

DOI: 10.2478/s13545-012-0009-z
Original research paper

Received:

June 08, 2011

Accepted:

December 05, 2011

Relationships between epipellic diatoms, aquatic macrophytes, and water quality in Akarçay Stream, Afyonkarahisar, Turkey

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Key words: water quality parameters, epipellic diatoms, macrophytes, ecological state, Akarçay Stream

Abstract

The Akarçay is the most important stream in the Afyonkarahisar region in central Turkey. In this study, the relationships between epipellic diatoms, macrophytes, and the water quality of Akarçay Stream are presented. According to Canonical Correspondence Analysis (CCA), BOD₅, COD, TDS, NH₄-N, NO₂-N, and PO₄-P had the most significant effects on the diatom and macrophyte community structures of the stream. According to CCA and Correspondence Analysis (CA), dominant diatom species and macrophytes constituted two groups, eutrophic and polluted. While eutraphentic taxa were abundant among upstream diatoms, hypereutraphentic taxa were found downstream in the Akarçay. The diatom assemblages in the sites upstream were generally characterized by an abundance of β -mesosaprobous and α -mesosaprobous species, while the diatom assemblages downstream had a very high abundance of

polisaprobous species. Eutrophic and hypertrophic macrophyte taxa (such as *Lemna trisulca*, *Potamogeton nodosus*, and *Ranunculus* sp.) covered a high percentage of the stream bottom. Both diatom indices and macrophyte indices with the exception of the Biological Macrophyte Index of Rivers (IBMR) were correlated with BOD₅, COD, TDS, NH₄-N, NO₂-N, PO₄-P, and EC. Physicochemical variables, diatom and macrophyte taxa and the results of diatom and macrophyte indices indicated that the Akarçay stream basin is eutrophic and organically polluted.

INTRODUCTION

Various groups of living organisms, including algae, macrophytes, bacteria, protozoa, invertebrates, and fish, have been adversely affected by eutrophication and other pollution events involving urban, industrial, and agricultural wastes. Their sensitivity towards different environmental parameters is often used in biological monitoring (Hering et al. 2006, Soininen and Könönen 2004). Diatoms and macrophytes are particularly recommended as indicators of environmental conditions by the Water Framework Directive (WFD) (European 2000, Schaumburg et al. 2004).

Diatoms are the main components of microalgal benthic communities. Benthic diatoms have been especially widely used as water quality indicators in rivers and streams worldwide (Kelly 1998, Tang et al. 2006, Bellinger et al. 2006, Resende et al. 2010, Kalyoncu et al. 2009, Solak 2011).

In the absence of anthropogenic impacts, the macrophyte vegetation of a section of river depends on the river type, which is determined by its physical and chemical nature, as is stressed by many authors (Harding 1981, Carbiener et al. 1995). A number of authors have reported that aquatic macrophytes are highly sensitive to chemical pollution in rivers (Kolher 1971, Haslam 1987, Daniel and Hauray 1995, Ali et al. 1999). The number of studies exploring the use of macrophytes to investigate lowland water quality has been increasing (Caffrey 1986, Husák et

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al. 1989, Thiébaud and Muller 1999, Kargioğlu 2001, Haury et al. 2006, Triest 2006, Daniel et al. 2006, Chatenet et al. 2006, Serteser et al. 2008). Since these assessments are based on the difference between actual macrophyte vegetation and reference vegetation, it is extremely important to correctly define a reference macrophyte community, which depends on river type. River type, in turn, depends on factors such as stream size, water chemistry, flow velocity, and substratum composition (Robach et al. 1996, Riis et al. 2000). In addition, climatic conditions influence macrophyte vegetation (Holmes et al. 1998, Barendregt and Bio 2003, Janauer and Dokulil 2006). However, the properties of a good water quality indicator must include not only sensitivity to pollution, but selectivity as well (Murtaugh 1996).

Water pollution has been increasing in Turkey due to human population growth, industrialization, and agricultural usage of pesticides and fertilizers. In general, physical and chemical parameters are used exclusively to determinate water quality in Turkey. Studies regarding biological indicators in this region are rare (Gürbüz and Kivrak 2002, Dere et al. 2006, Serteser et al. 2008), which is why this study is unique.

The main purposes of this paper are:

- to investigate the relationships between physicochemical water parameters and diatom and macrophyte communities;
- to assess the ecological status of Akarçay Stream;
- to test the use of epipellic diatoms and macrophytes as indicators of water quality;
- to compare the use of diatom and macrophyte indices as tools for evaluating water quality of the stream.

STUDY AREA AND SAMPLING SITES

The Akarçay is the most important stream in the Afyonkarahisar region in central Turkey. It is composed of two main tributaries: Aksu and Acıçay. The former originates in western Sincanlı borough and flows to Akarçay in the Afyonkarahisar plain by passing through Akdeğirmen, Ayvalı, Balmahmut and Köprülü. The Acıçay originates in Gazlıgöl and merges with the Akarçay in western part Afyonkarahisar. The Akarçay joins Kali Stream, which flows in from the eastern part of Afyonkarahisar Plain, and runs 80 km through

lowlands before reaching Eber Lake. The Akarçay is used for drinking water at its source, however water quality decreases downstream after it passes through many villages, hot springs, farmlands, and polluted urban areas (Afyonkarahisar). This pollution causes eutrophication in Eber Lake.

