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Original Research

Community Structure, Temporal and Spatial Changes of Epiphytic Algae on Three Different Submerged Macrophytes in a Shallow Lake

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Abstract

The aim of this study was to determine the composition, biodiversity, and relative abundance of epiphytic algal species on three submerged aquatic plant species (the macrophytes *Ceratophyllum demersum*, *Myriophyllum spicatum,* and *Potamogeton crispus*) in Lake Gala in Lake Gala National Park, Turkey, and the associations of the observed relationships with environmental variables. The aquatic plants were collected at monthly intervals between March 2014 and November 2014, and epiphytic algae on the plants were identified. In total, 98, 74, and 66 taxa of epiphytic algae were identified on *C. demersum*, *M. spicatum,* and *P. crispus*, respectively. The species composition of the epiphytic algae on the three macrophyte species showed a statistically significant difference ($F = 7.07$, $p<0.05$). There was also a statistically significant difference in epiphytic algae species diversity, depending on the sampled month ($F = 3.59$, $p<0.05$). The mean species richness and species diversity on *C. demersum* was 33 and 1.546, respectively. On *M. spicatum*, the mean species richness and species diversity was 23 and 1.407, respectively. On *P. crispus*, the mean species richness was 19, and the species diversity was 1.256. The following species were the dominant epiphytic taxa in Gala Lake: *Cocconeis placentula*, *Anabaena constricta, Gomphonema acuminatum, Oscillatoria limosa, Cymbella cistula,* and *Epithemia sorex*. Although the species composition of the epiphytic algae was different, the diversity values were similar on all the macrophyte species.

Keywords: epiphytic algae, biodiversity, shallow lake, submerged macrophytes

Introduction

Macrophytes play an important role in the production of aquatic systems by recycling nutrients and increasing the biodiversity of aquatic organisms [1-2]. In shallow lakes, periphyton is particularly important, contributing to the nutrient cycle, energy flow, and food chain [3-4]. Periphyton can also affect the rate of regeneration in aquatic habitats, support nutrient flow between pelagic and benthic areas, and regulate the amount of light and carbon sources in the water [5]. Epiphyton, which is contained within periphyton, is important for primary producers. Macrophytes have different morphological and physiological characteristics, and macrophyte diversity can affect species diversity and community structure of epiphytic species and periphyton communities [6]. Diatoms, cyanobacteria, and green algae are the main groups of benthic microalgae on macrophytes and

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constitute the greatest part of the epiphyton biomass [7-9].

Epiphytic algae are an important nutrient source for invertebrates and are important for assessing the trophic status of lakes [10]. They are widely used as indicators of water quality because they rapidly respond to hydrological and water quality changes [11]. The responses of these organisms over time to sources of pollution can be determined at the community level [12-13]. Waves can destroy the sediment structure, which in turn leads to reduction in biomass in the wave-zone [14-15]. The effect of waves in deep lakes decreases with increasing depth, but opposite cases can occur in shallow lakes [16]. As the characteristics of each aquatic ecosystem are different, the characteristics of the epiphytes are also different [17]. The aims of this study were: 1) to identify epiphytic algal species associated with three macrophyte species in Lake Gala, a shallow and eutrophic lake within Lake Gala National Park and an important part of the Meriç Delta, which is an international class A wetland, and 2) to identify environmental and hydrological factors affecting the substrate selection of these epiphytes.

Material and Methods

Study Area

Gala Lake, an alluvial dam lake, is located at 40°46′05″N latitude and 26°10′59″E longitudes and is connected to the Meriç River and Saroz Bay (Fig. 1). The lake has a depth of 50-200 cm [18-19]. The area, which was a nature reserve in 1991, was designated a Natural Protected Area in 1992 and a national park (Turkey's 36th) in 2005. The lake is located on one of the two most important bird migration routes in the western Palaearctic region. The lake is feed by the Meriç River, which is surrounded by rice fields. The release of irrigation water from rice farming areas into Gala Lake has resulted in chemical fertilizers and pesticides entering the lake and placing it under permanent anthropogenic-induced stress [20-21].

Sampling

From March 2014 to November 2014 samples were collected at monthly intervals, as winter months are not between March and November, from three submerged macrophyte species (*Ceratophyllum demersum* L., *Myriophyllum spicatum* L., and *Potamogeton crispus* L.) that are dominant in Gala to determine the epiphytic algal composition of the lake. The macrophytes were harvested from the sampling sites using quadrats of 1 m^2 in size in 3-20 replicates, according to standard heterogeneity. The macrophytes in the quadrats were counted. At least three macrophytes were cut above ground level or removed from the ground. They were then washed in 250 ml of distilled water or scrubbed with a brush, and the epiphytic algae were collected. The water used to wash the macrophytes was divided into defined amounts and then subjected to chlorophyll-*a* analysis to determine species composition and count their abundance. For the last purpose subsamples were preserved with mixtures of Lugol's solution and glycerol [22-23].

The washed macrophytes were placed in separate polyethylene bags for biometric analysis, transported to the laboratory, and stored at 4ºC. The number and density of submerged macrophytes per 1 m^2 in the lake, number and density of epiphytic algae on the macrophytes, and chlorophyll-*a* concentration of the epiphytic algae in the sampled material were determined [24-26]. In addition,

