i	alf	b	ate	e
Cocconeis placentula var. *lineata* (Ehrenberg) van Heurck	CO001C	1-3	1	1	2	0	P-B		st-str	sx	i	alf	x-o	ate	e
Craticula accomoda (Hustedt) D.G.Mann	CRA01Y	1	0	1	1	0	P			sp	i		o-a		
Craticula ambigua (Ehrenberg) D.G.Mann	CRA00A	0	0	0	1	1	B	warm	st	es	i	alf	o		
Craticula cuspidata (Kutzing) D.G.Mann	CRAcus	0	0	0	0	1	B	temp	st	es	i	alf	o		
Craticula halophila (Grunow) D.G.Mann	CRATG	1	0	0	0	0	B		st-str	es	mh	alf			
Cyclotella atomus Hustedt	CY011A	0	0	0	0	1-3	P-B		st-str	sp	hl	alf	o	ate	e
Cyclotella meneghiniana Kützing	CY003A	0	1	0	1	1-4	P-B	temp	st	sp	hl	alf	o-a	hne	e
Cyclotella ocellata Pantocsek	CY009A	0	0	0	0	1-5	P-B		st	es	i	ind	o	ats	me
Cyclotella striata (Kützing) Grunow	CYCstr	0	0	0	0	1				es	hl	alf			
Cymatopleura elliptica (Brébisson) W.Smith	CL002A	0	1	1	1	0	P-B		st-str		i	alf	b-o	ate	e
Cymatopleura solea (Brébisson) W.Smith	CL001A	0	1	1	1	0	P-B		st-str		i	alf	o	ate	e
Cymatopleura solea var. *apiculata* (W.Smith) Ralfs	CYMAso	0	1	1-2	1	0	B				i	alf	x-o		
Cymbella affinis Kützing	CM022A	2-6	1	0	1	1	B	temp	st-str	sx	i	alf	b-o	ats	e
Cymbella aspera (Ehrenberg) Cleve	CM005A	0	0	1	0	0	B		st-str	es	i	alf	b-o	ats	o-e
Cymbella helvetica Kützing	CYMhel	0	0	1	0	1	B		str		i	alf	o-a		
Cymbella hungarica (Grunow) Pantocsek	CYMhun	0	0	0	0	1	B						x-o		
Cymbella hustedtii Krasske	CM033A	1	1	1	1	0	B		str		i	alf	o	ats	o-m
Cymbella neocistula Krammer	CYMneo	1	0	0	1	0									
Cymbopleura amphicephala (Nägeli) Krammer	CYMam	0	0	0	0	1	B		str	sx	i	ind	o-b	ats	o-m
Cymbopleura hercynica (A.Schmidt) Krammer	CYMher	1	0	0	1	0	B						o		
Denticula elegans Kützing	DENele	1	0	0	0	1	B				i	alf	o		
Diatoma vulgaris var. *linearis* Grunow	DIAvul	0	1	0	0	0	B		str	es	i	alf	b	ate	me
Diatoma vulgaris var. *ovalis* (Fricke) Hustedt	DIAvuo	0	0	1	0	0	B				i	alf			

Table 3. Continued.