The Akarçay Basin has a continental climate, with average temperatures of 20–25°C in summer and 0–3°C in winter, and an annual average of 11°C. The annual rainfall average is 400–500 mm, with slightly higher levels in winter than in summer. The basin formation dates to the Quaternary age, and is geologically composed of lake and stream sediment (Anonymous 2002).

Four sampling sites were chosen along Akarçay Stream. While sampling sites I (SL1) and II (SL2) were situated upstream in western Afyonkarahisar, sampling sites III (SL3) and IV (SL4) were downstream in eastern Afyonkarahisar (Fig. 1). All stations selected have been affected by human activities, such as urban, industrial, and agricultural wastes. While SL1 is only exposed to agricultural pollution, SL2 has been subjected to both agricultural and thermal pollution. SL3 and SL4 are located far downstream, and have been polluted heavily with urban, industrial, and agricultural wastes.

MATERIALS AND METHODS

Water samples, diatoms, and macrophytes were collected monthly from each sampling site from March through July 2008. Water temperature, dissolved oxygen (DO), electrical conductivity (EC), and pH were measured using a multilab-P4 (WTW) apparatus in the field during the sampling. During transfer to the laboratory, all samples were stored at 4°C in darkness. Concentrations of ammonium (NH₄-N), nitrite (NO₂-N), nitrate (NO₃-N), orthophosphate, total dissolved substances (TDS), chemical oxygen demand (COD) and biological oxygen demand (BOD₅) were analyzed in the laboratory according to standard methods (APHA 1995).

Epipellic diatom samples were collected from sediment using a core 1 cm in diameter. This was performed according to the recommendations of Kelly et al. (1998). The samples were fixed in a 4% formaldehyde solution and then cleaned using hot hydrochloric acid (HCl) and potassium permanganate (KMnO₄) in the laboratory (Hasle 1978). Cleaned diatom valves were washed with distilled water and permanent diatom preparations mounted on slides

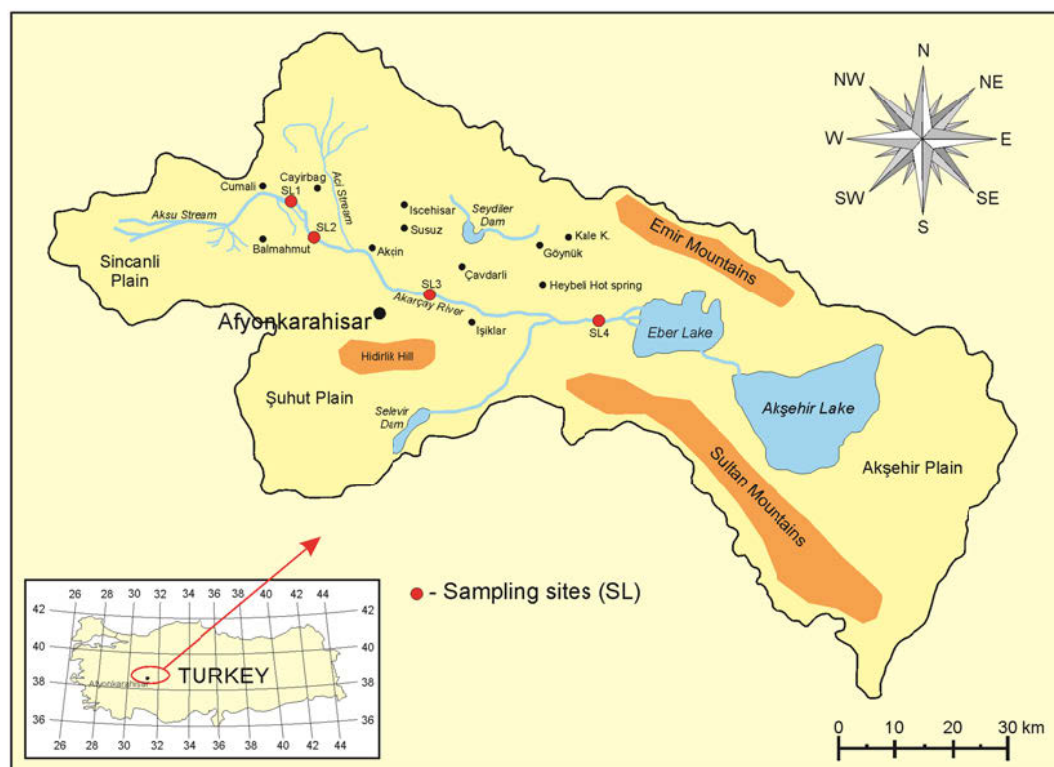


Fig. 1. Akarçay Stream and location of sampling sites (SL).

with Entellan. At least 300 valves were counted and identified in each sample using a light microscope with a $\times 1000$ magnification. Abundances of all observed taxa were expressed as relative counts (%). The identifications were carried out according to Hustedt (1930), Patrick and Reimer (1966, 1975), and Krammer and Lange-Bertalot (1986, 1991a, 1991b, 1999). The names of taxa and authors were determined by following the standardized databases (Guiry and Guiry 2007). The sabrobity and trophic features of diatom species were taken from Van Dam et al. (1994) and Krammer and Lange-Bertalot (1986, 1991a, 1991b, 1999). The presence of each species and their percentages of the area covered were examined in river segments 100 m long at each sampling site. The field assessment of macrophytes was performed according to STAR guidelines (Dawson 2002). Macrophytes were identified and counted using regional floras (Davis 1965-1985, Davis et al. 1988, Güner et al. 2000). The Biological Macrophyte Index of Rivers (IBMR) and Mean Trophic Rank (MTR) were calculated according to Haury et al. (2002) and Holmes et al. (1999), respectively.