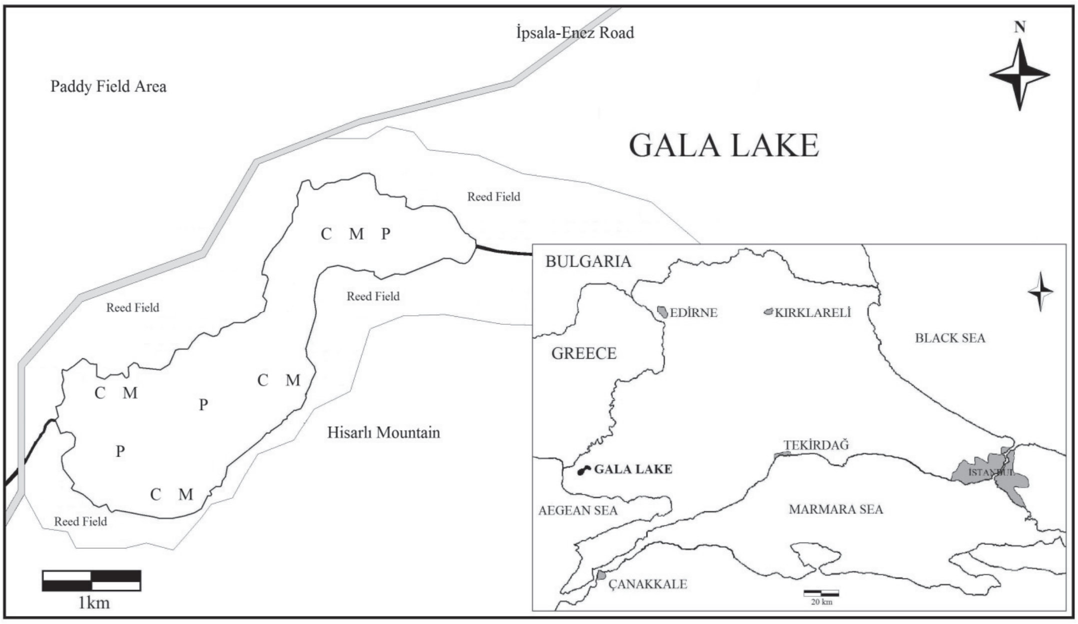

Fig. 1. The macrophyte distribution and sampling localities in Gala Lake (C: *Ceratophyllum demersum*, M: *Myriophyllum spicatum*, and P: *Potamogeton crispus*).

Table 1. Some physicochemical parameters measured in Lake Gala during the study period.

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
D.O.	14.1	**15.2**	13.2	12.4	10.8	**9.5**	12.6	9.6
NO_3-N	**7.2**	4.04	1.8	4.4	1.19	1.88	3.32	**0.01**
NO_2-N	0.001	0.00	0.00	0.00	0.00	0.00	0.24	0.02
o-PO_4	**0.01**	**0.01**	**0.01**	**0.06**	0.03	0.03	0.03	**0.06**
pH	**8.1**	8.4	**8.7**	8.2	8.3	8.2	8.3	8.4
Con.	145	**143**	187	163	270	250	310	**320**
Temp.	14.8	17.8	19.3	26.7	27.6	25.6	23.6	19
Secchi	48	**46**	56	47	76	**91**	26	51
Depth	**198**	111	126	164	128	132	145	**109**

D.O. (dissolved oxygen $mg.L^{-1}$), NO_3-N (nitrate-nitrogene $mg.L^{-1}$), NO_2-N (nitrite-nitrogene $mg.L^{-1}$), o-PO_4 (orthophosphate $mg.L^{-1}$), Temp. (water temperature ºC) and Con. (electrical conductivity $\mu S.cm^{-1}$), Secchi (cm), Depth (cm)

sub-surface water samples were collected using a Ruttner water sampler to analyse the physico-chemical properties of the water column and changes in these properties during the study period.

Analyses

The samples were dried in oven at 85ºC for 24 h, and the dry mass of the macrophytes collected from the lake was then determined. To identify the epiphytic algae samples collected after washing the macrophytes in 250 ml of distilled water, a light microscope was used, with the samples placed under temporary mounts. The samples used for determining the diatoms (50 ml) were first washed in a 1:1 mixture of H_2SO_4 and HNO_3 and purified with distilled water. Permanent preparations were obtained using Naphrax. An average of 600-800 valves were counted on each preparation, the number of frustules in a pre-determined length was determined, and species identification was done using an Olympus CX21 microscope [27]. Sub-samples (10-25 ml and 50 ml) were also prepared, precipitated according to the Utermöhl method, and an inverted microscope (Olympus CK2 series) was used for organism counting and calculations [28].

Algal identification was done at 1000×magnification under immersion oil according to established methods [29-34]. All the identified species were checked in algaebase [35]. Chlorophyll-*a* analysis was made according to Nush (using a Cecil 5502 instrument) [36].

Water temperature, pH, dissolved oxygen, and conductivity values were measured at the sampling sites using portable equipment and probes (Lovibond-SensoDirect). Water transparency was measured at the sampling sites using a Secchi Disc. Nitrate nitrogene (NO_3-N), Nitrite nitrogene (NO_2-N), and orthophosphate (o-PO_4) values were measured in the laboratory in accordance with APHA-AWWA-WPCF methods [37].

Species density in cm^2 was calculated according to the method of Ros et al. by finding the surface area of macrophytes in which epiphytic samples were collected [38-39]. Biovolume calculations were done according to the methods of Hillebrand et al. and Sun and Lui [40-41]. The biovolume value of each species was mathematically determined, and the results were given in $mm^3.cm^{-2}$. The species diversity (H′) and evenness index were calculated using equations developed by Shannon and Weaver. Pearson correlations between the environmental variables and species diversity, richness, and evenness were determined using SPSS 22.0 software [42]. To classify the algal composition on different macrophytes, cluster analyses was used and canonical correspondence analysis (CCA) was carried out using the XLSTAT-ADA statistical package [43]. CCA was carried out on the log-normal transformed abundance data to determine the relationships between the algae, environmental variables, and the sampling period.

Results

Environmental Variables

During the study period, the highest temperature was 27.6ºC, and the lowest was 14.8ºC. The highest pH was 8.7 and the lowest was 8.1. The highest and lowest dissolved oxygen levels were 15.2 $mg.L^{-1}$ and 9.5 $mg.L^{-1}$, respectively. The level of NO_3-N varied from 0.01 $mg.L^{-1}$ to 7.2 $mg.L^{-1}$, and conductivity varied from 143 $\mu S.cm^{-1}$ to 320 $\mu S.cm^{-1}$ (Table 1). Spearman's correlation analysis revealed a direct correlation between the number of epiphytic organisms and water temperature and turbidity (r = 0.85, p<0.01; r = 0.78, p<0.01, respectively).

