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Seasonal Variations and Occurrence of Epiphytic Diatom Assemblages on Mats of *Cladophora glomerata* in Lake Ladik, Samsun, Turkey

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Abstract – The composition and seasonal variations of epiphytic diatoms from Lake Ladik were studied using samples collected from one station between June 2000 and May 2001. 50 taxa of diatoms were identified in the epiphyton. *Gomphonema olivaceum*, *Gomphonema minutum* and *Nitzschia fonticola* were particularly important on *Cladophora*. During the winter several species of *Navicula* become progressively more important. *Gomphonema lateripunctatum* was particularly notable. Other diatoms were occasionally abundant, including *Cyclotella ocellata*, *Aulacoseria distans*, *Cymbella affinis*, *C. ventricosa* and *Navicula halophila*. *Fragilaria ulna* and *Gomphonema ventricosum* were conspicuous, owing to their large size, but never numerically abundant.

Cluster analysis was applied to the epiphytic algae community. The seasonal variations of the samples were classified according to their similarity levels. Samples were collected, species richness and diversity (Shannon-Wiener, *H'*) were measured monthly. The relationship between the algal composition and physicochemical variables is analyzed by means of Canonical Correspondence Analysis techniques.

***Cladophora glomerata* / lake / species composition / seasonal variation / CCA / cluster analysis / shannon diversity / evenness**

Résumé – Variation saisonnière et composition des communautés de diatomées épiphytes sur les tapis de *Chladophora glomerata* dans le lac Ladik, Samsun, Turquie. La composition et la variation saisonnière des diatomées épiphytes dans une station du lac de Ladik a été étudiée sur des prélèvements effectués entre juin 2000 et mai 2001. 50 diatomées ont été identifiées dans l'épiphyton. *Gomphonema olivaceum*, *Gomphonema minutum* et *Nitzschia fonticola* sont particulièrement développées sur *Cladophora*. Pendant l'hiver quelques espèces de *Navicula* deviennent progressivement plus importantes. *Gomphonema lateripunctatum* est particulièrement remarquables. D'autres diatomées comme *Cyclotella ocellata*, *Aulacoseria distans*, *Cymbella affinis*, *C. ventricosa* et *Navicula halophila* sont occasionnellement abondantes. *Fragilaria ulna* et *Gomphonema ventricosum* sont très visibles par leur grande taille, mais sont peu abondantes.

Une analyse par dendrogramme a été appliquée à la communauté d'algues épiphytes. Les variations saisonnières sont classées d'après leur niveau de ressemblance. On a calculé la richesse et la variété des espèces ramassées mois par mois (Shannon-Wiener, *H'*). La relation entre la variété algale et les variables physicochimiques a été mise en évidence par des analyses de correspondance.

***Cladophora glomerata* / lac / composition spécifique / variation saisonnière / CCA / analyse par dendrogramme / indice de diversité de Shannon / abondance spécifique relative**

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INTRODUCTION

Cladophora Kützing is distributed worldwide in fresh and marine waters and provides habitat and food for numerous organisms. Generally, *Cladophora* is an attached benthic alga, growing on rocks and other substrata in nearshore water where it can become detached and accumulate along the shoreline as large mats, but it can also be found as floating mats or as loose masses on soft substrata. Growths of *Cladophora* reach nuisance proportions at times in a water body, often as a result of eutrophication; however, in natural water systems *Cladophora* is found at lower densities. Problems attributed to such blooms include: clogging of water works, excessive diurnal swings in O_2, fouling of fish lines, unpleasant odours and appearance, and lowering of property values.

Diatoms are the most common and diverse group of algae in freshwater and important components of ecosystems. These communities play an important role as primary producers in aquatic ecosystems. To effectively manage and restore aquatic resources, managers must identify which water bodies or portions of water bodies are affected, and to what degree the systems have been degraded. Accordingly, diatom assemblages have been effectively used as indicators of environmental change, for example, eutrophication, acidification, salinification, sea level change and land use change, because they have narrow tolerance for many environmental variables. In addition, epiphytic diatoms may be especially useful as biological indicators of inputs to water bodies as they are ubiquitous, sessile, and integrate physical and chemical characteristics over time (O'Connell *et al.*, 1997).