Taxa	Code	F1	F2	F3	F4	F5	Hab	T	Reo	D	Sal	pH	Sap	Htr	Tro
Diatoma vulgaris var. *productum* Grunow	DIAvup	0	2	0	0	0	B		st-str	es	i	alf	o-b	ate	me
Diatoma vulgaris var. *vulgare* Bory	DIAvuv	0	1	1	2	1	P-B		st-str	sx	i	ind	b-a	ate	me
Diploneis oblongella (Nägeli) Cleve-Euler	DP007A	0	0	0	0	1	B		str	sx	i	alf	o-a	ats	
Encyonema minutum (Hilse) D.G.Mann	ENCmin	1	1	1	1	0	B		st-str	sx	i	ind	x-o		
Encyonema prostratum (Berkeley) Kützing	ENCpro	0	0	0	1	1	B			es	i	alb	o-a		
Epithemia adnata (Kützing) Brébisson	EPIadn	0	0	0	0	1	B	temp	st	sx	i	alb	b-a	ats	me
Epithemia argus (Ehrenberg) Kützing	EP003A	0	1	0	0	0	P-B		st-str	es	i	ind	o		m
Fallacia pygmaea (Kützing) A.J.Stickle & D.G.Mann	FP001Y	1	1	1	0	0	B		st-str	es	mh	alb	b-o	hne	e
Fragilaria capucina subsp. *rumpens* (Kützing) Lange-Bertalot	FRAcap	0	0	1	1	0	B		st-str		i	acf	o		o-m
Fragilaria leptostauron var. *dubia* (Grunow) Hustedt	FR014B	1	0	1	1	1-2	B				hb	alf			
Fragilaria parasitica var. *subconstricta* Grunow	FR045E	0	1	0	1	1	Ep		st-str	sx	i	alf	o-b	ats	me
Frustulia vulgaris (Thwaites) De Toni	FU001A	0	1	0	1	1-2	P-B		st	es	i	alf	x-b	ate	me
Geissleria decussis (Østrup) Lange-Bertalot & Metzeltin	GEIsde	0	0	0	0	1	B						b-o		
Gomphonema affine Kützing	GO020A	1	1	0	1	0	P-B		st	es			o-b		
Gomphonema augur Ehrenberg	GO019A	0	1	1	1	1	B		str	es	i	ind	b	ats	me
Gomphonema gracile Ehrenberg	GO004A	1	1	1	1	0	P-B	temp	st	es	i	alf	b-o	ats	m
Gomphonema olivaceum (Hornemann) Brébisson	GO001A	1	1-2	1-5	1-2	1-2	B		st-str	es	i	alf	b-a	ate	e
Gomphonema parvulum (Kützing) Kützing	GO013A	1	1	1	1-2	1-6	B	temp	str	es	i	ind	x	hne	e
Gomphonema truncatum Ehrenberg	GOMtru	1	1	0	0	1-4	P-B		st-str	es	i	alf	o-x	ats	me
Gyrosigma acuminatum (Kützing) Rabenhorst	GY005A	1	0	0	1	1	B	cool	st-str		i	alf	o-x	ate	e
Gyrosigma attenuatum (Kützing) Cleve	GY001A	1	1	1	1	0	P-B		st		i	alf	x	ate	e
Gyrosigma spencerii (J.W.Bailey ex Quekett) Griffith & Henfrey	GYRspe	0	0	1	0	0	B			es	mh	alf	o		
Halamphora veneta (Kützing) Levkov	HALven	1	0	1	1	1	B		st-str	es	i	alf	o	ate	e
Hantzschia amphioxys (Ehrenberg) Grunow	HANamp	0	0	0	1	0	B	temp	st-str	es	i	neu	b-o	ate	o-e
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski	HIPcap	0	1	0	1	1	B	temp	st-str	es	hl	alf	o-b	ate	me
Lemnicola hungarica (Grunow) F.E.Round & P.W.Basson	LEMhun	0	1	0	1	1	B		st	es	mh	alf	o-a	ate	he
Luticola mutica (Kützing) D.G.Mann	LUM01Y	0	1-3	1-5	1-5	1-2	B,S		st-str	sp	i	ind	o	ate	e
Luticola nivalis (Ehrenberg) D.G.Mann	LUTniv	0	0	0	0	1-4	B,S		ae		hl	ind	b		e
Melosira varians C.Agardh	ME015A	2-4	1-5	1-4	1-2	0	P-B	temp	st-str	es	hl	alf	a-b	hne	e
Meridion circulare (Greville) C.Agardh	MR001A	0	0	0	0	1-5	B		str	es	i	alf	o-b	ate	o-e
Navicula angusta Grunow	NA037A	0	0	0	0	1-6	B		str	sx	hl	acf	o	ats	ot
Navicula cari Ehrenberg	NA051A	0	1	0	0	0	P-B			es	i	ind	b-a		o-e
Navicula cincta (Ehrenberg) Ralfs	NA021A	0	1	1	1	0	B	warm	st-str	es	hl	alf	x-o	ate	e
Navicula lanceolata (C.Agardh Ehrenberg	NA009A	1	1-2	1-3	1-4	1	B		st-str	es	i	alf	x-b	ate	e

Table 3. Continued.