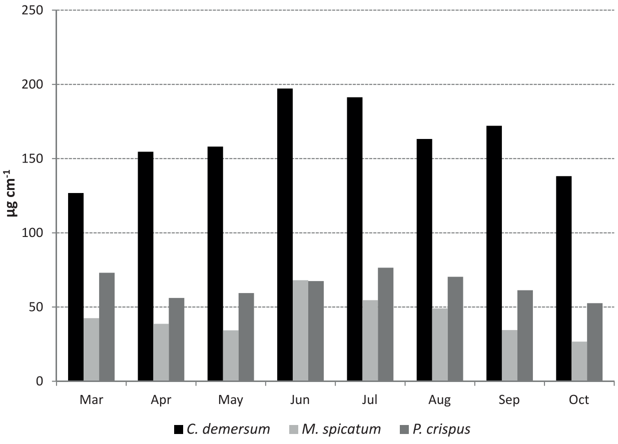

Fig. 2. Distributions of epiphytic chlorophyll-a concentrations on three macrophytes in Lake Gala.

The depth of the lake during the study was 109-200 cm, and the Secchi disc visibility was 29-76.2 cm. The water temperature showed a positive correlation with conductivity (r = 0.77, p<0.05), and dissolved oxygen showed a negative correlation with temperature (r = -0.73, p<0.05) and NO_3^-N (r = -0.65, p<0.05). NO_3^-N concentrations were significantly correlated with dissolved oxygen (r = 0.81, p < 0.01) and Secchi disk transparency (r = 0.71, p<0.01).

The highest chlorophyll-*a* concentration of epiphytic algae was on *C. demersum* in June (197.2 $\mu g.cm^{-1}$), and the lowest amount was recorded on *P. crispus* in September (26.7 $\mu g.cm^{-1}$), as shown in Fig. 2.

Macrophyte Abundance in Lake Gala

During the study period, the average numbers of *C. demersum*, *M. spicatum,* and *P. crispus* per square meter were 24, 21, and 7, respectively (Fig. 3).

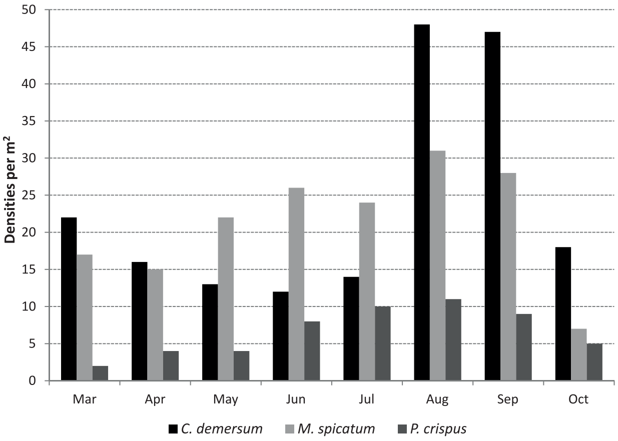

Fig. 3. Submerged macrophyte distribution in Lake Gala.

Epiphytic Algal Composition

In total, 131 taxa belonging to epiphytic algae were recorded in the lake. Bacillariophyta was the most abundant group (n = 66 taxa), followed by Chlorophyta (n = 31 taxa), Cyanophyta (n = 19 taxa), Euglenophyta (n = 8 taxa), Charophyta (n = 4 taxa), Miozoa (n = 2 taxa), and Cryptophyta (n = 1 taxon). When the epiphyton-forming algae on the macrophytes were considered, the most algae-rich macrophyte species was *C. demersum,* with 98 taxa, followed by *M. spicatum* (n = 74 taxa) and *P. crispus* (n = 66 taxa), as shown in Table 2.

When the entire sampling period considered *Cocconeis placentula*, it represented 12.25% of the total average relative biovolume and was the dominant organism on *C. demersum*. This was followed by *Anabaena constricta* (8.08%), *Encyonema silesiacum* (7.28%), and *Oscillatoria sancta* (4.95%). Analysis of the relative biovolume revealed that *Cymatopleura solea* (9.98%), *C. placentula* (8.90%), *Gomphonema acuminatum* (8.38%), *A. constricta* (7.94%), *Gomphonema affine* (7.51%), and *Melosira varians* (7.25%) were the dominant organisms on *M. spicatum*. The same analysis revealed that *C. placentula* (12.89%), *Gomphonema parvulum* (10.68%), *Oscillatoria limosa* (10.19%), *A. constricta* (9.01%), *Cymbella cistula* (8.35%), and *G. acuminatum* (8.18%) were the dominant taxa on *P. crispus* (Figs 4(a-c)).

During the sampling period, the highest relative abundance of *C. placentula* was recorded on *C. demersum*. The relative biovolume of *C. placentula* was over 10% in all the sampled months. The highest relative biovolumes of *O. sancta* were recorded in August and October (11.5% and 11.4%, respectively). The highest relative biovolumes of *A. constricta* occurred in August (9.2%), September (9.7%), and October (11.3%). The highest relative biovolume of *Stauridium tetras* was recorded in October (11.3%). Since this species was only at highest value in October and was found at very low numbers during sampling periods except for October, it wasn't among the dominant organisms in the lake.

When the epiphytic algae on *M. spicatum* were considered with respect to the period in which they were most abundant, *C. solea* and *G. acuminatum* appeared to be common in spring months, *C. placentula*, *M. varians,* and *Epithemia sorex* seemed to be common in summer and autumn months, and *S. tetras* seemed to be common in autumn months. Among the epiphytic algae on *P. crispus*, the relative biovolume of *C. placentula* was above 10% during the entire sampling period, except in April. The highest relative biovolume values of *O. limosa* were found in March (12.4%) and April (11.6%), and those of *R. abbreviata* were recorded in March (16.8%), April (12.8%), and July (10.6%). The highest relative biovolume values of *A. constricta* were recorded in August (11.4%), September (15.1%), and October (14.2%), and those of *E. sorex* were found in September (19.3%) and October (18.3%). These taxa were also among the dominant organisms of the epiphytic community.