The annual cycle of algae epiphytic on *Cladophora glomerata* (L.) Kützing in a tributary near the head of River Wylye (UK) were studied by Moore (1977). Surveys of the occurrence and abundance of epiphytic algae on *Cladophora glomerata* in the River Skawa (Poland) were made by Chudyba (1965, 1968) while Allen (1971) studied the production of epiphytes on littoral macrophytes of a North American lake. Dodds (1991) studied community interactions between the filamentous alga *Cladophora glomerata*, its epiphytes, and epiphyte grazers in several large Montana Rivers. In addition, seasonal variations of phytoplankton (Maraşlıoğlu *et al.*, 2005a) and epilithic diatoms of Lake Ladik (Turkey) were investigated by Maraşlıoğlu *et al.* (2005b).

The main goals of our study are to determine the structure of diatom assemblages epiphytic on *Cladophora*, considering the environmental factors affecting diatom abundance, and determine the temporal changes in the diversity and richness of the epiphytic diatoms in Lake Ladik. The relationship between algal composition and physicochemical variables is analyzed by means of Canonical Correspondence Analysis techniques.

MATERIALS AND METHODS

Study Area

Lake Ladik (36°01'15" E, 41°03'45" N) is located in the North of Turkey. It is near the Ladik-Taşova highway, 10 km from Ladik-Samsun (Fig. 1). The total surface area of the lake is about 10 km^2; the depth averages from 2.5 to 3 meters.

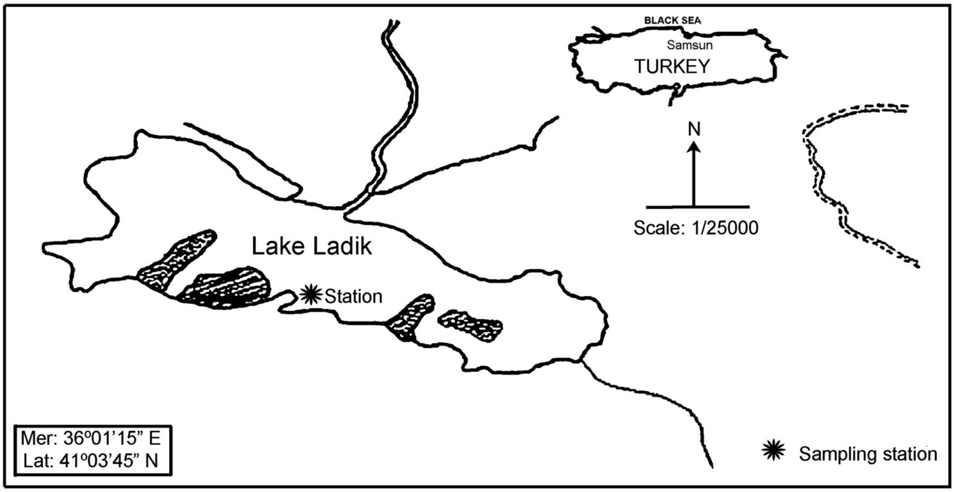

Fig. 1. Lake Ladik and Sampling station.

The lake is generally eutrophic, resulting in increased *Cladophora* growth and reduction in species richness and stability in the Ladik ecosystem.

The lake habitat is composed of alluvial sediments supplied by tributaries from the North slope of Ak Mountain. Ladik includes volcanic agglomerate (rock composed of rounded or angular volcanic fragments) belonging to Mesozoic age, conglomerate (sedimentary rocks composed of more than 50% particles that are larger than 2 mm) sandstone and chipping belonging to Neogene age. The climate of the study area has a transitional character between oceanic and continental climate. Therefore the climate regime in the area is characterised by the transition from the climate of the Middle Black Sea Region to that of Central Anatolia (Aydın, 1997).