The data obtained from the study were statistically analyzed, with $p < 0.05$ accepted as a

significant value. Statistical methods were employed as follows. While showing relations between diatom assemblages and macrophyte communities, Correspondence Analysis (CA) was applied, and the relationships between diatom assemblages, macrophyte communities, and environmental variables were shown by Canonical Correspondence Analysis (CCA). All eleven physicochemical variables of water were included in the analysis. The importance of these variables in relation to diatom assemblages and macrophyte communities was tested using a Monte Carlo permutation test (499 permutations, $p < 0.05$). CCA was performed using CANOCO, version 4.5 statistics software (Ter Braak and Smilauer, 2002). Pearson correlation coefficients were performed using SPSS, version 11.0 (SPSS Inc., 2001).

RESULTS

Physicochemical parameters

Table 1 summarizes selected physicochemical variables with mean, standard deviations, and maximum and minimum levels. During the study period, water temperature (T) varied between 3°C

Table 1

Physicochemical characteristics of water in the Akarçay River.

Variable	SL1		SL2		SL3		SL4	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
T (°C)	13.10 ±7.89	3 - 21.7	15.5 ±10.19	5.7 - 38.4	16.7 ±7.48	6.3 - 23.3	17.8 ±7.26	7.6 - 24.6
pH	7.76 ±0.11	7.6 - 7.9	8.1 ±0.21	7.9 - 8.4	7.44 ±0.23	7.2 - 7.8	7.86 ±0.23	7.5 - 8.0
EC (μS cm ⁻¹)	489.00 ±38.70	430 - 536	2402 ±1976	559 - 4684	1538 ±348	1114 - 1910	1590 ±385.2	968 - 1964
TDS (mg l ⁻¹)	342.00 ±36.26	292 - 364	601 ±374.7	362 - 1131	985 ±274.5	713 - 1310	875 ±326.2	425 - 1148
DO (mg l ⁻¹)	8.92 ±2.88	6.2 - 12.6	5.66 ±1.93	3.1 - 8.4	3.7 ±2.83	1.1 - 6.3	4.26 ±1.8	2.6 - 6.3
BOD ₅ (mg l ⁻¹)	7.44 ±2.71	5.1 - 11.8	24.4 ±6.15	17.1 - 32	163 ±135.9	42 - 390	119 ±64	36.3 - 166
COD (mg l ⁻¹)	9.62 ±1.67	7.3 - 11.3	38.2 ±9.01	28 - 49	191 ±80.23	62.3 - 242	129 ±87.47	28.3 - 171
NH ₄ -N (mg l ⁻¹)	0.40 ±0.29	0.11 - 0.88	0.89 ±0.65	0.14 - 1.64	10.4 ±8.5	1.53 - 19.4	5.2 ±1.76	3.06 - 7.16
NO ₂ -N (mg l ⁻¹)	0.03 ±0.01	0.01 - 0.04	0.03 ±0.01	0.02 - 0.06	1.56 ±0.7	0.96 - 2.58	0.07 ±0.016	0.061 - 0.09
NO ₃ -N (mg l ⁻¹)	2.02 ±0.71	1.32 - 3.21	1.25 ±0.27	0.9 - 1.57	0.65 ±0.43	0.2 - 1.22	1.33 ±0.54	0.68 - 1.91
PO ₄ -P (mg l ⁻¹)	0.34 ±0.13	0.14 - 0.49	1.11 ±0.65	0.34 - 1.84	2.98 ±2.09	0.83 - 5.81	3.82 ±2.02	1.79 - 5.89

and 38.4°C. Maximum water temperatures were measured at SL2 in early summer, where thermal spring wastewater was discharged. Alkalinity ranged from a pH of 7.2 to 8.4. Conductivity (EC) was generally high at all sampling sites. EC reached 4684 μS cm⁻¹ at SL2 in early summer, due to inputs from richly mineralized thermal spring water from thermal facilities. High EC values were generally measured downstream (mean 1538 μS cm⁻¹ at SL3, 1590 μS cm⁻¹ at SL4) due to the effects of urban, industrial, and agricultural pollution. Whereas high dissolved oxygen (DO) concentrations were recorded upstream, very low DO concentrations were measured downstream. There were progressive increases in TDS, BOD₅, and COD concentrations as one travelled downstream. Except for NO₃-N, all nutrient (NH₄-N, NO₂-N, and PO₄-P) concentrations reached their highest values downstream.