Table 2. The macrophytes sampled and the epiphyton-forming algae determined in Lake Gala.

	C. demersum	*M. spicatum*	*P. crispus*
Cyanophyta			
Anabaena sp.	x	x	x
A. oscillarioides Bory.	x	x	x
A. constricta (Szafer) Geitler	x	x	x
Calothrix sp.	x	-	-
Chroococcus turgidus (Kütz.) Näg.	x	-	x
Geitlerinema amphibium (Ag.) Anag.	x	x	-
Gleocapsa sp.	-	-	x
Komvophoron constrictum (Szafer) Anag.&Kom.	x	x	-
K. crassum (Voz.) Anag.&Kom.	x	-	-
Lyngbya sp.	-	-	-
Merismopedia glauca (Ehren.) Kütz.	x	x	x
Oscillatoria limosa Ag.	x	-	x
O. tenuis Ag.	-	x	x
O. sancta Kütz.	x	-	-
Planktolyngbya contorta (Lemm.)Anag.& Kom.	x	-	-
Planktothrix sp.	-	-	x
Pseudoanabaena sp.	-	-	x
P. limnetica Lemm. (Kom.)	x	-	-
Spirulina sp.	x	-	-
Chlorophyta			
Actinastrum hantzschii Lag.	x	-	-
Chlorella vulgaris Beyerinck	x	x	x
Cladophora glomerata (L.) Kütz.	x	-	-
Coelastrum astroideum De-Not	-	-	x
Crucigenia tetrapedia West.	-	-	x
Crucigeniella sp.	x	x	x
Desmodesmus magnus (Meyen) Tsarenko	-	x	x
Kirchneriella sp.	-	-	x
Monoraphidium arcuatum Hind.	x	-	-
M. contortum Kom-Legn.	x	x	x
Oocystis sp	x	-	-
O. parva West.	x	x	x
Pediastrum duplex Meyen	x	x	-

Table 2. Continued.

	C. demersum	*M. spicatum*	*P. crispus*
Pseudopediastrum boryanum (Turp.) Hegewald	x	-	-
Raphidocelis subcapitata (Korsh.) Nygaard	x	-	x
Scenedesmus bijuga (Turp.) Lagerheim	-	x	-
S. obtusus Mey.	-	-	x
S. quadricauda (Turp.) Breb.	x	x	x
Schroederia setigera (Schr.) Lemm.	x	-	-
S. spiralis (Printz) Korsh.	x	-	-
Stauridium tetras (Ehren.) Hegewald	x	x	-
Stigeoclonium lubricum (Dillwyn) Kütz.	x	-	-
Tetradesmus lagerheimii Wynne & Guiry	x	-	x
T. obliquus (Turp.) Wynne	-	x	-
Tetraedron caudatum Hansg.	-	x	x
T. minimum Hansg.	x	-	x
T. trigonum Hansg.	x	-	x
Tetrastrum komarekii Hind.	-	-	x
T. staugeniforme Lemm.	-	-	x
T. triangulare (Chod.) Kom.	-	x	x
Ulothrix zonata (Weber&Mohr) Kütz.	x	-	-
Charophyta			
Closterium littorale Gay	x	-	-
C. lunula Ehren.	x	x	x
Cosmarium sp.	x	x	x
Spirogyra maxima (Hass.) Witt.	x	-	-
Miozoa			
Peridinium cinctum (Müller) Ehren.	x	-	x
Gymnodinium helveticum Penard	-	-	x
Euglenophyta			
Euglena granulata (Klebs) Schmitz	x	x	x
Lepocinclis radiata Chade	-	x	x
L. texta (Duj.) Lemm.	-	x	x
Phacus acuminatus Stokes	x	-	x
Trachelomonas armata (Ehren.) Stein	x	-	x
T. hispida (Perty) Stein	x	-	-
T. minima Drezepolski	x	x	x
T. volvocina (Ehren.) Ehren.	x	x	-

Table 2. Continued.

Cryptophyta			
Cryptomonas sp.	-	x	x
Bacillariophyta			
Achnanthidium affine (Grun.) Czarnecki	x	-	-
Achnanthes exiguum (Grun.) Czarnecki	-	x	-
Amphora ovalis (Kütz.) Kütz.	x	x	-
Asterionella formosa Hass.	x	-	x
Brebissonia lanceolata (Ag.) Mah.&Reimer	x	x	x
Caloneis amphisbaena (Bory) Cleve	x	x	-
C. bacillum (Grun.) Cleve	x	-	-
Cocconeis pediculus Ehren.	x	x	-
C. placentula Ehren.	x	x	x
Craticula cuspidata (Kütz.) Mann	x	x	x
Cyclotella meneghiniana Kütz.	x	x	x
C. radiosa (Grun.) Lemm.	x	x	x
Cymatopleura solea (Breb.) Smith	x	x	-
Cymbella cistula (Hemprich) Grun.	x	x	x
Entomoneis alata (Ehren.) Ehren.	x	-	-
Denticula kuetzingii Grun.	-	-	x
Diploneis didyma (Ehren.) Ehren.	-	x	x
Encyonema silesiacum (Ble.) Mann	x	-	-
Encyonopsis microcephala (Grun.) Krammer	-	x	-
E. minuta Kram.&Reich.	x	-	-
Epithemia sorex Kütz.	x	x	x
E. turgida (Ehren.) Kütz.	-	x	x
Fragilaria sp.	x	x	-
F. capucina Desm.	x	-	-
Fragilaria construens (Ehren.) Grun.	x	-	-
Fragilariforma virescens (Ralfs) Williams&Round	x	x	-
Gomphonema acuminatum Ehren.	x	x	x
G. affine Kütz.	-	-	x
G. gracile Ehren.	x	x	-
G. olivaceum (Horn.) Bréb.	x	x	-

Table 2. Continued.