Cladophora glomerata was sampled at one site from a known surface of the lake bottom between June 2000 and May 2001. The station was located near the north of Gölbaşı restaurant, 30 m away from the Ladik-Taşova highway. The benthic zone of the lake consists of brown coloured mud. Samples were collected monthly at 0.3-1 m depth from the shallow littoral zone. *Cladophora glomerata* and its epiphytes were placed in a Whirl-pak^{TM} containing 100 ml of filtered Ladik Lake water and shaken for 60s to remove periphyton. This procedure removed at least 80% of the diatoms, based on microscopic analysis, and was found to be the most effective technique for separating intact epiphytic diatoms from *Cladophora* filaments (Blinn *et al.*, 1995). Epiphytic diatom samples were preserved in 4% formaldehyde. For preparing permanent slides, sub-samples were taken and H_2SO_4-HNO_3 (50:50) solutions were added to dissolve organic material. These samples were boiled on a hot plate for 15 minutes to expedite the destruction process and were subsequently left for cooling. Samples were neutralized by rinsing with distilled water and dried on to cover slips. Prepared slides were mounted in Naphrax high refractive index medium. At least 600 diatom valves per slide were counted and identified under oil immersion at 1000X magnification on a Nikon microscope. The taxonomic identification was mainly based on Krammer & Lange-Bertalot (1991a, b, 1999a, b).

At the time of sampling, the water temperature, pH and conductivity were measured *in situ* with C 534 multi-parameter analyser (Consort nv, Belgium). Other chemical analyses were measured by C 200 multiparameter ion specific meter.

The data set was analysed by a cluster analysis (complete linkage method) applied to a dissimilarity matrix obtained from the calculation of the Bray-Curtis index. The diversity (log 10 base) calculated by the Shannon-Wiener index (Shannon & Weaver, 1949) and dissimilarity matrix were computed with BioDiversity Professional 2.0. The species richness was represented as the total number of taxa presented within the samples. Canonical Correspondence Analysis (CCA) was carried out using Multi-Variate Statistical Package.

RESULTS

Some physical and chemical properties of the surface water of the lake are presented in Table 1. The water temperature varied between 7 and 28ºC; the maximum water temperature (28ºC) was observed in July and the minimum temperature (7ºC) in December, January, and February. pH fluctuated between 6.9 and 8.6, indicating a slightly alkaline environment. Nitrate reached maximum values in the spring months (about 1.5 mg/l), and minimum values (0.35 mg/l) in the summer months. Although phosphorus was very low, with values around 0.001 mg/l during summer, its concentration increased (0.22 mg/l) in December. The total hardness in the lake varied between 120 and 198 mg/l $CaCO_3$.

Table 1. Some physical and chemical properties of Lake Ladik during 2000-2001.

Parameters	*Lake Ladik*											
	Summer months			*Autumn months*			*Winter months*			*Spring months*		
	Ju	*Jy*	*Au*	*Se*	*Oc*	*No*	*De*	*Ja*	*Fe*	*Ma*	*Ap*	*My*
Temperature (ºC)	23	28	22	21	17	12	7	7	7	9	14	19
PH	7.9	8	8.5	8	7.2	7.5	7	6.9	7	8.5	8.6	8
Elec. cond. (mhos/cm)	325	217	275	290	280	300	278	336	306	444	215	220
Cl^{-2} (mg l^{-1})	7.5	6.8	7	7	7	7.2	7.2	7	7.4	7.5	6.7	6.7
NH_3-N (mg l^{-1})	0.09	0.02	0.04	0.08	0.09	0.5	0.4	0.5	0.5	0.1	0	0.1
NO_3^- (mg l^{-1})	0.49	0.35	0.38	0.42	0.4	0.9	0.5	0.9	0.4	1.01	0.7	1.5
PO_4^3 (mg l^{-1})	0.001	0.001	0.001	0.02	0	0.03	0.22	0.1	0.19	0.08	0.05	0.03
SO_4^{2-} (mg l^{-1})	4.9	5.8	5.15	18	22	28	26.2	28.6	33.1	58	36	28
Na^+ (mg l^{-1})	7.2	6.9	6.6	7.9	8	12	9	8.1	7.07	9	10	6
K^+ (mg l^{-1})	2.6	2.1	2.3	2.3	3	2.7	2.6	2.1	2.3	2.1	2.2	2.1
Ca^{2+} (mg l^{-1})	46	49	46	44	41	45	44	44	42	44	36	34
Tot. hard.$CaCO_3$ (mg l^{-1})	120	141	121	135	140	152	198	189	197	168	175	190

Table 2. The list of epiphytic diatoms in Lake Ladik. Key: *** = Present, ** = sometimes present, * = seldom present on *Cladophora*; Numbers indicate species selected for CCA analysis.

