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Temporal fluctuations of the phytoplankton community in an isolated floodplain lake (North Mollaköy Lake) of the Sakarya River (Northern Turkey)

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Key words: connectivity, functional groups, water discharge, floodplain lake, phytoplankton

Abstract

The aim of this study was to determine the spatial and temporal variation of phytoplankton and water quality in response to the hydrological regime in an isolated floodplain lake (North Mollaköy Lake) of the Sakarya River. Variations in the composition, biomass and functional groups of phytoplankton and environmental parameters were monthly analyzed in sub-surface samples collected from the pelagic zone at four stations from July 2012 to June 2013. A total of 109 taxa were identified, and the species which contributed the most to the phytoplankton biomass were grouped into 14 functional groups (FGs). The distribution of FGs was linked to the transition (T1 and T2), high (HW) and low (LW) water periods in North Mollaköy Lake. FGs J, MP, N, G, X1, X2, Y, W1, W2, S1, H1, B and C were the contributors to the phytoplankton biomass during the low-water period (LW) and the transition periods (T1 and T2), while Lo contributed the most during the high-water period (HW). RDA revealed that the most important factor affecting the temporal distribution of FGs was the water discharge and that there are some differences between stations in terms of Si, pH values and the distribution of FGs.

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INTRODUCTION

Rivers and adjacent floodplains are integrated systems, connected by strong interactions between hydrological and ecological processes (Junk et al. 1989). The flood pulse of river discharge, which determines the connectivity and fluctuation processes of matter and organisms across river-floodplain gradients, is the major driving force (Mihaljevic et al. 2009). As a result of flooding events, these systems have a seasonal and generally predictable hydrological cycle (Hamilton et al. 2002). The volume and surface area of floodplains can increase by orders of magnitude during high-water periods (or potamophase) (Lesack and Melack 1995), while during low-water periods (or limnophase), they may vary from isolated, very shallow, or even desiccated water bodies, to much deeper water bodies inundated with local runoff and precipitation (Hamilton and Lewis 1990, Lesack and Melack 1995).

The phytoplankton composition of floodplain lakes show significant temporal fluctuations in response to variable hydraulic conditions imposed by the flood pulse (Ibañez 1998, De Oliveira and Calheiros 2000). During potamophase, these environments are usually characterized by low values of phytoplankton biovolume and high abundance of species adapted to mixing of the water column (Huszar and Reynolds 1997, Train and Rodrigues 2004, Train and Rodrigues 1998). During limnophase, floodplain lakes isolated for several months, favor the abundance of acclimating species, mainly nitrogen-fixing cyanobacteria (Reynolds 1997, Train and Rodrigues 2004, Train et al. 2004).

In recent years, the functional groups approach based on the physiological, morphological and ecological attributes of species has been proved to be

an efficient way to analyze seasonal changes in the phytoplankton dynamics (Becker et al. 2010). Therefore, studies of phytoplankton functional groups (FGs) provide additional information on the ecology of phytoplankton assemblages (Salmaso and Padisák 2007) and on the functioning of the ecosystem (Padisák et al. 2009). Studies of changes in FGs in floodplain lakes have demonstrated that changing environmental conditions are associated with a high degree of fluctuations in several FGs, representing diverse life strategies with no phylogenetic affinities (Huszar and Reynolds 1997, Nabout et al. 2006, Townsend 2006).

The response of phytoplankton communities to water level fluctuations in floodplain lakes of tropical rivers have been largely investigated (Pedrozo et al. 1992, Ibañez 1998, Zalocar de Domitrovic 2003, Nabout et al. 2006, Butler et al. 2007). Results indicate that phytoplankton dynamics are hydrologically driven, and the flood pulse influences the composition and the population density of phytoplankton communities. Some recent studies have been conducted on the impact of inundation on the phytoplankton dynamics in floodplain lakes of temperate zones (Van den Brink et al. 1992, Stoyneya 2003, Mihaljevic et al. 2009). These studies have also focused on the major effects of flood dynamics on both the limnological characteristics of lake and the composition of phytoplankton.