G. parvulum (Kütz.) Kütz	x	x	x
Gyrosigma acuminatum (Kütz.)	x	x	-
Halamphora veneta (Kütz. Levkov	x	x	-
Hippodonta capitata (Ehren.) L.-Bert., Metz.&Witk.	x	x	-
Mastogloia smithii Grun.	x	x	-
Mayamaea atomus (Kütz.) Lange-Bertalot	-	x	-
Melosira varians Agardh	x	x	-
Navicula cryptocephala Kütz	x	x	-
N. lanceolata (Ag.) Kütz.	x	-	-
N. radiosa Kütz.	x	x	-
N. reinhardtii (Grun.) Grun.	x	-	-
N. tripunctata (Müll.) Bory	x	x	x
N. viridula (Kütz.)	x	x	x
Nitzschia sp.	x	-	x
N. acicularis Smith	x	x	x
N. balcanica Hustedt	x	x	-
N. capitellata Husted	-	-	x
N. frustulum (Kütz.) Grun.	x	x	-
N. linearis Smith.	x	x	-
N. obtusa Smith	-	-	x
N. palea (Kütz.) Smith	x	x	x
N. perminuta (Grun.) Peraga.	-	x	x
N. sigmoidea (Ehren.) Smith	x	x	-
Pinnularia divergens Smith	-	x	-
P. viridis (Nitzs.) Ehren.	-	x	-
Placoneis clementis (Grun.) Cox	x	x	-
P. elginensis (Greg.) Cox	x	-	x
Rhoicosphenia abbreviata (Ag.) Lange-Bertalot	x	x	x
Stauroneis anceps Ehren.	x	-	-
Stephanodiscus astraea (Ehr.) Grun.	x	x	x
Surirella ovalis Breb.	x	-	-
Tabellaria fenestrata (Lyng.) Kütz.	x	x	x
T. flocculosa (Roth) Kütz.	-	x	-
Tryblionella sp.	x	-	-
T. hungarica (Grun.) Frenguelli	x	x	x
Ulnaria ulna (Nitzs.) Compère	x	-	-

Cluster analysis showed that the species composition of epiphytic algae on the three macrophyte species varied, with similar species of epiphytic algae found on *C. demersum* and *P. crispus* (67%), but different species were found on *M. spicatum* (Fig. 5).

Species Diversity and Richness of Epiphytic Algae

Throughout the study period, high numbers of diatoms and blue-green algae were recorded. The maximum number of species (n = 41) was recorded in May on *C. demersum*, and the minimum number (n = 12) was recorded in April on *P. crispus* (Figs 6-8). The species diversity of epiphytic algae on the three macrophyte species sampled was significantly different (F = 7.07, p<0.05). There was also a significant difference in algal diversity, according to the sampling month (F = 3.59, p<0.05). The species diversity and species richness values for *C. demersum*, *M. spicatum,* and *P. crispus* were 1.546 and 33, 1.407 and 23, and 1.256 and 19, respectively.

Canonical Correspondence Analysis

CCA analysis was conducted to determine the association between the relative abundance of the epiphytic algae and environmental factors. The 18 dominant taxa in the epiphyton and the association of these taxa with seven environmental variables are listed in Fig. 6. According to the CCA biplot analysis, the eigenvalues of the first two axes were 0.79 and 0.41, respectively. The first axis of CCA explained 16.39% of the total variance in species, and the second axis explained 53.42% of the total variance. On the three macrophyte species, *C. placentula* was placed near the origin of the ordination diagram. In the spring months, *Geitlerinema amphibium* and *Gomphonema parvula* showed a positive correlation with pH, nitrite, and nitrate. In June and July, the relative abundance of *Planktolyngbya contorta* and *G. acuminatum* showed a positive correlation with light transmission. In August and September, the relative abundance of *A. constricta* and *E. sorex* displayed a positive correlation with conductivity, temperature, and o-PO_4 (Fig. 9).

Discussion

In common with many shallow lakes, Gala is exposed to pressure from nearby agricultural activities [44-45]. Other than temperature, seasonal variations in the physical and chemical properties of the lake are primarily determined by irrigation channels connected to the lake for agricultural purposes [19, 46]. The key role of nutrients in algal development is well known [47]. In Gala, the nutrient levels change constantly throughout the year as a result of the agricultural areas surrounding the lake. During the study period, the average environmental values did not reach eutrophication values. The pH was slightly alkaline. Although the dissolved oxygen level was high, it was not as high as that recorded in previous studies [48]. In the present study, the decrease in concentrations of both NO_3-N and o-PO_4 may be attributed to dense macrophyte vegetation associated with periods of agricultural activity.

In this study, lake turbidity increased and light transmission decreased in accordance with the period of phytoplankton multiplication and wind. Therefore, in the spring months, especially in March and April, low epiphyton biovolumes and low species richness and