Amphora delicatissima Krasske	*
Amphora pediculus (Kützing) Grunow	*
Aulacoseria distans (Ehrenberg) Simonsen 1	**
Cocconeis pediculus Ehrenberg 2	**
Cocconeis placentula Ehrenberg	*
Cyclotella ocellata Pantocsek 3	**
Cymbella affinis Kützing 4	**
Cymbella brehmii Hustedt	*
Cymbella cistula (Hemprich) O. Kirchner	*
Cymbella lanceolata Ehrenberg	*
Cymbella prostrata (Berkeley) Cleve 5	**
Cymbella ventricosa C. Agardh 6	**
Diatoma vulgaris Bory	*
Epithemia adnata (Kützing) Brebisson	*
Fragilaria ulna Lange-Bertalot 7	**
Gomhonema affine Kützing	*
Gomphonema angustum Agardh	*
Gomphonema lateripunctatum Reichardt *et* Lange-Bertalot 8	**
Gomphonema longiceps Ehrenberg var. *subclavata* Grunow 9	**
Gomphonema minutum (C. Agardh) C. Agardh 10	***
Gomphonema olivaceum (Hornemann) Brebisson 13	***
Gomphonema parvulum (Kützing) Kützing 11	**
Gomphonema truncatum Ehrenberg	*
Gomphonema ventricosum Gregory 12	**
Gyrosigma acuminatum (Kützing) Rabenhorst	*
Gyrosigma distortum (W. Smith) Cleve	*
Melosira varians C. Agardh	*
Navicula cari Ehrenberg 14	**
Navicula cryptocephala Kützing 15	**
Navicula cuspidata (Kützing) Kützing 16	**
Navicula gregaria Donkin 17	**
Navicula halophila (Grunow) Cleve 18	**
Navicula heufleriana (Grunow) Cleve	*
Navicula lanceolata (Agardh) Ehrenberg	*
Navicula laterostrata Hustedt	*
Navicula placentula (Ehrenberg) Kützing	*
Navicula radiosa Kützing	*
Navicula rhynchocephala Kützing	*
Navicula veneta Kützing 19	**
Nitzschia angustata (W. Smith) Grunow	*
Nitzschia fonticola Grunow 20	**
Nitzschia heufleriana Grunow 28	**
Nitzschia palea (Kützing) W. Smith 21	**
Nitzschia paleacea (Grunow) Grunow 22	**
Nitzschia sublinearis Hustedt	*
Nitzschia umbonata (Ehrenberg) Lange-Bertalot	*
Pinnularia microstauron (Ehrenberg) Cleve	*
Pinnularia molaris Grunow	*
Rhoicosphenia curvata (Kützing) Grunow 23	**
Surirella linearis W. Smith	*

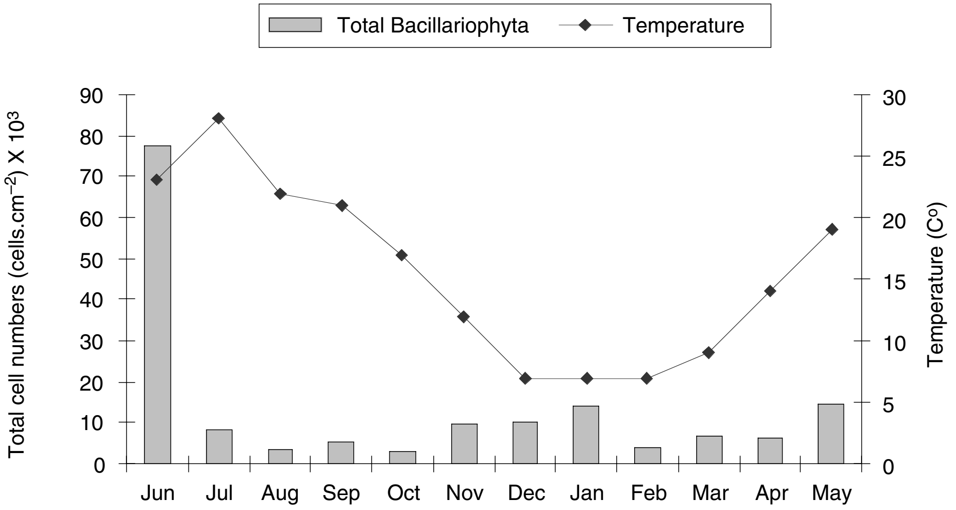

Fig. 2. The seasonal variation of total Bacillariophyta in the epiphyton and temperature during 2000-2001.