The Sakarya River is situated in the northwest Anatolian region of Turkey. Numerous reservoirs have been built and put into operation for various purposes on the Upper and Middle Sakarya Rivers during the past 50 years. The same period has seen the construction of levees for flood control, as well as many bridge constructions over the river and its tributaries. All these interventions have changed the hydrology and morphology of the river (Işık et al. 2008). Moreover, as a result of municipal and industrial wastewater discharges, the Sakarya River has been polluted by heavy metals (Dündar and Altundağ 2007). Furthermore, it is a highly eutrophic system (Carlson 1977, Karadžić et al. 2010) with the annual mean chlorophyll-*a* concentration of 97 $\mu g\ l^{-1}$ and the total phosphorus concentration of 83 $\mu g\ l^{-1}$ (Küçük 2012). Even though antropogenic effects have altered the hydrology and water quality of the Sakarya River, some of the floodplain areas still functionally exist. Mollaköy Lakes, which are located on the east bank of the lower Sakarya River basin, are one of these floodplain areas.

The aim of this study is to test the following hypotheses: (1) changes in hydrological connectivity affect environmental parameters and phytoplankton biomass, composition and FGs in an isolated temperate lake (North Mollaköy Lake) of the lower Sakarya River and (2) due to different distances to the overflow connection point, and different depths, there are some differences between the monitoring stations in terms of environmental parameters and phytoplankton composition.

MATERIALS AND METHODS

Study Area

The Sakarya River, which is one of the largest rivers in Turkey, discharges into the Black Sea and has a drainage area of 56.504 km^2 and a length of 824 km (Algan et al. 2002). The discharge rate of the Sakarya River is 5.6 $km^3\ yr^{-1}$ and is influenced by the Marmara regime (average rainfall is about 770 mm yr^{-1}) (Koçman 1993, Işık et al. 2008). The discharge rate increases in December, and decreases in April, reaching its minimum during summer (Algan et al. 2002). The river basin is commonly divided into three zones: upper, middle and lower sections. The lower Sakarya River has gentle slopes with its sinuous and meandering shape and stretches over 110 km from north to south (Işık et al. 2008). Mollaköy Lakes (40°41' N, 30°24'E) are located at 40 m above the sea level and on the east bank of the lower Sakarya River and consist of nine small lakes (Fig. 1). This study was carried out in North Mollaköy Lake (NML) which has a length of 2.1 km and a surface area of 2.8 km^2. It contains four small lakes connected to each other with small channels. NML and the Sakarya River are separated by a levee and the overspill connection occurs at the southern part of NML. During the study period, the overspill connection occurred between November and April 2013. Four stations were chosen, considering the partitioned morphology of the lake. The first and second stations have a maximum depth of 3 m and water level falls to 1 m during limnophase. The third station was chosen in the middle section which receives flood waters during inundation. The water level ranges between 2 m and 5 m at this station. The fourth station was selected in the deepest section and the water level ranges between 8 m and 15 m.