Diatom assemblages

Composition of diatom assemblages and dominant species of diatoms were very similar at the two upstream sites SL1 and SL2. Downstream sites SL3 and SL4 also shared many similarities. However, composition of diatom assemblages and dominant species of diatoms at the upstream sampling sites were very different from those downstream. The mean relative abundances of the dominant epipellic diatom species and their autecology are given in Table 2. At both SL1 and SL2, *Amphora venata*, *Cocconeis placentula*, *Cymatopleura solea*, and *Encyonema minutum* were abundant. *Navicula viridula* and *Sellophora*

pupula were dominant only at site SL1. *Nitzschia palea* (over 65% of the total abundance) was the dominant species in the diatom assemblages at both sites SL3 and SL4, and were at the highest abundance in the diatom assemblages in these sites throughout the study period. On the other hand, *Navicula cryptocephala* were found continually in average abundance at all sites. According to the ecological classes of Van Dam et al. (1994), the diatom assemblages in the upstream sites comprised eutraphentic taxa, with the exception of *Sellophora pupula*. Hypereutraphentic taxa *Nitzschia palea* was dominant in the diatom assemblages in the downstream sites. The diatom assemblages in the upstream sites consisted generally of β-mesosaprobous and α-mesosaprobous species and the diatom assemblages downstream had a very high abundance of polisaprobous species, e.g. *Nitzschia palea*.

Macrophytes

The composition of macrophytes at each sampling site and the percentage coverage are given in Table 3. The number of macrophytes covering the stream bottom was lower upstream (SL1 and SL2) than downstream (SL3 and SL4). *Lemna trisulca* had the highest percentage coverage of bottom at four of the sampling sites and covered approximately 60% of the river bottom at SL1, 70% at SL2, 85% at SL3, and 85% at SL4. Whereas *Plantago major* subsp. *intermedia*, *Polygonum amphibium*, *Ranunculus saniculifolius*, and *Veronica anagallis-aquatica* subsp. *anagallis-aquatica* covered a relatively high percentage of the stream bottom upstream, *Bolboschoenus maritimus* var.

Table 2

Mean relative abundance (%) of dominant epipellic diatom taxa in the Akarçay River in studied sites together with their affinity towards sabrobity and trophic status (Van Dam et al. 1994).

Diatom Taxa	Code	Trophic state	Sampling stations				
			Sabrobity	SL1	SL2	SL3	SL4
<i>Amphora veneta</i> Kütz.	AMPVEN	eutrathentic	α -meso-/ polysaprobous	10.25	32.5	2	1.74
<i>Cocconeis placentula</i> Ehrenb.	COCPLA	eutrathentic	β -mesosaprobous	10	12.25	1.25	4
<i>Cymatopleura solea</i> (Bréb.) W. Smith	CYMSOLEA	eutrathentic	β -mesosaprobous	9	6	0.25	0
<i>Encyonema minutum</i> (Hilse) D.G. Mann	ENCYM	-	-	2.5	4	0.5	0
<i>Navicula cryptocephala</i> Kütz.	NAVCRYP	Oligo-to eutrophentic	α -mesosaprobous	8	4.25	4.75	7.75
<i>Navicula pupula</i> Kütz.	NAVUPUP	Meso-eutrathentic	α -mesosaprobous	8.75	2	0.5	0
<i>Navicula viridula</i> (Kütz.) Kütz.	NAVIR	eutrathentic	α -mesosaprobous	10.25	2.5	1.75	1.75
<i>Nitzschia palea</i> (Kütz.) W. Smith	NTPALEA	hypereutrathentic	Polysaprobous	0	1	74.75	64.5
<i>Nitzschia tubicola</i> Grun.	NTTUBI	-	-	8.75	2.5	0.75	0
<i>Ulnaria ulna</i> (Nitzsch) P. Compère	ULULNA	Oligo-to eutrophentic	α -meso-/ polysaprobous	8	1.75	1.5	4.25

Table 3

The taxonomic composition of macrophytes and relative percentage cover of the individual species in the Akarçay River.

Species	Code	Family	SL1	SL2	SL3	SL4
<i>Alisma plantago-aquatica</i>	APLA	Alismataceae	12	8	3	1
<i>Alopecurus arundinaceus</i>	AARU	Poaceae	8	10	15	20
<i>Althaea officinalis</i>	AOFF	Malvaceae	8	5	3	2
<i>Bolboschoenus maritimus</i> var. <i>maritimus</i>	BMAR	Cyperaceae	2	4	25	30
<i>Eleocharis palustris</i>	EPAL	Cyperaceae	15	10	6	4
<i>Juncus inflexus</i>	JINF	Juncaceae	3	6	45	55
<i>Lemna trisulca</i>	LTRI	Lemnaceae	60	70	85	80
<i>Lepidium latifolium</i>	LLAT	Brassicaceae	1	2	12	15
<i>Lycopus europaeus</i>	LEUR	Lamiaceae	6	4	2	1
<i>Mentha aquatic</i>	MAQU	Lamiaceae	10	7	2	1
<i>Oenanthe aquatica</i>	OAQU	Apiaceae	8	6	2	1
<i>Phragmites australis</i>	PAUS	Poaceae	5	7	60	80
<i>Plantago major</i> subsp. <i>intermedia</i>	PMAJ	Plantaginaceae	35	28	4	1
<i>Plantago maritima</i>	PMAR	Plantaginaceae	1	3	4	6
<i>Polygonum amphibium</i>	PAMP	Polygonaceae	35	30	8	4
<i>Polypogon monspeliensis</i>	PMON	Poaceae	5	6	45	55
<i>Potamogeton nodosus</i>	PNOD	Potamogetonaceae	17	12	2	0
<i>Ranunculus cornutus</i>	RCOR	Ranunculaceae	2	3	7	9
<i>Ranunculus saniculifolius</i>	RSAN	Ranunculaceae	35	25	8	3
<i>Sparganium erectum</i> subsp. <i>erectum</i>	SERE	Sparganiaceae	4	7	30	55
<i>Typha angustifolia</i>	TANG	Typhaceae	3	5	45	65
<i>Veronica anagallis-aquatica</i> subsp. <i>anagallis-aquatica</i>	VANA	Scrophulariaceae	35	25	5	2