50 taxa were identified in the epiphytic diatoms samples from Lake Ladik. The list of the recorded species and selected species for Canonical Correspondence Analysis (CCA) is presented in Table 2. The total numbers of epiphytic algae on *Cladophora* ranged between 2880 cells.cm^{-2} in October and 77520 cells.cm^{-2} in June (Fig. 2). *Gomphonema olivaceum*, *G. minutum* and *Nitzschia fonticola* were especially prominent diatoms and ranged between 1% and 75% of algal cells in all samples throughout the year. *Gomphonema minutum* (up to 35% of all algal cells) was important during summer and autumn, but not in winter and spring. *Navicula lanceolata* (up to 30%), *Navicula cryptocephala* (up to 74%) increased through winter and spring. *Nitzschia angustata* comprised 23% of the diatom community in January. *Melosira varians*, *Amphora delicatissima*, *A. veneta*, *Cocconeis placentula* var. *euglypta*, *Cymbella cistula*, *C. ventricosa*, *Gomphonema parvulum*, *Navicula gothlandica, N. gregaria*, *N. radiosa*, *Pinnularia gibba* var. *parva*, *P. microstauron*, *P. silvatica* and *Surirella angusta* were recorded from only one sample during the sampling period.

The seasonal variations of *Gomphonema olivaceum*, *G. minutum* and *Nitzschia fonticola* made the greatest contribution to the diatom community (Fig. 3).

Shannon diversity and evenness presented small variations during the study period. Relative species abundance (evenness) around 0 indicates high single-species dominance (*Gomphonema olivaceum*) that formed 67% of the density in June. The bloom pattern of this species with a resulting decrease of *H’*, also indicates low evenness. Lake Ladik presented low values of species richness and for the six months of the study period the seasonal variations of species richness presented small modifications. The highest values were recorded in January (Fig. 4).

The diagram obtained by cluster analysis indicates that at the lowest hierarchical level two clusters are clearly separated in the station (Fig. 5). The first

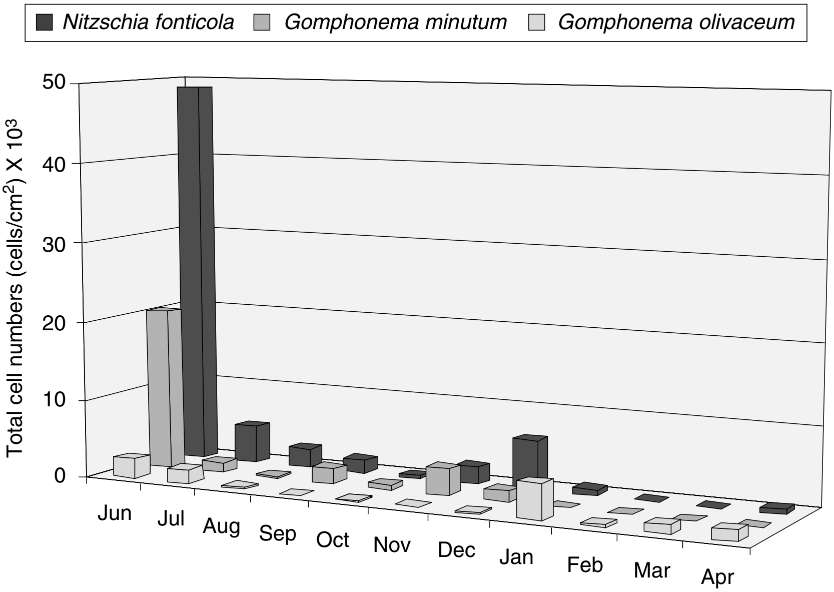

Fig. 3. The seasonal variations of *Nitzschia fonticola*, *Gomphonema minutum* and *Gomphonema olivaceum* in the epiphyton.

cluster, formed by autumn, winter and spring samples, is from the absolute prevalence of *Gomphonema olivaceum* and *G. lateripunctatum.* The second group includes summer and autumn samples and characterised by the dominance of *Gomphonema olivaceum* together with *G. minutum*. The association of August and September unites with July, November and December, which in turn unites with May are most significant in the study period.