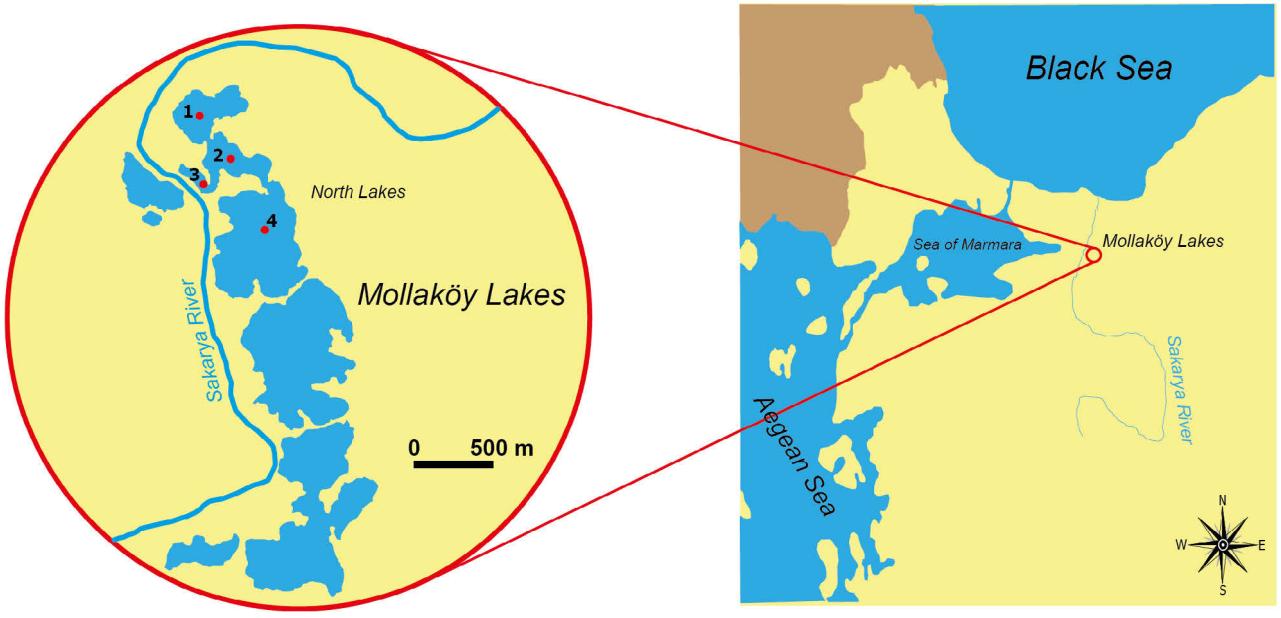

Fig. 1. The map of North Mollaköy Lake located on the east bank of the lower Sakarya River and the location of sampling stations

Phytoplankton analysis

Sampling was carried out monthly at the four monitoring stations between July 2012 and June 2013. Samples were collected from 10 cm below the surface. In the field, samples were placed in 250 ml bottles and fixed with Lugol's solution. In the laboratory, samples were first agitated, then poured into 50 ml graduated cylinders and were allowed to settle at least for 24 hours. At the end of the settling period, 45 ml of water was aspirated from each graduated cylinder and the remaining 5 ml of water was poured into a small glass vial for microscopic analysis (Utermöhl 1958). Enumeration and identification of algae were performed using a Palmer-Maloney counting cell (volume 0.1 ml) and a compound microscope equipped with water immersion lenses and a phase-contrast attachment. The final abundance of each species was considered to be the average from three replications. Algal species were identified according to Huber-Pestalozzi (1941, 1950, 1961, 1962, 1969, 1972, 1975, 1976, 1982, 1983), Round et al. (1990), Kramer and Lange-Bertalot (1986, 1991a, 1991b, 1999, 2003), Sims (1996), John et al. (2003), Komarek and Anagnostidis (2008). Taxonomy of algae was checked according to Guiry and Guiry (2014). Phytoplankton biomass was calculated from biovolume estimations (Edler 1979, Wetzel and Likens 2000). Biovolume was calculated from the number of cells and cell size measurements (Wetzel and Likens 1991, Sun and Liu 2003). Species contributing more than 5% to the total phytoplankton biomass were grouped in FGs according to Reynolds et al. (2002) and Padisa´k et al. (2009). The species diversity index (H) and evenness (E) were computed according to Shannon and Weaver (1963):

$$H' = -\sum p_i \ln(p_i)$$

In this formula, p_i is a relative frequency of the biomass of the i^{th} species.