maritimus, *Juncus inflexus*, *Phragmites australis*, *Polypogon monspeliensis*, *Sparganium erectum* subsp. *erectum*, and *Typha angustifolia* covered high percentages of the stream bottom downstream. The other species of macrophytes covered a relatively low percentage of the bottom at all sites.

Relationships between water parameters, epipellic diatoms, and macrophytes

CCA was used to determine the relationship between the diatom and macrophyte species data and the environment. The Monte Carlo permutation test

($p < 0.01$) was used to set the significance of both diatom abundance and environmental variables. The first two CCA axes had eigenvalues of 0.091 and 0.028 respectively. Diatom-environmental correlations were higher than 0.88 for both axes and explained collectively 76.1% of the diatom-environment variations. The first axis of CCA explained 33.5% of the total variance in dominant diatom taxa, and the second axis explained 10.2% of the total variance. The CCA ordination diagram shows the location of diatom taxa in the ordination space of axes 1 and 2 and the direction and intensity of changes in the value of environmental variables (Fig. 2). CCA showed that the most important parameters were BOD₅, COD, TDS, NH₄-N, NO₂-N, and PO₄-P. These variables indicated the increase in pollution downstream. In the ordination diagram of the CCA, *Nitzschia palea* were located in the positive part of the first axis and were related to BOD₅, COD, TDS, NH₄-N, NO₂-N, and PO₄-P. In the ordination diagram of the CCA, *Nitzschia palea* was located in the positive part of the first axis and was related to BOD₅, COD, TDS, NH₄-N, NO₂-N, and PO₄-P.

According to results of the CCA, correlations between the percentage cover of macrophytes and the environmental variations were higher than 0.83 for both axes. The CCA had an eigenvalue of 0.022

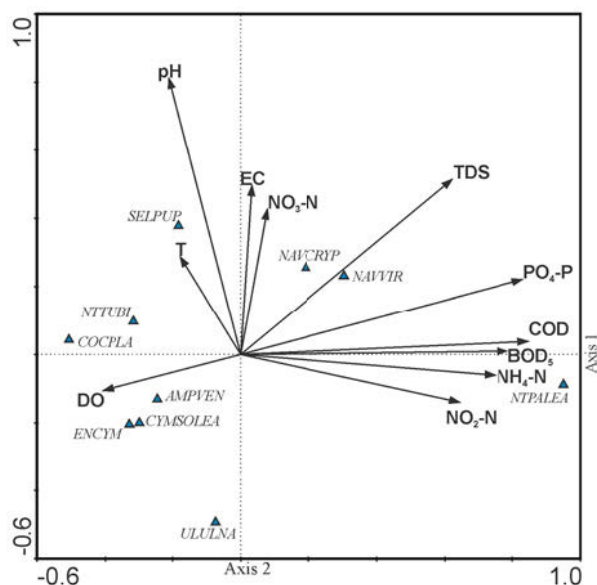


Fig. 2. Canonical Correspondence Analysis (CCA) computed on the relative abundance of diatoms in relation to the chemical and physical variables of water.

and explained 73.7% of the total variance in the percentage cover of macrophytes. The second axis had an eigenvalue of 0.013 and explained 4.2% of the total variance. The first CCA axis summarized the distribution of the macrophyte communities throughout a pollution gradient. *Bolboschoenus maritimus* var. *maritimus*, *Juncus inflexus*, *Lepidium latifolium*, *Phragmites australis*, *Polypogon monspeliensis*, *Ranunculus cornutus*, *Sparganium erectum* subsp. *erectum*, and *Typha angustifolia* were located in the positive part of the first axis. All these taxa related to BOD₅, COD, TDS, NH₄-N, NO₂-N, and PO₄-P. *Alisma plantago-aquatica*, *Althaea officinalis*, *Eleocharis palustris*, *Lycopus europaeus*, *Mentha aquatica*, *Oenanthe aquatica*, *Plantago major* subsp. *intermedia*, *Polygonum amphibium*, *Potamogeton nodosus*, *Ranunculus saniculifolius*, and *Veronica anagallis-aquatica* subsp. *anagallis-aquatica* were located in the negative part of the first axis in the ordination diagram of the CCA and were related to DO (Fig. 3).