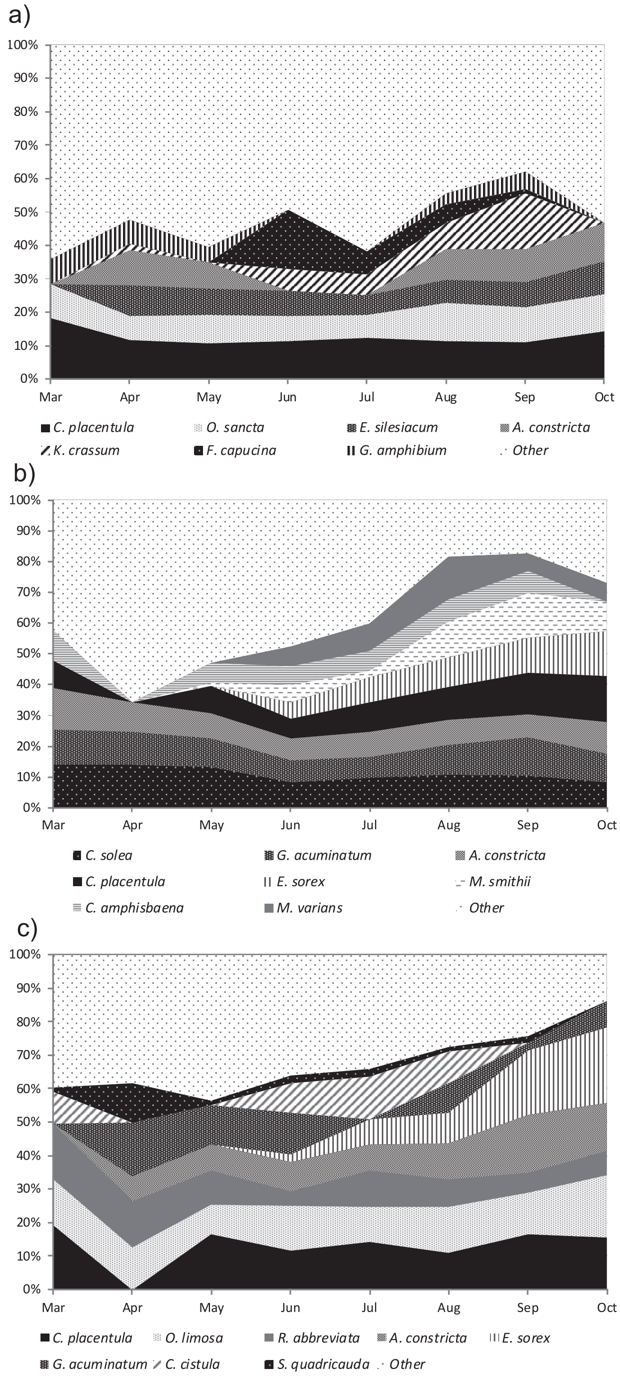

Fig. 4. Monthly distributions of the relative biovolume of the dominant epiphytic algae sampled on macrophytes in Lake Gala: a) *C. demersum,* b) *M. spicatum,* and c) *P. crispus.*

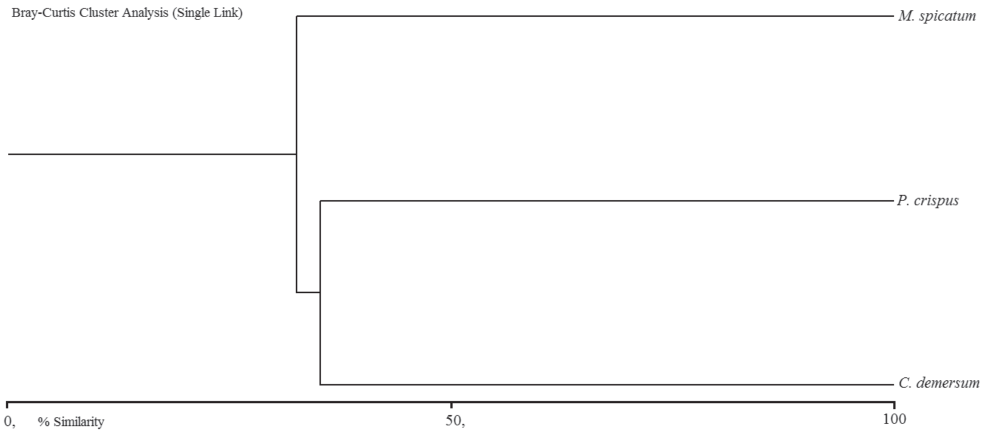

Fig. 5. Bray-Curtis similarity diagram of the epiphytic algae determined on sampled macrophytes in Lake Gala.

evenness were detected. In addition, the diversity index was lower. During the turbid-water period, phytoplankton overshadowing of the epiphytic community may have initially been pronounced. However, upon the development of submerged macrophyte stands between September and October, light conditions promoted epiphyte growth. As both the density of emergent macrophytes and submerged plant cover were low at all the sampling sites, shadowing likely had little influence on epiphytic growth. Similar results have been reported for similar lakes [49].

The depth of the macrophyte-dominated Gala was low during the study period. In lakes exposed to open and windy conditions, a high rate of turbidity and waves result in low Secchi disc visibility. These conditions produce a suitable environment for the development of diatoms [50]. Compared to environmental variables, attached diatoms appear to be more supplementary indicators that respond rapidly to environmental changes [51-52]. In Gala, in terms of the number of taxa, abundance, and biovolume, diatoms were the dominant group of epiphytic algae. This group was followed by cyanobacteria, with higher numbers in terms of the number of colonies and cells and number of species. Other studies of shallow lakes reported similar findings [13, 53]. The presence of high-order planktonic species in the epiphyton, especially on submerged macrophytes in shallow systems, such as Gala, is to be expected. As reported previously, there is a

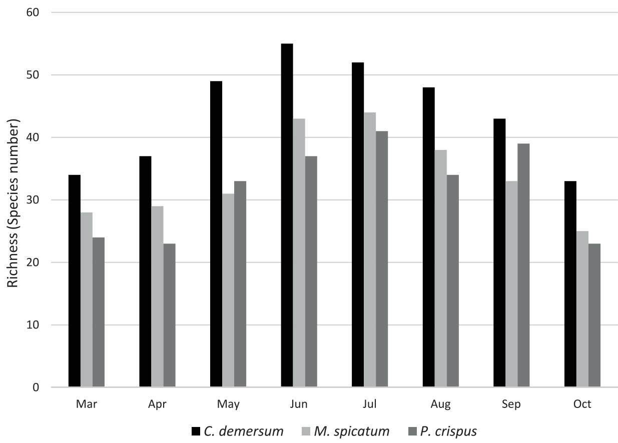

Fig. 7. Species richness of epiphytic algae species of three submerged macrophytes during the study period.