Physical and chemical analyses

Sampling for chemical analyses and measurement of physical variables was carried out together with phytoplankton collection. Specific conductance (EC), total dissolved solid (TDS), pH, dissolved oxygen (DO) and water temperature (T) were measured at 10 cm below the surface using a YSI ProPlus water quality instrument. Water transparency was measured on each sampling day using a Secchi disk. Concentrations of nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), total phosphorus (TP), orthophosphate (PO_4-P), silica (Si) and sulfate (SO_4) were determined spectrophotometrically according to

Strickland and Parsons (1972) and Technicon Industrial Methods (1977 a, b). Chlorophyll-*a* (Chl-*a*) was determined via extraction with 90% methanol spectrophotometrically (Youngman 1978).

The General Directorate of Electrical Power Resources Survey and Development Administration (EIE) has been taking measurements of water discharge at the Dogancay gauging station (40º 37' N, 30º 19'E) on the Lower Sakarya River since 1952 (EIE 2013). Water discharge rates for the Sakarya River between 2000 and 2012 were provided by the EIE.

Data analysis

The analysis of variance (ANOVA) test was applied to determine the statistical differences in species richness, diversity, biomass, chlorophyll-*a* and the main physical and chemical parameters in different periods using the SPSS 20.0 software. Pearson correlations between the physicochemical parameters including the water discharge, and species richness, diversity, biomass and chlorophyll-*a* were also determined using the SPSS 20.0 software. Redundancy Analysis (RDA) was carried out using the CANOCO software (Ter Braak and Smilauer 2002). In order to determine the relationship between the biomass of the functional groups, sampling periods and environmental variables, RDA was carried out on the log-normal transformed abundance data. Statistical significance of the environmental predictor variables was assessed by 999 restricted Monte Carlo permutations.

RESULTS

Environmental characteristics

Monthly average water discharges in Dogancay between 2000 and 2012 are presented in Fig. 2. The depth of NML was positively correlated with changes in the water discharges of the Sakarya River (R = 0.52, $P < 0.05$). NML became hydraulically isolated and sustained low-water (LW) conditions from July to October 2012. During LW, the lake became shallower (maximum depth of 8 m at the fourth station) and allowed mixing events throughout the water column. Between November and December 2012, the Sakarya River began to inundate its floodplain. A transition from lake to riverine conditions (T1) occurred during this phase. Due to the turbulence caused by the inflow of the Sakarya

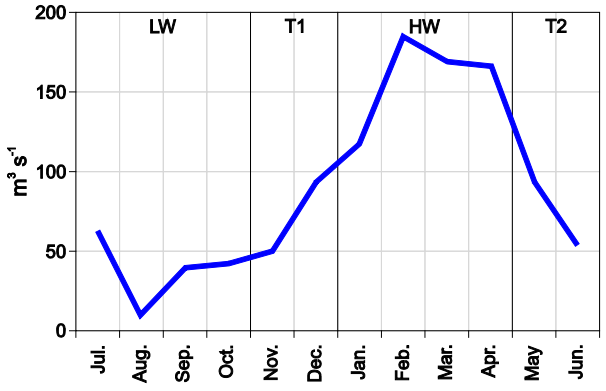

Fig. 2. Variations of monthly avarage water discharges between 2000 and 2012 at Dogancay gauging station (40°37' N, 30°19' E) on the Lower Sakarya River

River waters and fall mixing, Secchi disk values decreased to around 80 cm and the lake remained turbid. The water level increased to 15 m at the fourth station and the high-water period (HW) prevailed at the lake from January to April 2013. In April, the flow rate of the Sakarya River is gradually reduced, representing a transition from riverine to lake conditions (T2).

The average concentrations and standard deviations of the measured physical and chemical parameters in HW and LW are listed in Table 1. The maximum temperature (33.02°C) was observed in LW and the minimum (8.51°C) in the T1 period. The pH values ranged from 8.23 to 9.09 with the highest pH measured in HW. NML water can be characterized as slightly alkaline. EC values were high during LW due to evaporation and began to decrease with the T1 phase. EC values were minimal (557.0 µS cm^{-1}) in February 2013 (HW). TDS values were relatively high during LW compared to HW. However, the fourth station showed high TDS values during HW. Dissolved oxygen levels were minimal (3.81 mg l^{-1}) in November 2012 (T1) and high during HW, reached the maximum (23.16 mg l^{-1}) in March 2013 at the fourth station. Secchi disk visibility ranged from 30.0 cm to 255.0 cm and was higher at the beginning of HW.