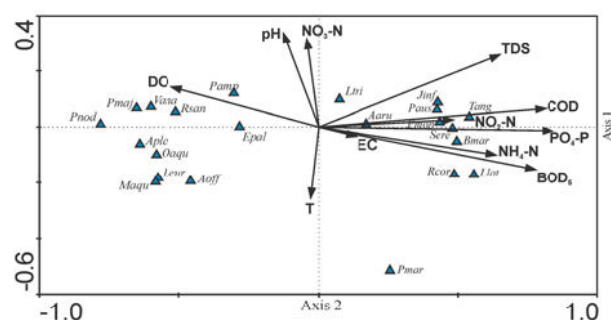


Fig. 3. Canonical Correspondence Analysis (CCA) computed on the relative percentage cover of individual macrophyte species in relation to the chemical and physical variables of water.

The CA had an eigenvalue of 0.204 and explained 67.9% of the total variance in the percentage cover of macrophytes and diatom abundance. The second axis had an eigenvalue of 0.024 and explained 8% of the total variance. Axis 1 clearly collected the communities of diatoms and macrophytes in the right and left two areas. *Bolboschoenus maritimus* var. *maritimus*, *Juncus inflexus*, *Lepidium latifolium*, *Phragmites australis*, *Polypogon monspeliensis*, *Ranunculus cornutus*, *Sparganium erectum* subsp. *erectum*, and *Typha angustifolia* (macrophytes) with *Nitzschia palea* (diatom) were located in the positive part of the first axis. *Alisma plantago-aquatica*, *Althaea officinalis*, *Eleocharis palustris*, *Lycopus europaeus*, *Mentha aquatica*, *Oenanthe aquatica*, *Plantago major* subsp.

intermedia, *Polygonum amphibium*, *Potamogeton nodosus*, *Ranunculus saniculifolius*, and *Veronica anagallis-aquatica* subsp. *anagallis-aquatica* (macrophytes) with *Cocconeis placentula*, *Cymatopleura solea*, *Encyonema minutum*, and *Ulnaria ulna* (diatoms) were located in the negative part of the first axis in the ordination diagram of the CA and were related to each other (Fig. 4).

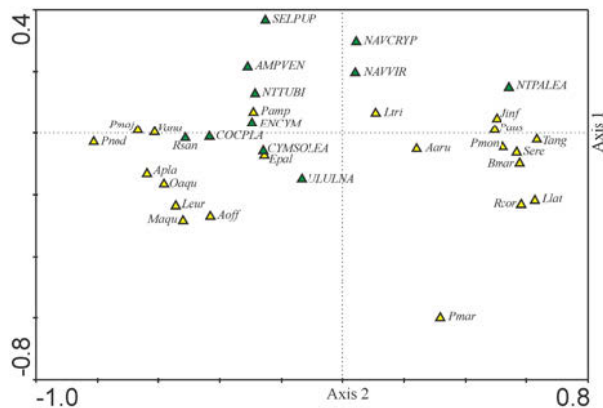


Fig. 4. Correspondence Analysis (CA) computed on the relative abundance of diatoms and the relative percentage cover of individual macrophyte species.

Diatom and macrophyte indices

The average values of SI were 2.25 at site SL1 and 2.32 at site SL2, indicating an α - β -mesosaprobic level. Sites SL3 and SL4 had the highest mean values, 2.85 and 2.83, respectively, indicating an α -mesosaprobic level. The average values of TDI at the upstream sites varied between 66.6 and 69.3, indicating eutrophication. There were increases in TDI values downstream. TDI values also indicated that sites SL3 and SL4 were eutrophic and organically polluted. The average values of EPI-D were 2.02 at site SL1 and 2.18 at site SL2, indicating a moderately polluted status. Sites SL3 and SL4 had the highest average values at 2.41 and 2.47, respectively. This was an indication of the poor quality of the water (Fig. 5).

The average values of IBMR were calculated as a mean of 10.28 at site SL1 and 10.06 at site SL2. These values indicated moderate organic pollution and eutrophication. There were slight decreases in IBMR values at the downstream sites, with 9.44 at site SL3 and 9.13 at site SL4. IBMR values indicated that sites SL3 and SL4 were badly polluted by organic pollutants (Fig. 5).