Taxa	Code	F1	F2	F3	F4	F5	Hab	T	Reo	D	Sal	pH	Sap	Htr	Tro
Navicula menisculus Schumann	NA030A	1-2	1-2	1	1-2	1-2	B		st-str	es	i	alf	x-b	ate	e
Navicula oblonga (Kützing) Kützing	NA024A	0	1	0	0	0	B		st-str	sx	i	alf	b	ate	e
Navicula radiosa Kützing	NA003A	1	1-3	1-3	1-3	1	B	temp	st-str	es	i	ind	o	ate	me
Navicula tripunctata (O.F.Müller) Bory de Saint-Vincent	NA095A	1-4	0	0	0	1-2	B		st-str	es	i	ind	b	ate	e
Navicula upsaliensis (Grunow) Peragallo	NAVupp	2	0	1	1	1	B			es	i	alf	o		
Neidium binodis (Ehrenberg) Hustedt	NE008A	1-2	0	1	0	0	B		str		i	ind	o	ats	me
Neidium dubium (Ehenberg) Cleve	NEIdub	0	1	0	0	0	B		str		i	alf	x	ats	me
Neidium iridis (Ehrenberg) Cleve	NE001A	0	0	1	0	0	B		st	es	hb	ind	o-x	ats	m
Nitzschia acicularis (Kützing) W.Smith	NI042A	0	3-6	1-5	1-5	1	P-B	temp		es	i	alf	o-b	hce	e
Nitzschia amphibia Grunow	NI014A	1-2	0	0	0	1-6	P-B, S	temp	st-str	sp	i	alf	o	hne	e
Nitzschia capitellata Hustedt	NI028A	1	0	0	0	1-5	B			es	i	alf	o-p		he
Nitzschia commutata Grunow	NI011A	0	1-6	1-2	1-5	0	B				mh				
Nitzschia dissipata (Kützing) Grunow	NI015A	1-3	1-2	1	1-2	1-2	B		st-str	sx	i	alf	x	ate	me
Nitzschia dissipata var. *media* (Hantzsch) Grunow	FSN053	1-3	1-2	1-2	1	1				sx	i	alf	o-b		
Nitzschia dubia W.Smith	NI018A	0	1-3	1-2	1-3	0	P-B		st-str		mh	acb	o-b	hne	e
Nitzschia fonticola (Grunow) Grunow	NI002A	1-6	1	1-3	1-2	1	B		st-str		oh	alf	o-b	ate	me
Nitzschia frustulum (Kützing) Grunow	NI008A	1	2	1-2	0	1	B	temp	st-str	sp	hl	alf	b	hce	e
Nitzschia gracilis Hantzsch	NI017A	1	1-5	1-6	1-3	1	P-B	temp	st-str	sp	i	ind	o-x		m
Nitzschia linearis (C.Agardh) W.Smith	NI031A	1-2	1-3	1-6	1-6	1-5	B	temp	st-str	es	i	alf	x	ate	me
Nitzschia palea (Kützing) W.Smith	NI009A	1-3	1	1	1	2-6	P-B	temp		sp	i	ind	o-x	hce	he
Nitzschia recta Hantzsch ex Rabenhorst	NI025A	1	1	0	1	1	B		st	es	i	alf	x	ate	o-e
Nitzschia sigmoidea (Nitzsch) W.Smith	NI046A	0	0	0	0	0	P-B		st-str		i	alf	o	ate	e
Nitzschia tryblionella Hantzsch	NITtry	1-2	1	1	1	1	B		st-str		hl	alf	o	ate	e
Nitzschia vermicularis (Kützing) Hantzsch	NI049A	0	0	0	1	0	B		str		i	alf	o		o-e
Pinnularia borealis Ehrenberg	PI012A	0	0	1	1	0	B		ae	es	i	ind	o-b	ate	o-m
Pinnularia viridis (Nitzsch) Ehrenberg	PI007A	0	1	1-2	0	0	P-B	temp	st-str	es	i	ind	o-x	ate	o-e
Planothidium conspicuum (A.Mayer) M.Aboal	PLANco	0	1	1	1	1-2	B		st	sx	i	alf	o-a		
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	PLANla	1	1	1	1	1	B	warm	st-str	sx	i	alf	o-x		
Pseudostaurosira brevistriata (Grunow) D.M.Williams & Round	PLSTbr	1	0	1	1	1	P-B		st-str		i	alf	x-o		
Reimeria uniseriata S.E.Sala, J.M.Guerrero & M.E.Ferrario	REIuni	0	1	1	0	0									
Rhopalodia gibberula (Ehrenberg) Otto Müller	RH003A	0	1	0	1	0	B	temp	str	es	mh	ind			
Sellaphora pupula (Kützing) Mereschkovsky	SELP1Y	1-3	1	0	1	0	B	eterm	st	sp	hl	ind	o-x		
Stauroneis smithii Grunow	SA003A	1	5	0	0	0	P-B		st-str		i	alf	x-o	ate	o-e
Staurosirella pinnata (Ehrenberg) D.M.Williams & Round	STApin	0	1	0	0	0	B	temp	st-str	es	hl	alf	b-a		
Surirella biseriata Brébisson	SU004A	0	0	1	0	0	P-B		st-str	sx	i	alf	o-b		e
Surirella linearis W.Smith	SU005A	1	0	0	0	0	P-B			es	i	ind	o-b		o-m
Surirella ovalis Brébisson	SU003A	0	0	0	1	1	P-B		st-str	es	mh	alf	o	ate	e

Table 3. Continued.

Taxa	Code	F1	F2	F3	F4	F5	Hab	T	Reo	D	Sal	pH	Sap	Htr	Tro
Surirella subsalsa W.Smith	SURsub	1	0	1	1	0	B				hl				
Surirella tenera W.Gregory	SURten	0	0	0	1	0	P-B		st	es	i	alf	o		e
Synedrella parasitica (W.Smith) Round & N.I.Maidana	SYNpar	1	0	0	0	0	B			es	i	alf	x		
Tabularia fasciculata (C.Agardh) D.M.Williams & Round	TBF01Y	0	0	0	0	1	B		st	sx	hl	alf	x-o		
Tryblionella angustata W.Smith	TRYang	0	1	1-2	1	0	B						b-p		
Tryblionella apiculata Gregory	TYA01Y	1-2	1	1	1-2	1	B			es	mh	alf	o-a		
Tryblionella hungarica (Grunow) Frenguelli	TYH01Y	1	1	1-2	1-2	0	P-B			sp	mh	alf	a-b		
Ulnaria acus (Kützing) M.Aboal	ULNacu	1	0	0	1	1-5	P		st-str	es	i	alb	o-a		
Ulnaria ulna (Nitzsch) P.Compère	ULNuln	1	1	1-2	1-3	0	B	temp	st-str	es	i	alf	b-o	ate	o-e

Abbreviations: Hab: Ecological types, B: benthic, P: planktic, P–B: planktic-benthic, S: aerophytic, Ep: epiphytic: T: temperate, temp: temperate water, eterm: eurythermic water, warm: warm water, cool: cool water, Reo: streaming and oxygenation, st: standing water, str: stream, st-str: standing-streaming, aer: aerophile, D: saprobity, es: eurysaprobe, sx: saproxen, sp: saprophile, Sal: halobity, ph: polyhalobe, mh: mesohalobe, oh: oligohalobe, i: oligohalobious-indifferent, hl: oligohalobious-halophilous, hb: oligohalobious-halophobous, pH: Acidity, ind: indifferent, alf: alkaliphile, acf: acidophil, alb: alkalibiont, Sap: Saprobity, o: oligosaprobe, o-b: oligo-beta-mesosaprobe, b: beta-mesosaprobe, b-o: beta-oligomesosaprobe, b-a: beta-alpha-mesosaprobe, a, alpha-mesosaprobe, a-b: alpha-beta-mesosaprobe, x, xenosaprobe, x-o: xeno-oligosaprobe, o-x: oligo-xenosaprobe, a-p: alpha-meso-polysaprobe, p: polysaprobe, o-a: oligo-alpha-mesosaprobe, o-p: oligo-polysaprobe, Htr: nitrogen uptake metabolism, ats: nitrogen-autotrophic taxa, ate: nitrogen-autotrophic taxa, hne: facultatively nitrogen-heterotrophic taxa, hce: obligately nitrogen-heterotrophic taxa, Tro: trophic state, ot: oligotraphentic, o-m: oligo-mesotraphentic, m: mesotraphentic, m-e: meso-eutraphentic, e: eutraphentic, he: hypereutraphentic, o-e: oligo- to eutraphentic (hypereutraphentic).