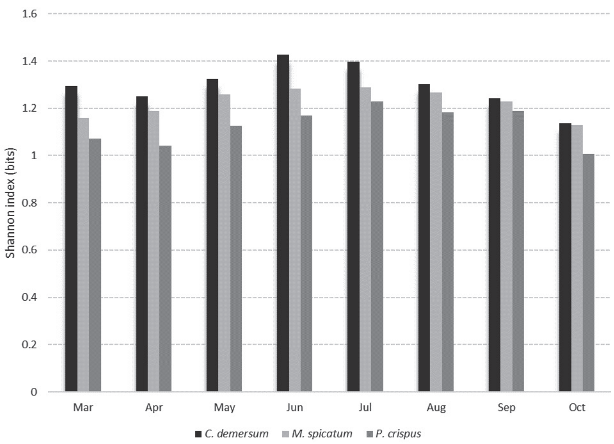

Fig. 6. Shannon diversity index (H′) of epiphytic algae species of three submerged macrophytes during the study period.

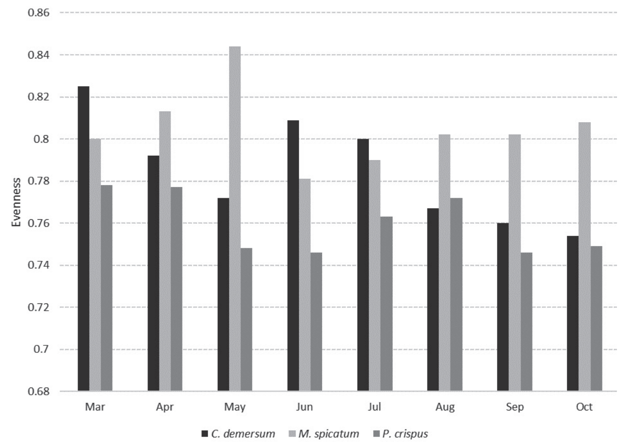

Fig. 8. Evenness index of epiphytic algae species of three submerged macrophytes during the study period.

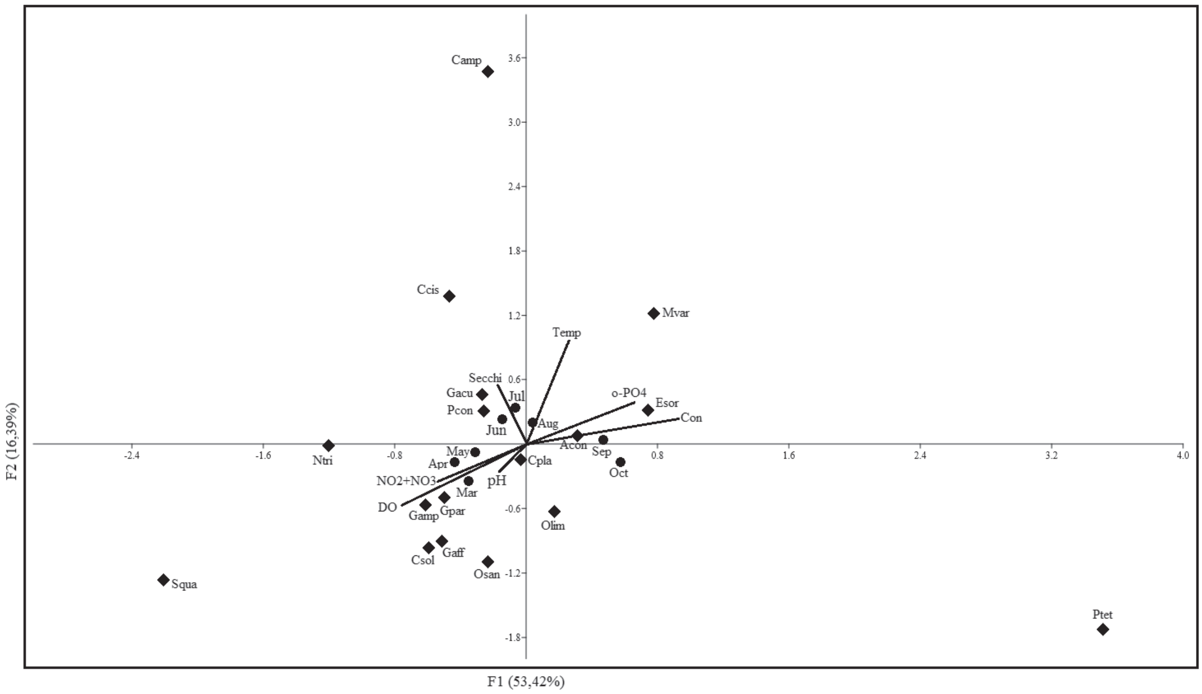

Fig. 9. Canonical correspondence analysis (CCA) results showing the sampling months, environmental variables and dominant taxa on three macrophytes. Environmental variables – DO: dissolved oxygen, NO_2+NO_3: nitrite and nitrate, o-PO_4: orthophosphate, Con: conductivity, and Temp.: water temperature; epiphytic algal species – *Acon: Anabaena constricta, Camp: Caloneis amphisbaena, Cpla: Cocconeis placentula, Csol: Cymatopleura solea, Ccis: Cymbella cistula, Esil: Encyonema silesiacum, Esor: Epithemia sorex, Gamp: Geitlerinema amphibium, Gacu: Gomphonema acuminatum, Gaff: Gomphonema affine, Gpar: Gomphonema parvulum, Mvar: Melosira varians, Ntri: Navicula tripunctata, Olim: Oscillatoria limosa, Osan: Oscillatoria sancta, Pcon: Planktolyngbya contorta, Squa: Scenedesmus quadricauda,* and *Stet: Stauridium tetras.*

strong correlation between limnetic and benthic habitats due to the high proportions of mixture of the water column and resulting sediment re-suspension [54]. The high degree of species richness can be attributed to environmental and biological factors, such as host plant surface heterogeneity and nutrient concentrations [55].