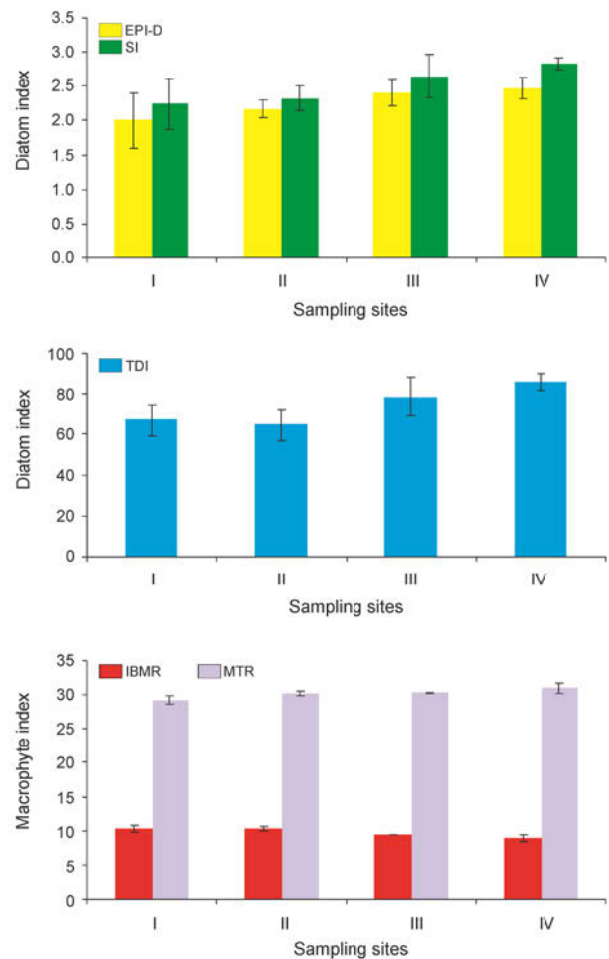


Fig. 5. Changes in the diatom index (EPI-D, SI and TDI) and macrophyte index (IBMR and MTR) at sampling sites along Akarçay Stream.

The average values of MTR at all sites studied were similar: 29.26 at SL1, and 29.93 at SL2, 30.2 at SL3, and 31.63 at SL4. These values indicate that the stream was damaged by either eutrophication or organic pollution (Fig. 5).

The results of the statistical analysis also showed that diatom and macrophytes indices (except IBMR) had strong positive correlations with BOD₅, COD, TDS, NH₄-N, NO₂-N, PO₄-P and EC. Pearson correlation coefficients showed that most of the diatom indices and MTR had significant, negative correlations with DO (Table 4). Very strong positive correlations were found between calculated diatom and macrophytes indices, except for IBMR. Both diatom indices and macrophytes indices indicated that the Akarçay River were eutrophicated and organically polluted (Table 5).

Table 4

Pearson correlation coefficients between diatom indices, macrophyte indices, and chemical and physical variables of water.

	PH	EC	TDS	NH ₄ -N	NO ₂ -N	NO ₃ -N	PO ₄ -P	DO	BOD ₅	COD
IBMR	-0.012	-0.218	-0.619**	-0.502**	-0.295	0.088	-0.740**	0.519**	-0.727**	-0.664**
MTR	0.227	0.381*	0.538**	0.300	0.107	-0.065	0.677**	-0.498**	0.570**	0.586**
TDI	0.161	0.172	0.709**	0.640**	0.481**	0.174	0.783**	-0.507**	0.725**	0.722**
SI	-0.032	0.096	0.540**	0.521**	0.349*	0.016	0.687**	-0.546**	0.667**	0.630**
EPI-D	0.072	0.196	0.569**	0.543**	0.399*	-0.073	0.649**	-0.663**	0.612**	0.627**

** - Correlation is significant at the level of $p < 0.01$.

* - Correlation is significant at the 0.05 level.

Table 5

Pearson correlation coefficients between diatom indices and macrophytes indices.

	IBMR	MTR	TDI	SI	EPI-D
IBMR	1				
MTR	-0.748**	1			
TDI	-0.725**	0.500**	1		
SI	-0.702**	0.622**	0.755**	1	
EPI-D	-0.584**	0.450**	0.731**	0.821**	1

** - Correlation is significant at the level of $p < 0.01$.

EPI-D - Diatom-Based Eutrophication/Pollution Index;

SI - Sabrobic Index;

TDI - Trophic Diatom Index;

IBMR - the Biological Macrophyte Index of Rivers;

MTR - Mean Trophic Rank.

DISCUSSION AND CONCLUSION

The chemical analyses obtained from the study showed that the stream was polluted with organic matter. DO was recorded at very low concentrations for sites SL3 and SL4. This level of DO downstream could be considered a result of the oxygen demands of biochemical oxidation and nitrification (Soyupak et al. 1993). TDS, BOD₅, COD, NH₄-N, NO₂-N, and PO₄-P concentrations were highest downstream. CCA analysis also showed that DO had a negative correlation with TDS, BOD₅, COD, NH₄-N, NO₂-N, and PO₄-P concentrations, increasing with organic pollution. TDS, BOD₅, COD, NH₄-N, NO₂-N, and PO₄-P values exhibited a dramatic increase downstream. According to the evaluation of water quality by LAWA (1980), upstream water quality was classified as class II-III on the basis of DO, TDS, BOD₅, COD, NH₄-N concentrations and downstream water quality as class IV-V on the basis of DO, TDS, BOD₅, COD, and NH₄-N concentrations.