Note: For saprobity, “D” according to Watanabe et al. (1986), “pH” according to Van Dam et al. (1994), and “Sap” according to Sladeček (1986).

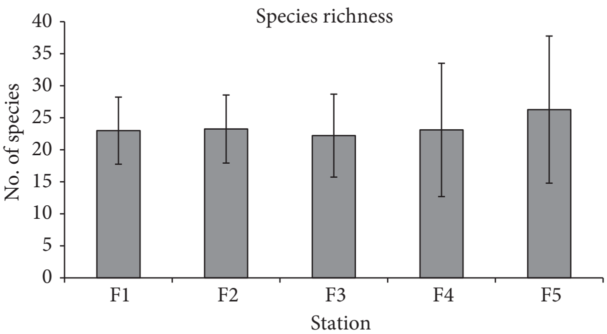
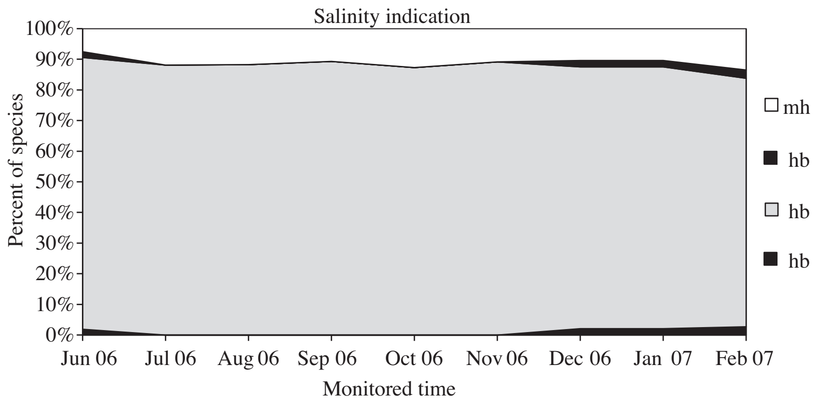


Figure 2. The diatom taxa number of the stations in Felent creek.

In relation to salinity indication, the diatoms of Felent creek are divided into 4 groups comprising 84 indicator species (71.8%). The “indifferent” constitute the dominant group, such as *Cymbella affinis*, while halophobes, mesohalobes, and halophile groups such as *Melosira varians* were in the minority (Barinova et al., 2006b). Similar results were observed in the Yarqon (Tavassi et al., 2004) and Hadera rivers in Israel (Barinova et al., 2006a). However, with respect to organic pollution indicators most of the species were Class II, fewer were Class III, and a few species were Class IV and V, reflecting low to middle organic pollution (Figure 3).

There were 87 (74.4%) indicator species for streaming and oxygenation. In the diagram, they were arranged along the gradient of water flow. Most of the species preferred moderate rates of low water flow (52) to standing water (19). This group includes such abundant species as *Cymbella affinis*. Therefore, the low water flow comprised most of the diatom diversity in Felent creek. Five groups of acidophility indicators comprised 104 (88.9%) species. In the diagram, these groups were arranged along the



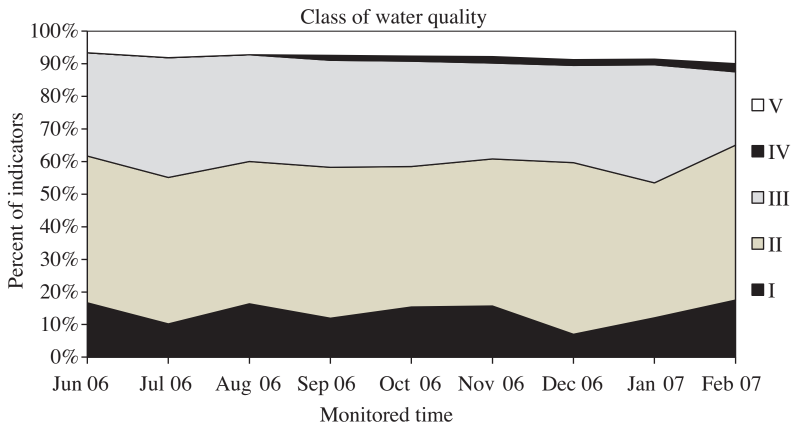
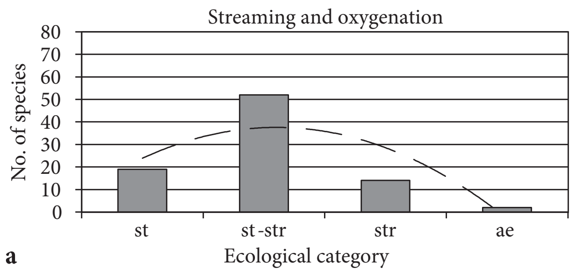


Figure 3. The percentage of species in groups of salinity (a) and organic pollution (b) indicators in Felent creek.

pH gradient. The ratio of the groups reflected the influence of carbonate substrates. Alkaliphiles predominated, with 73 species (62.4%). The most abundant of them were *Amphora pediculus, Melosira varians*, and *Nitzschia fonticola*. The "indifferents", usually prevailing over silicate substrates, were subordinate here, with 23 species. Prominent among them was *Navicula tripunctata*. Alkalibiontes tolerating an excessive alkalinity were represented by 5 species, but they were never abundant (Figure 4).