Among the variables analyzed, only ten of twelve were included in the model by forward selection (temperature, pH, conductivity, NH_3-N, NO_3^-, PO_4^-, SO_4^-, Na^+, K^+, Ca^{++} and $CaCO_3$). The first two axes accounted for 58.7% of the variance (axis 1: 43.5%; axis 2: 15.2%). The first eigenvalue indicated that abiotic factors were significantly correlated with the first axis.

The diplot of the species and environmental variables according to the first two axes is shown in Fig. 6. The taxa illustrated were selected taking in to account their abundance, frequency of occurrence along the study period and their fitness to the environmental variables included in the model.

The first axis is mainly defined by a combination of temperature and $CaCO_3$ (intra-set correlation coefficients: –0.73; 0.67 respectively). Axis 2 is mainly correlated with K^+, NO_3^- and conductivity (intra-set correlation coefficients: 0.46; –0.45; 0.42).

While most of the species are ordinated towards the right side of the figure, some species such as *Gomphonema minutum* (10) *G. olivaceum* (13) and *Navicula gregaria* (17), are plotted towards the left side. There is an association between *Gomphonema olivaceum* (13), *G. minutum* (10), *Navicula gregaria* (17) and K^+, temperature in June, August, September and December months. Also *Navicula cari* (14), *N. cuspidata* (16), *N. veneta* (19), *Nitzschia palea* (21),

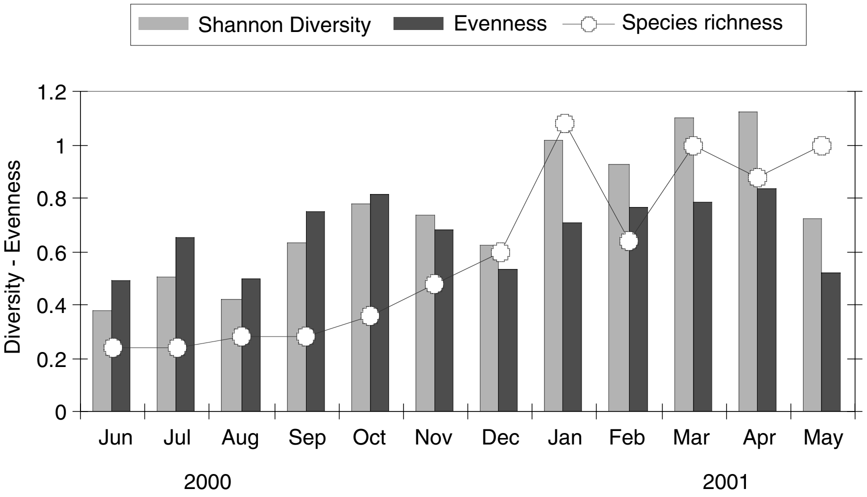

Fig. 4. Shannon Diversity (log 10 base) calculated by the Shannon-Wiener index, evenness and species richness in the epiphyton.