SO_4 and Si values increased in the T1 period and reached 240.23 mg l^{-1} and 9.58 mg l^{-1}, respectively. With the beginning of transition from lake to riverine conditions, NO_2-N concentrations rapidly reached the maximum of 0.021 mg l^{-1} at the fourth station. NO_2-N concentrations varied between 0.0011 and 0.012 mg l^{-1} during HW, while decreased to 0.0003 mg l^{-1} with the beginning of the T2 period. However,

Table 1

The mean and standard deviation (SD) of environmental variables measured at the sampling sites in North Mollaköy Lake during low water (LW) and high water (HW) periods. (T: water temperature, EC: specific conductance, TDS: total dissolved solid, DO: dissolved oxygen concentration, NO_3: nitrate-nitrogen concentration, NO_2: nitrite-nitrogen concentration, PO_4: orthophosphate concentration, TP: total phosphorus concentration, SO_4: sulphate concentration, Si: silica concentration, Chl-*a*: chlorophyll-*a*)

Variable	Station 1		Station 2		Station 3		Station 4	
	Mean±SD		Mean±SD		Mean±SD		Mean±SD	
	LW	HW	LW	HW	LW	HW	LW	HW
T(°C)	25.41±5.43	13.61±3.97	24.88±5.95	13.05±3.64	25.25±5.66	13.43±3.78	25.81±5.71	13.15±3.83
pH	8.64±0.15	8.74±0.24	8.57±0.14	8.58±0.33	8.65±0.089	8.73±0.32	8.67±0.074	8.89±0.18
EC (µS cm^{-1})	885.5±45.74	674.30±90.09	913.63±74.59	658±92.68	850.51±22.89	666.75±87.27	825.01±56.51	646.75±68.26
TDS (mg l^{-1})	601±50.68	560.63±40.20	677.5±142.89	552.51±49.51	568.63±37.79	555.75±40.59	520.63±24.42	544.41±13.40
DO (mg l^{-1})	9.63±2.71	16.38±4.50	8.41±2.09	11.74±1.24	8.91±1.19	14.15±5.81	8.83±1.93	16.35±5.67
Secchi disk (cm)	80±35.6	110±8.16	103.75±12.5	110±37.41	102.51±17.08	130±63.77	128.75±29.55	167.50±87.03
NO_3–N (mg l^{-1})	0.79±0.7	2.47±2.60	1.46±1.21	3.08±3.04	1.41±1.21	1.38±0.91	1.07±0.09	1.95±1.51
NO_2–N (mg l^{-1})	0.0016±0.001	0.005±0.004	0.0029±0.002	0.015±0.01	0.0016±0.001	0.003±0.002	0.0022±0.002	0.002±0.001
PO_4–P (mg l^{-1})	0.0035±0.003	0.02±0.01	0.0066±0.0059	0.019±0.015	0.0022±0.002	0.024±0.018	0.0022±0.0019	0.014±0.017
TP (mg l^{-1})	0.0094±0.009	0.02±0.009	0.012±0.011	0.02±0.008	0.0069±0.006	0.031±0.014	0.0056±0.004	0.019±0.008
SO_4 (mg l^{-1})	124.74±119.59	111.31±99.99	180.74±159.57	140.1±97.26	185.13±171.11	154.62±101.09	176.07±157.69	108.34±94.45
Si (mg l^{-1})	8.57±5.55	2.77±2.38	7.27±7.29	3.84±2.95	6.95±5.34	3.86±2.73	4.64±1.66	3.28±1.77
Chl-*a* (µg l^{-1})	14.31±10.61	2.47±2.59	8.87±8.34	3.67±2.97	11.22±11.17	6.1±5.11	9.49±4.04	6.21±4.39