The indicators of salinity (106 species, 90.6%) are assigned to 4 ecological groups arranged along the gradient of salinity; the organic pollution indicators of Watanabe's classification (81 species, 69.2%) constitute 3 groups, showing a medium concentration of organic substances available to the diatoms. The peak of the trend corresponds to the maximum of eurysaprobionts such as the dominant species *Melosira varians* and others. The organic pollution indicators of Sládeček's classification (105



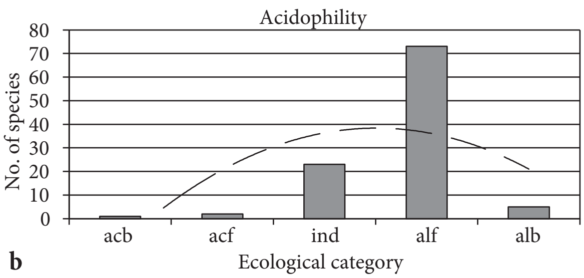


Figure 4. Number of species in groups of streaming and oxygenation (a) and acidophility (b) indicators in Felent creek.

species, 89.7%) constitute 13 groups. The Sládečék's index calculated for each sampling stations vary from 1.36 to 2.08, that is from oligo- to betamesosaprobic self-purification zones attesting to Class II of water quality at the outlet to Class III of low polluted water at the stations. Index S fluctuated mostly in June-July, but over the entire period it was between 1.5 and 2.0, which was marked as Class III but the lower polluted part of Class III, because the full range is 1.5-2.5. Furthermore, in June-July the water temperature was highest and pH was lowest during the monitored year. Species richness was also rather high in June as well as in September-October and fluctuated mostly at F4 and F5, below the wastewater input (Figure 5).

As a result, species richness and environmental variables (temperature, conductivity, and pH) showed a seasonal fluctuation. Thus, we calculated the RPI after Sumita (1986) for each defined environmental variable as well as for species richness and index of saprobity over stations in summer and winter. As can be seen in Table 4, the river water was mostly alkaline and temperate with low salinity. According to the Sládečék's system, there was organic pollution in summer in the creek. Species richness was mostly higher in winter than in summer.

Relationships between environmental variables and species diversity in each season and for all the revealed diversity were statistically calculated.

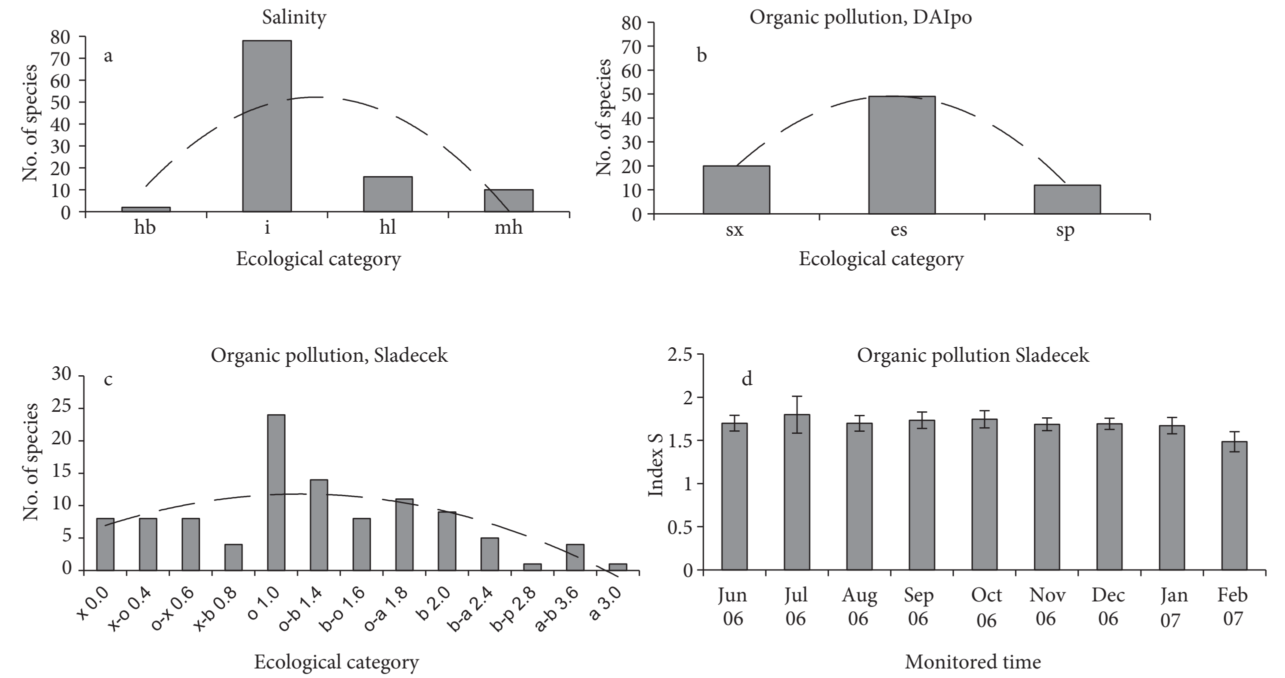


Figure 5. Number of species in groups of salinity (a), organic pollution on the Watanabe's (b), and organic pollution on the Sládečék's (c, d) indicators in Felent creek.