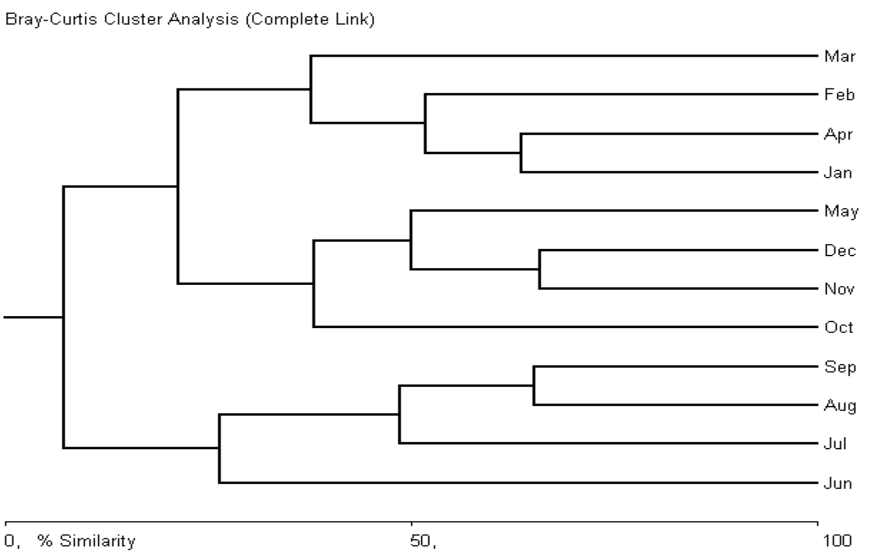

Fig. 5. Dendrograms for hierarchical clustering of the months in Lake Ladik, using complete linking of Bray-Curtis similarities calculated epiphyton abundance data during 2000-2001.

N. paleaceae (22) and *Cymbella ventricosa* (6) species indicated a relation with $CaCO_3$. In this analysis, *Navicula cryptocephala* (15) and October, February, March months were not correlated with abiotic factors, other species and other months (Fig. 6).

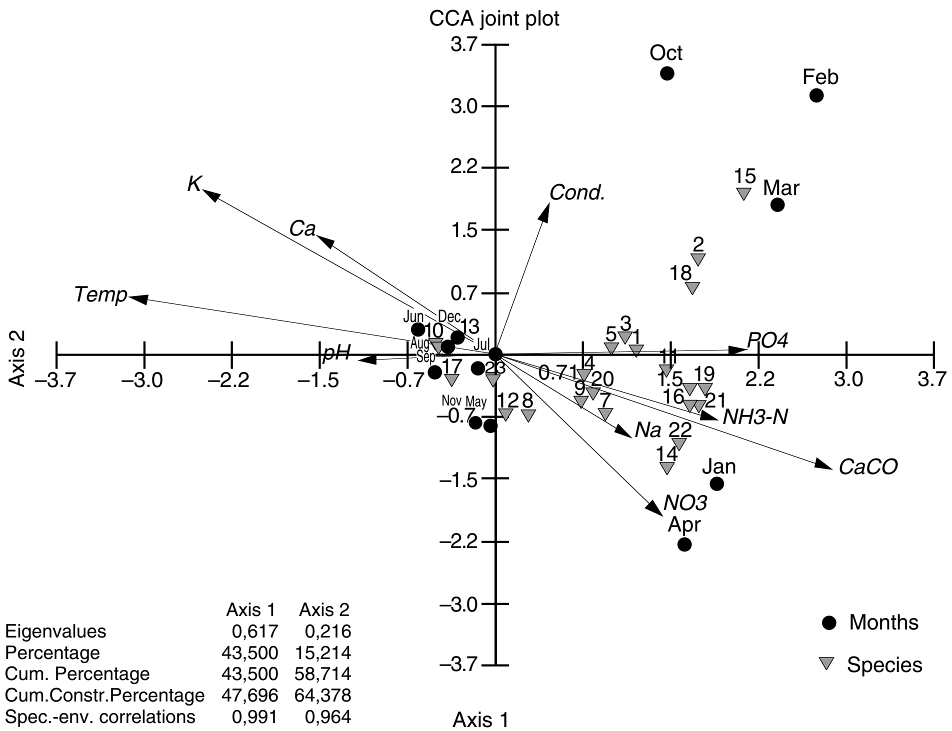

Fig. 6. Species and months biplot based on the Canonical Correspondence Analysis of the algal densities and sampling months in Lake Ladik. Only the selected species indicated with a number in Table 1 are displayed. Environmental variables are indicated by arrows.