the lowest values were measured during LW. TP values were low during LW and T1 periods and began to increase with the beginning of HW. The highest value (0.049 mg l^{-1}) was measured at the third station in February 2013. During the transition from riverine to lake conditions, TP concentrations decreased and stayed around 0.004 mg l^{-1}. PO_4-P concentrations ranged from 0.0002 mg l^{-1} to 0.197 mg l^{-1}. PO_4-P values were low during LW and began to increase with the T1 period. The highest values were measured in HW. NO_3-N concentrations were low from August to October 2012 (LW) and increased twofold with the beginning of the T1 period. NO_3-N values decreased with the beginning of HW. However, they began to increase again and reached the highest measured value (8.09 mg l^{-1}) in April at the second station. During the transition period from riverine to lake conditions, NO_3-N concentrations slowly decreased and stayed around 2.1 mg l^{-1}. EC, pH, TDS, temperature, dissolved oxygen, Secchi disk depth, TP, NO_3-N, Si and SO_4 values were significantly different in different periods (df = 11, $P < 0.05$).

Phytoplankton

A total of 109 taxa were identified in the lake and most of them (53) belonged to Chlorophyta. The remaining taxa were Heterokontophyta (18), Cyanobacteria (15), Dinophyta (9), Euglenophyta (7), Cryptophyta (4) and Charophyta (3). Heterokontophyta, Chlorophyta, and Charophyta dominated at least once during LW and T1 periods, while Dinophyta dominated during HW and Cyanobacteria dominated during T2 periods (Fig. 3). Taxa that represented more than 5% of the total biomass were members of 14 FGs (Table 2), however, **J, MP**, **Lo** and **N** were the main FGs (Fig. 3).

Taxonomic richness ranged from 2 to 45 (Fig. 4) and was significantly different between HW and T2, between HW and LW, and between T1 and LW (df = 11, $F = 16.88$, $P < 0.01$). Species richness was positively correlated with temperature ($R = 0.69$, $P < 0.01$), EC ($R = 0.71$, $P < 0.01$) and negatively correlated with water discharge ($R = -0.81$, $P < 0.01$), DO ($R = -0.51$, $P < 0.01$), TP ($R = -0.61$, $P < 0.01$)

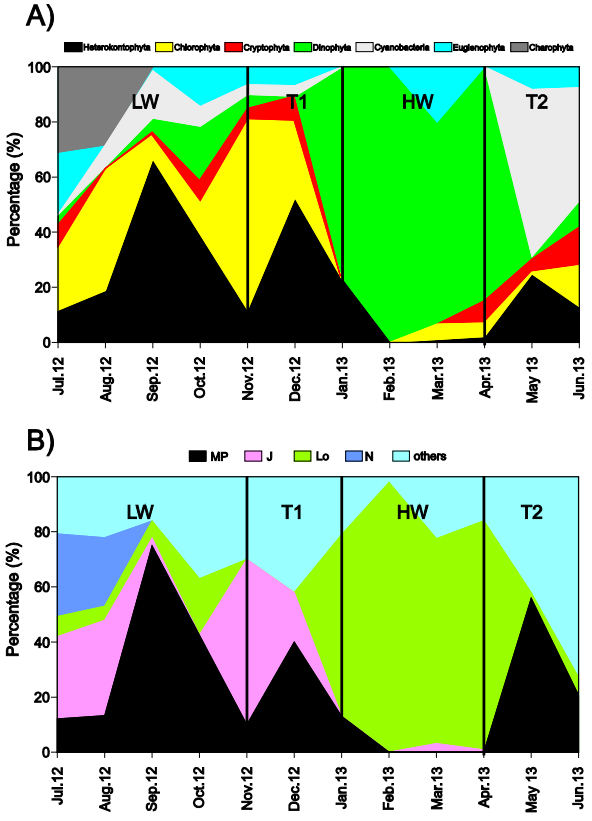

Fig. 3. A) Relative frequency (%) of each phytoplankton taxonomical group according to biomass values and **B)** relative frequency (%) of dominant phytoplankton functional groups according to biomass values during low water (LW), transition from lake to riverine (T1), high water (HW) and transition from riverine to lake (T2) periods