Our results indicated that TDS, BOD₅, COD, and

nutrient (NH₄-N, NO₂-N, PO₄-P) concentrations were the main variables in determining the structure of epipellic diatom communities in the stream. In the CCA ordination diagram, *Nitzschia palea* was placed near the BOD₅, COD, NH₄-N, NO₂-N and PO₄-P vectors. This species was dominant in the diatom assemblages at both the SL3 and SL4 sites downstream heavily polluted by urban, industrial, and agricultural wastes. *Nitzschia palea* was then established as an indicator species for polysaprobic or hypereutrophic environments, occurring in waters with low concentrations of dissolved oxygen according to Van Dam et al. (1994). Cox (1996) states that this species was found in α -mesosaprobic to polysaprobic environments. Palmer (1969) reported that *N. palea* was the diatom species most tolerant of organic pollution. Similar reports on *N. palea* were noted by a number of researchers (Gómez and Licursi 2001, Soininen 2002, Bellinger et al. 2006, Szczepocka and Szulc 2009). This species is also commonly found in polluted Turkish rivers (Gürbüz and Kivrak 2002, Dere et al. 2006, Kalyoncu et al. 2009, Solak 2011). In the CCA ordination diagram, *Navicula cryptocephala* was placed near axis 1 and axis 2 in the positive part of the first axis near TDS and the NO₂-N vector, and these species were established as indicator species of α -mesosaprobic or oligo- to eutraphentic (hypereutraphentic) environments, according to Van Dam et al. (1994). *Navicula* species are abundant in many rivers and lakes throughout Turkey (Soylu and Gönülol 2005, Dere et al. 2006, Kalyoncu et al. 2009, Solak 2011). Nather Khan (1990) explained that this species of *Navicula* was common and abundant in both organically enriched and non-enriched areas. In the CCA ordination diagram, *Amphora venata*, *Cocconeis placentula*, *Cymatopleura solea*, *Encyonema minutum*, *Navicula pupula*, and *Nitzschia tubicola* were located near the DO vector in the negative part of the first. The above-mentioned species are also established as indicator species of generally β -mesosaprobic or eutraphentic

environments according to Van Dam et al. (1994). They are abundant in eutrophic habitats worldwide (Kwandrans et al. 1998, Soininen 2002, Szczepocka and Szulc 2009). These species were also found in eutrophic habitats in rivers in Turkey (Gürbüz and Kıvrak 2002, Dere et al. 2006, Kalyoncu et al. 2009).

Lemna trisulca appeared to cover the highest percentage of the bottom at all sites and showed a wide distribution along the stream bottom. *Lemna trisulca* was reported to grow in chalky and mesotrophic regions (Haslam 1982). *Lemna trisulca* was classified as an indicator of tolerance to eutrophication throughout Europe by Penning et al. (2008). *Plantago major* subsp. *intermedia*, *Polygonum amphibium*, *Ranunculus saniculifolius* and *Veronica anagallis-aquatica* subsp. *anagallis-aquatica* covered relatively high percentages of the river bottom upstream. *Bolboschoenus maritimus* var. *maritimus*, *Juncus inflexus*, *Phragmites australis*, *Polygomon monspeliensis* *Sparganium erectum* subsp. *erectum*, and *Typha angustifolia* covered the highest percentages of the river bottom downstream. Most of the aquatic *Ranunculus* species were present in alkaline eutrophic waters in Mediterranean climates (Lumberas et al. 2009). Robach et al. (1996) reported *Potamogeton nodosus* from eutrophic and hard waters in France. Haury et al. (2006) observed this species in hypertrophic waters with $\text{NH}_4\text{-N}$ at $255 \mu\text{g l}^{-1}$ and $\text{PO}_4\text{-P}$ at $191 \mu\text{g l}^{-1}$, while our studies showed that it can develop at even higher values of $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$, $400 \mu\text{g l}^{-1}$, and $340 \mu\text{g l}^{-1}$, respectively. CA showed that there was a clear relationship between *Potamogeton nodosus* and eutraphentic diatom species (*Amphora venata*, *Cocconeis placentula*, *Cymatopleura solea*, *Encyonema minutum*, *Navicula pupula*, *Nitzschia tubicola*).

The diatom indices (SI, TDI and EPI-D) indicated that Akarçay Stream was organically polluted and these indices were positively correlated with BOD_5 , COD, TDS, $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$, $\text{PO}_4\text{-P}$ and EC. Most of the diatom indices applied to Europe and Turkey's rivers were clearly related to water quality variables (such as COD and BOD_5) indicating organic pollution (Kwandrans et al. 1998, Gürbüz and Kıvrak 2002, Kalyoncu et al. 2009, Solak 2011). Macrophyte indices also showed that Akarçay Stream was both eutrophic and organically polluted, and they were clearly related to water quality variables such as COD and BOD_5 .

We found that in Akarçay Stream, pollution-tolerant diatom and macrophyte taxa were present in large quantities. Multivariate analyses (CCA and CA) also showed a significant relationship between

diatoms, macrophytes, and water quality variables. Physicochemical variables, diatom and macrophyte taxa, and the results of indices calculated in Akarçay Stream all indicated that the pollution increased intensely downstream. This is due to exposure to pollution by sewage and factory discharges downstream. Therefore, there was an increase in the population of tolerant species downstream. In this respect, diatoms and macrophytes could be recommended as the best indicators of environmental conditions according to the Water Framework Directive (WFD) (European Union 2000, Schaumburg et al. 2004). Water quality evaluation using diatom and macrophyte indices is a new topic in Turkey and little work has been done in this area of study. The use of diatom and macrophyte indices as a tool in evaluating the water quality of inland waters will become one of the more focused research areas in Turkey.

ACKNOWLEDGEMENT

The authors wish to thank Dr H Shazly, Swansea-UK, for editing the language of this paper.

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