DISCUSSION

The persistence and survival of diatoms on *Cladophora* under natural conditions seems to depend on a variety of factors (temperature, sunlight and predation). Michel *et al.* (1989) stated that temperature has been proposed to be one of the factors determining algal growth and photosynthetic activity, while cold temperatures have been shown to restrict algal mobility (Raven & Geider, 1988). Our multivariate analysis showed temperature was an important factor in the distribution and abundance of diatoms in our study area. However, it is interesting that total cells numbers were also found to be low in August when water temperature was high. So, diatom assemblage may be affected indirectly by temperature. In agreement with what has already been suggested by Blinn *et al.* (1989), frequencies of *Rhoicosphenia curvata* and *Diatoma vulgare* decreased when water temperature was > 18ºC. But these species were found to be abundant in winter months in Lake Ladik. In the summer *Cladophora* dies off, a phenomenon normally related to temperature, as discussed by Shamsudin & Sleigh (1995); it was not recorded by Moore (1977) in the study of the River Wylye or in our study area.

It is known that nutrients are important for the physiological and growth activities of all organisms. In the surface water of Lake Ladik, nitrate values varied between 0.35 and 1.5 mg/l while phosphate values were between 0.001 and 0.22 mg/l. These high values were probably because the research area is located between urban areas and excessive usage of fertilizers in the surrounding agricultural areas. Nutrients in municipal wastewater may have had a positive effect on *C. glomerata* biomass. Other investigators have reported increased nutrient loading associated with secondary sewage affluent stimulating growth of *Cladophora* (Auer *et al.*, 1982). Moss (1998) suggests that if the catchment, as is likely, is dominated by agricultural systems; there is an increased chance that the shallow lake will display a loss in user and amenity values due to fertilization.

The level of nutrients (chlorine, ammonia-nitrogen, sodium, calcium and potassium) is low in Lake Ladik. According to the pH values (from between 6.9 and 8.6) the lake is slightly alkaline. *Cladophora glomerata* is known to rely on high pH values (Schönborn, 1996). Algal growth can decline with pH (e.g. Vinebrooke, 1996). Likewise in our study area total cell numbers were found to be low in August and pH value was a minimum in this month. But in some months (Jun., Jan., May), although pH values were low, total Bacillariophyta cell numbers reached high values. Alkalinity-related variables (e.g. DIC, pH) are often the most important variables influencing the distribution and the abundance of diatom taxa (e.g. Dixit *et al.*, 1992). However, it should be kept in mind that other unmeasured variables not included in the Lake Ladik data set may also exert a strong influence, such as physical mixing, day-length effects, grazing, parasitism and availability of microhabitats.

Gomphonema olivaceum, *G. minutum* and *Nitzschia fonticola* were the most abundant and common diatoms in Lake Ladik. However, these diatoms were not found to be abundant in the other Turkish lakes that have similar characteristics (Obalı *et al.*, 1989; Gönülol, 1993; Şahin, 2002). Species of *Cocconeis, Cymbella* and *Rhoicosphenia* are thought to be major components of the epiphyton (Otten & Willemse, 1988). Reavie & Smol (1997) and Hardwick *et al.* (1992) postulated the existence of a distinct diatom assemblage on *Cladophora* in St Lawrence River and the Colorado River. They found *Cladophora* was colonized by an epiphyte assemblage dominated by *Cocconeis pediculus*, *Diatoma vulgare* and *Rhoicosphenia curvata*. Similar assemblages were found at sites in the Great Lakes (Lowe *et al.*, 1982; Stevenson & Stoermer, 1982). However, these species (except *Cocconeis pediculus*) were not found to be common in the epiphytic algal flora of Lake Ladik. Shamsudin & Sleigh (1995) and Hardwick *et al.* (1992) also found *Diatoma* to be prominent on *C. glomerata* in the River Itchen and River Colorada.

Authors have long argued that species abundance and proportional diversity are simply and directly related to species richness (Schluter & Ricklefs, 1993; Stirling & Wilsey, 2001). Species richness was surprisingly low for epiphytic diatom community in our study. This may be due to competition between epiphytes and macrophytes. Previous work has also shown a negative correlation between epiphyte diatoms and *Cladophora* (Stevenson & Stoermer, 1982). Shannon diversity and evenness also presented small variations during the study period. *Gomphonema olivaceum*, which comprised 67% of the assemblage, shows high dominance values, low richness and diversity. One of the reasons of the lowest diversity and species richness in the same station in June was the dominance of *G. olivaceum*. The other reason might be the stability of water column. The influence of water stability on the composition and diversity of the algal community was also found by Figueredo & Giani (2001), Calijuri & Santos (1996) in Brazil.

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