Table 4. Integral indices RPI after Sumita (1986): RPI_{pH} – index of pH; RPI_t – index of water temperature; RPI_{Ec} – index of electrical conductivity; RPI_{Sp} – index of species richness; RPI_S – index of organic pollution on the basis of Index saprobity S.

Index	RPI_{pH}	RPI_t	RPI_{Ec}	RPI_{Sp}	RPI_S
Winter	7.590177	15.38297	820.2224	29.60776	1.633416
Summer	7.37648	22.78714	809.2572	25.47845	1.721323

The results of CCA analysis showed that *Craticula ambigua*, *Nitzschia vermicularis*, and *Pinnularia borealis* were associated with temperature in all seasons and associated with conductivity in winter at F5. Moreover, *Surirella tenera* and *Hantzschia amphioxys* were associated with temperature in all seasons and summer at F5, whereas they were associated with conductivity in winter at F5. Additionally, *Cyclotella striata* was associated with temperature in all seasons, and *Gyrosigma spencerii* and *Neidium iridis* were highly correlated with pH in both summer and winter, while *G. spencerii, Navicula oblonga, Fragilaria parasitica* var. *subconstricta*, and *Surirella subsalsa* had a strong correlation with conductivity in summer (Figure 6).

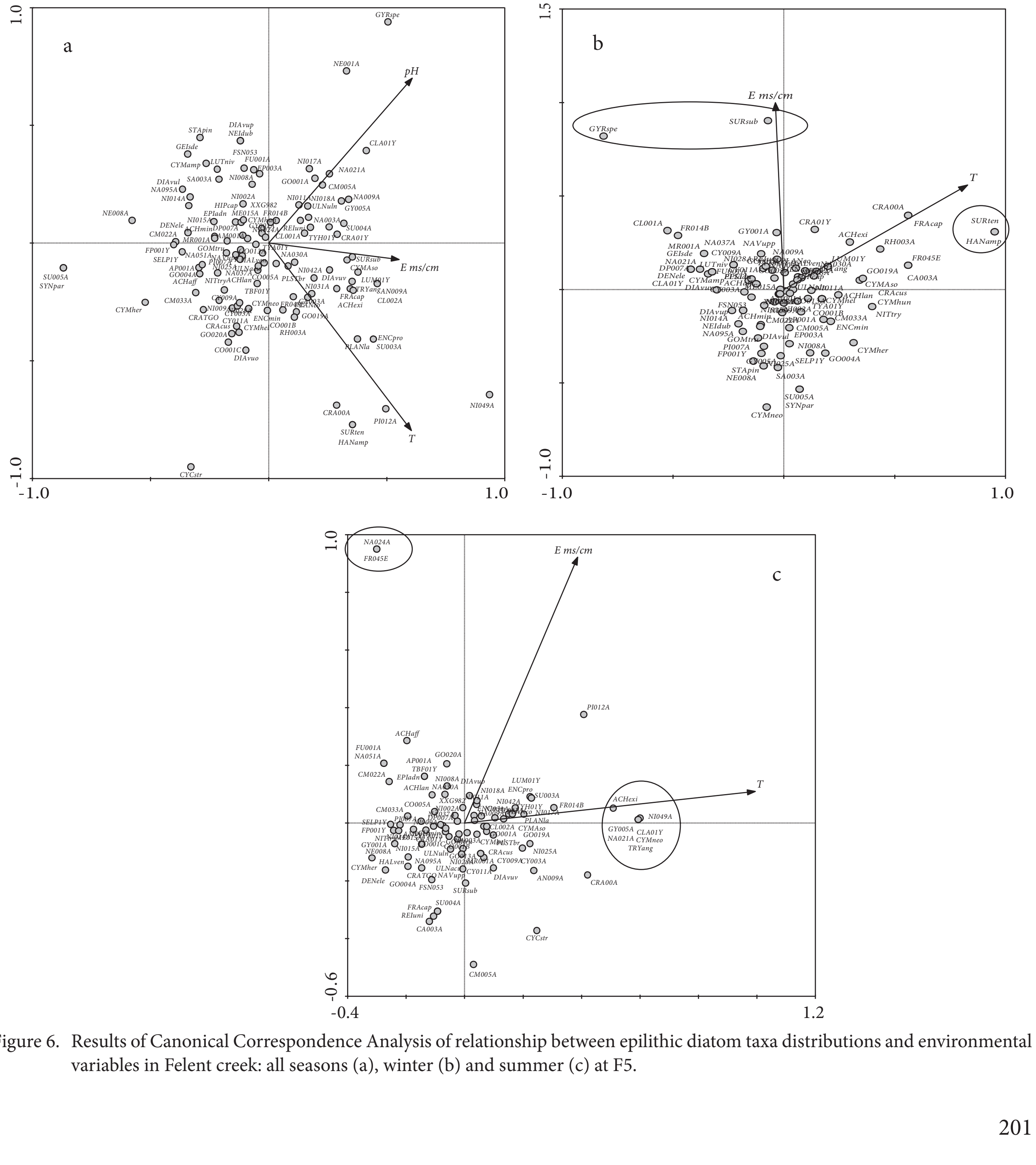


Figure 6. Results of Canonical Correspondence Analysis of relationship between epilithic diatom taxa distributions and environmental variables in Felent creek: all seasons (a), winter (b) and summer (c) at F5.