As expected, the highest number of species and biovolumes of epiphytic algae were associated with *C. demersum*, the dominant macrophyte in the benthic stratum of Gala. Although higher numbers of epiphytic algal species and higher biovolumes were recorded on *M. spicatum* than on *P. crispus*, the chlorophyll-*a* concentration of epiphytic algae associated with *M. spicatum* was reduced as compared to *P. crispus*. This finding may be due to the dominance of diatoms on *M. spicatum*. However, as noted in previous studies, they could also be due to the presence of planktonic green algae and euglenoid on *P. crispus* [20, 50, 57]. Green algae attach to the substratum in a less coherent way than diatoms, and some only accompany the overgrowing community [6]. Thus, numbers of green algae may be increased in interstem water, resulting in higher values of chlorophyll-*a* [49]. Representatives of this algal group are commonly unattached (e.g., due to waves) [56]. As a result, chlorophyte numbers may increase in the water between macrophyte stems [50].

The compositions of algae living on different macrophytes can vary considerably [56-57]. Our findings indicated that light conditions followed by substrate instability due to wave actions appear to be the main drivers of spatial and temporal variations of epipelon. Although some previous studies have reported that epiphytic algae displayed substrate selection, others indicated that they did not. Macrophytes with different morphological characteristics can naturally host different epiphytic communities [50]. In the present study, the species composition of submergent and emergent macrophytes differed, suggesting that the epiphytic algae in the lake displayed substrate selection. Emergent macrophytes (reed beds) surround the area around Gala, with colonies of *C. demersum* and *M. spicatum* spread in front of these macrophytes. Although Letáková et al. reported that *Potamogeton gramineus* is distributed along lake shores [10], in our study area *P. crispus* spreads out towards the centre of the lake, usually in the lake, far from the coastal areas. The epiphytic species composition of *P. crispus* was least similar to that of the other macrophyte species studied. This finding may explain the higher number of planktonic origins algae found on *P. crispus* as compared to on the other macrophyte species.

Throughout the study period, the numbers of *C. placentula*, *A. constricta*, and *E. silesiacum* on *C. demersum* were consistently high. In addition, the abundance of the green alga *Spirogyra maxima* and diatom *Amphora ovalis* was high on this macrophyte species in the summer months, whereas *S. tetras* was common in autumn. In the study, diatoms – especially *C. solea, C. placentula*, and *G. acuminatum* – were dominant on *M. spicatum*, and high numbers and biovolumes of the blue-green alga *A. constricta* were detected. High numbers of *M. varians* were also detected on *M. spicatum* in spring and summer. Among the three macrophyte species studied, the density of *P. crispus* was lowest. The numbers of *C. placentula*, *G. parvulum*, *O. limosa*, and *A. constricta* were high in all the samples. High numbers of *Scenedesmus quadricauda* and *Planktolyngbya contorta* were found on *P. crispus*, especially in spring, and high numbers of the diatoms *Cymbella cistula*, *Phacus acuminatus*, a planktonic euglenoid, and *Closterium lunula* (belonging to Charophyta), were found in summer. In common with the other macrophyte species, *Epithemia sorex* was the dominant species of epiphytic flora on *P. crispus* in the autumn.

Nutrient concentrations reduce the richness of algae species in aquatic environments. Some species can utilize these nutrients more rapidly than others, and these species exhibit faster growth rates. However, the present study did not reveal any significant association between nutrient levels and species richness. Species richness is generally derived from diversity calculations. In the present study, nutrient levels did not have a significant effect on biodiversity, as shown by the Shannon-Weaver biodiversity index, but the sampling month significantly affected community diversity. Diversity readings ranged from 1.006 to 1.427; typical ecological diversity levels do not exceed 4 [58, 59]. In the present study, the algae community can be considered to have a heterogeneous species composition due to the habitat complexity of the submerged macrophytes.

The species richness and diversity values of the epiphytic algae detected in Gala Lake increased from late spring to mid-summer, with no significant differences determined among the algae associated with the three macrophyte species. In the present study, high turbidity, extensive spreading by phytoplankton, and macrophytes (which compete with periphyton for nutrients and light during summer months) may have restricted the growth of the epiphytic algae [60]. Biodiversity was previously reported to be positively correlated with high-quality water [52]. Although physico-chemical dynamics and competition affect species diversity, other factors, such as interactions of bacteria, protozoa and grazers, in addition to physical disturbances as a result of human activities, should also be considered [61].

Zhang et al. reported a positive correlation between *Gomphonema* and dissolved oxygen levels, and Stevenson et al. reported a correlation between relative abundance of *Gomphonema* and pH [62-63]. In a study by Liu et al., *Gomphonema* showed a strong relationship with various physico-chemical parameters such as pH, dissolved oxygen, total nitrogen, and total phosporus [62-63]. In the present study, the results were similar to the CCA results. Other studies (by Blinn and Herbst, Miranda and Krishnakumar) reported a similar relationship of temperature with *Epithemia* and *Anabaena* [64-65]. The CCA revealed a significant correlation between water quality parameters and temporal changes in the dominant epiphytic algae [64]. In the present study, as revealed by the CCA, nitrogen compounds, dissolved oxygen levels, and pH in the spring; light transmission in June and July; and temperature, conductivity, and phosphate levels in August and September affected the colonization of epiphytic algae. Water transparency generally has direct ecological effects on littoral diatoms and is also used as an indication that reflects on other environmental parameters. Water transparency, which is inversely related to pollution gradient and conductivity, is in particular one of the important parameters determining the diatom assemblages in aquatic ecosystems [60, 66]. It is generally stated that there is a relationship between epiphytic algae and environmental variables, and submerged macrophytes have been recommended for routine monitoring [67]. We found a significant relationship with selected environmental variables in congruence with other studies [13, 52]. Increased numbers of submerged macrophytes and increased length resulted in overshadowing, which may have suppressed the development of some species. In an ecosystem, the aforementioned may benefit species that require relatively less light.

Conclusions

Temperature and water level were the main determinants of the seasonal variations in physical, chemical, and biological parameters. Hydrological pulses were the most important determinant of the epiphytic algae community. Substrate type affected algae epiphyte colonization in different seasons. The species composition of the epiphytic algae was diverse as a result of macrophyte morphology. However, the diversity values of the three submerged macrophyte species were similar.

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