Conclusion

We found 117 diatom taxa from 5 stations in epilithic samples from Felent creek and the members of the *Nitzschia* group were dominant. Except for *Cymbella neocistula* and *Reimeria uniseriata*, all the species were indicators of one or more autoecological indices (Table 3). Bio-indication analysis showed that the diatoms of Felent creek prefer low salinity because groups of "indifferent" and halophiles prevail. Indicators of saprobity, according to Watanabe's and Sládečék's methods as well as Index of saprobity S show a low and moderate level of organic pollution. Species richness was very similar at each station and mostly fluctuated with wastewater input and higher water temperature during the study period. Statistical analysis revealed that there were significant correlations between the community and environmental variables during all periods. The seasonality of species diversity was confirmed by RPI calculation, which showed that the river was alkaline with low salinity and had organic pollution during periods of high temperature in summer. On the other hand, species richness was higher in winter.

Finally, we can conclude that the ecosystem of Felent creek had great self-purification ability during the study period; bio-indication reflects low to moderately polluted water of quality Class II-III and the river is mostly polluted at F4 and F5 during July according to the environmental variables. Therefore, the diatom community is closely related to water quality and bio-indicational methods can be used in the river monitoring system in Turkey.

References

Akbulut A & Dügel M (2008). Planktonic diatom assemblages and their relationship to environmental variables in lakes of Salt Lake Basin (Central Anatolia-Turkey). *Fresenius Environ Bull* 17: 154-164.

Almeida SFP (2001). Use of diatoms for freshwater quality evaluation in Portugal. *Limnetica* 20: 205-213.

Atazadeh I, Sharifi M & Kelly MG (2007). Evaluation of the Trophic Diatom Index for assessing water quality in River Gharasou, Western Iran. *Hydrobiologia* 589: 165-173.

Atıcı T (1997). Pollution of Sakarya river and algae. *Ekoloji* 24: 28-32.

Atıcı T, Obalı O, Akköz C & Elmacı A (2001). Isolation and identification of halophytic algae from salty soil around Salt Lake of Turkey. *Pakistan J Biol Sci* 4: 298-300.

Atıcı T & Ahıska S (2005). Pollution and algae of Ankara Stream. *Gazi Üniv Fen Bil Derg* 18: 51-59.

Atıcı T & Obalı O (2010). The diatoms of Asartepe Dam Lake (Ankara), with environmental and some physicochemical properties. *Turk J Bot* 34: 541-548.

Atıcı T & Yıldız K (1996). Sakarya Nehri diyatomeleri. *Turk J Bot* 20: 119-134.

Ács É, Szabó K, Tóth B & Kiss KT (2004). Investıgatıon of benthic algal communities, especially diatoms of some Hungarian streams in connection with reference conditions of the Water Framework Directives. *Acta Botanica Hungarica* 46: 255-277.

Barinova SS, Tavassi M & Nevo E (2006a). Algal indicator system of environmental variables in the Hadera River basin, central Israel. *Plant Biosystems* 140: 65-79.

Barinova SS, Medvedeva LA & Anissimova OV (2006b). *Diversity of algal indicators in environmental assessment.* Pilies Studio, Tel Aviv (in Russian).

Barinova SS, Tavassi M & Nevo E (2010). Algal communities of the Hadera River (Israel) under dramatic niche changes. *Cent Eur J Biol* 5: 507-521.

Barinova SS, Kukhaleishvili L, Nevo E & Janelidze Z (2011). Diversity and ecology of algae in the Algeti National Park as a part of the Georgian system of protected areas. *Turk J Bot* 33: doi:10.3906/bot-1009-83.

Baykal T, Akbulut A, Açikgöz I, Udoh AU, Yıldız K & Şen B (2009). New records for the freshwater algae of Turkey. *Turk J Bot* 33: 141-152.

Bingöl N, Özyurt S, Dayioğlu H, Yamık A & Solak CN (2007). Yukarı Porsuk Çayı (Kütahya) epilitik diyatomeleri. *Ekoloji* 62: 23-29.

Blanco S, Bécares A, Cauchie H-M, Hoffmann L & Ector L (2007). Comparison of biotic indices for water quality diagnosis in the Duero Basin (Spain). *Arch Hydrobiol* (suppl. Large Rivers) 17: 267-286.

Blanco S, Ector L, Huck V, Monnier O, Cauchie H-M, Hoffmann L & Bécares A (2008). Diatom assemblages and water quality assessment in the Duero Basin (NW Spain). *Belg J Bot* 141: 39-50.

Bona F, Falasco E, Fassina S, Griselli B & Badino G (2007). Characterization of diatom assemblages in mid-altitude streams of NW Italy. *Hydrobiologia* 583: 265-274.

Çevre ve Orman Bakanlığı (2004). Türkiye Çevre Atlası. – T. C. Çevre ve Orman Bakanlığı, Çevre Envanteri Daire Başkanlığı, Ankara.

Dell'Uomo A & Torrisi M (2009). Freshwater algae and their usefulness in safeguarding the Mediterranean basin. *Bocconea* 23: 5-17.

Ector L & Rimet F (2005). *Using bioindicators to assess rivers in Europe: An overview*. In: Lek S, Scardi M, Verdonschot P, Descy J-P & Park YS (eds), *Modelling Community Structure in Freshwater Ecosystems,* pp. 7-19, Berlin: Springer Press.

Fieo MJ, Almeida SFP, Craveiro SC & Calado AJ (2009). A comparison between biotic indices and predictive models in stream water quality assessment based on benthic Diatom communities. *Ecol Indic* 9: 497-507.

Gezerler-Sipal U, Aysel V & Güner H (1994). Bandırma Kusgölü'ne dökülen Sıgırcı Dere'nin alg florası ve çevresinin kirlenmesindeki etkileri. Ege Üniv Fen Fak Derg 16: 351-356.

Guiry MD & Guiry GM (2009). *AlgaeBase*, World-wide electronic publication, National University of Ireland, Galway. Website: http://www.algaebase.org, [accessed December 2009].

Korde NV (1956). *The methods of biological studies for the bottom deposits of lakes (the field methods of biological analysis)*. Moscow, Leningrad: Nauka Press (in Russian).

Krammer K & Lange-Bertalot H (1986) *Bacillariophyceae*. 1. Teil: Naviculaceae. *Süßwasser von mitteleuropa*. Gustav Fischer Verlag, Band 2-1, Stuttgart.

Krammer K & Lange-Bertalot H (1988) *Bacillariophyceae*. 2. Teil: Bacillariophyceae, Epithemiaceae, Surirellaceae. *Süßwasser von mitteleuropa*. Gustav Fischer Verlag, Band 2-2, Stuttgart.

Krammer K & Lange-Bertalot H (1991a) *Bacillariophyceae.* 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. *Süßwasser von mitteleuropa*. Gustav Fischer Verlag, Band 2-3, Stuttgart.

Krammer K & Lange-Bertalot H (1991b) *Bacillariophyceae.* 4. Teil: Achnantheceae, Kritische Ergänzungen zu Navicula (Lincolatae) und Gomphonema. Cesamptliteraturverzeichnis . *Süßwasser von mitteleuropa*. Gustav Fischer Verlag, Band 2-4, Stuttgart.

Ongun-Sevindik T, Çelik K & Gönülol A (2010). Twenty-four new records for the freshwater algae of Turkey. *Turk J Bot* 34: 249-259.

Pantle E & Buck H (1955). Die biologische Uberwachung der Gewässer und die Darstellung der Ergebnisse. *Gas- und Wasserfach* 96: 1-604.

Resende PC, Resende P, Pardal M, Almeida S & Azeiteiro U (2009). Use of biological indicators to assess water quality of the Ul River (Portugal). *Environ Monit Assess* 170: 535-544.

Romanenko VD, Oksijuk OP, Zhukinsky VN, Stolberg FV & Lavrik VI (1990). *Ecological impact assessment of hydrotechnical constructions on water bodies*. Kijev: Naukova Dumka (in Russian).

Sládeček V (1973). System of water quality from the biological point of view. *Ergebnisse der Limnologie* 7: 1-128.

Sladeček V (1986). Diatoms as indicators of organic pollution, *Acta Hydroch Hydrob* 14: 555-566.

Solak CN (2011). The application of diatom indices in the Upper Porsuk River, Kütahya-Turkey. *Turk J Fish Aquat Sci* 11: 31-36.

Solak CN, Ector L, Wojtal A, Ács É & Morales E (2012). A review of investigations on diatoms (Bacillariophyta) in Turkish inland waters. *Nova Hedwigia Beihefte* 141: 431-462.

Squires LE & Saoud NS (1986). Effects of water quality and season on diatom community structure in the Damour River, Lebanon. *Hydrobiologia* 133: 127-141.

Sumita M (1986). A numerical water quality assessment of rivers in Hokuriku District using epilithic diatom assemblage in riverbed as a biological indicator. (II) The values of RPId in surveyed rivers. *Japan Journal of Diatomology* 2: 9-18.

Swift E (1967). Cleaning diatom frustules with ultraviolet radiation and peroxide. *Phycologia* 6: 161-163.

Tavassi M, Barinova SS, Anissimova OV, Nevo E & Wasser SP (2004). Algal indicators of environment in the Nahal (River) Yarqon basin, central Israel. *International Journal of Algae* 6: 355-382.

Tavassi M, Barinova SS & Nevo E (2008). Examination of water quality from the Yarqon River (Central Israel) using the glass slide method to define algal vegetative activity (*in vitro*). *Applied Ecology and Environmental Research* 6: 113-125.

ter Braak CJF (1987). The analysis of vegetation-environment relationships by canonical correspondence analysis. *Vegetatio* 69: 69-77.

ter Braak CJF (1990). Interpreting canonical correlation analysis through biplots of structural correlations and weights. *Psychometrica* 55: 519-531.

Urrea G & Sabater S (2009). Epilithic diatom assemblages and their relationship to environmental characteristics in an agricultural watershed (Guadiana River, SW Spain). *Ecol Indic* 9: 693-703.

Van Dam H, Mertens A & Sinkeldam S (1994). A coded checklist and ecological indicator values of freshwater diatoms from The Netherlands. *Netherland Journal of Aquatic Ecology* 28: 117-133.

Watanabe T, Asai K & Houki A (1986). Numerical estimation to organic pollution of flowing water by using the epilithic diatom assemblage-Diatom Assemblage Index (DAIpo). *Science Total Environment* 55: 209-218.

Whitton BA, Rott E & Friedrich G (1991). *Use of algae for monitoring rivers*. Innsbruck: Institut für Botanik University Press.

Yıldız K (1987). Diatoms of the Porsuk River, Turkey. *Turk J Biol* 11: 162-182.

Yıldız K & Atıcı T (1996). Ankara Çayı diyatomeleri. *Gazi Üniv Fen Edebiyat Fak Derg* 6: 59-87.

Yıldız K & Özkıran Ö (1994). Çubuk Çayı diyatomları. *Turk J Biol* 18: 313-329.

Ziller S & Montesanto B (2004). Phytobenthos (diatoms) and water framework directive implementation: The case of two Mediterranean rivers in Greece. *Fresenius Environ Bull* 13: 128-138.