and NO_2-N (R = -0.29, $P < 0.05$). The Shannon-Weaver diversity index and the evenness were low during HW (df = 11, F = 10.69 and F = 9.85, respectively, $P < 0.01$) (Fig. 4). This period coincided with the phytoplankton density which was caused by the increase of *Peridinium lomnickii* var. *splendidum* Woloszynska (group **Lo**), representing 80-92% of the total phytoplankton biomass. The diversity index was positively correlated with EC (R = 0.58, $P < 0.01$), temperature (R = 0.56, $P < 0.01$) and negatively correlated with water discharge (R = -0.69, $P < 0.01$), DO (R = -0.47, $P < 0.01$), PO_4-P (R = -0.29, $P < 0.05$), TP (R = -0.56, $P < 0.01$). Evenness was negatively correlated with water discharge (R = -0.45, $P < 0.01$) and DO (R = -0.41, $P < 0.01$).

Phytoplankton biomass ranged from 0.1 mg l^{-1} to 2.9 mg l^{-1}. The highest phytoplankton biomass was recorded in LW at the fourth station while the lowest

Table 2

Taxa (>5% of the total biomass) with their taxonomic and functional groups

Functional Group	Phytoplankton Species	Taxonomic Group
B	*Cyclotella ocellata* Pantoc.	Heterokontophyta
C	*C. meneghiniana* Kütz.	Heterokontophyta
G	*Eudorina elegans* Ehr.	Chlorophyta
H1	*Dolichospermum sigmoideum* (Nygaa.) Wack., Hoffm. & Kom.	Cyanobacteria
H1	*Trichormus catenula* (Kütz. ex Born. & Flah.)Kom. & Anag.	Cyanobacteria
J	*Actinastrum hantzschii* Lager.	Chlorophyta
J	*Acutodesmus acuminatus* (Lager.) Tsaren.	Chlorophyta
J	*Coelastrum astroideum* De Notaris	Chlorophyta
J	*C. microporum* Nägeli	Chlorophyta
J	*Desmodesmus communis* (Hege.) Hege.	Chlorophyta
J	*Tetrastrum glabrum* (Roll) Ahlst. & Tiffa.	Chlorophyta
J	*Crucigenia tetrapedia* (Kirch.) Kunt.	Chlorophyta
J	*Tetraedron minimum* (Braun) Hansg.	Chlorophyta
J	*Crucigeniella apiculata* (Lemm.) Komár.	Chlorophyta
Lo	*Ceratium hirundinella* (Müller) Dujar.	Dinophyta
Lo	*Peridiniopsis cunningtonii* Lemm.	Dinophyta
Lo	*P. elpatiewskyi* (Osten.) Bourre.	Dinophyta
Lo	*Peridinium aciculiferum* Lemm.	Dinophyta
Lo	*P. pygmaeum* Linde.	Dinophyta
Lo	*P. lomnickii* var. *splendidum* Wolosz.	Dinophyta
MP	*Nitzschia palea* (Kütz.) Smi.	Heterokontophyta
MP	*Cocconeis placentula* Ehr.	Heterokontophyta
MP	*Gomphonema acuminatum* Ehr.	Heterokontophyta
MP	*Ulnaria ulna* (Nitz.) Compe.	Heterokontophyta
MP	*Oscillatoria* sp.	Cyanobacteria
N	*Staurastrum cingulum* (West & G.S.West) Smi.	Charophyta
S1	*Phormidium* sp.	Cyanobacteria
W1	*Euglenaria clavata* (Sku.) Karnko. & Lint.	Euglenophyta
W1	*Phacus vigueri* Allorge & Lefèv.	Euglenophyta
W2	*Trachelomonas intermedia* Dange.	Euglenophyta
W2	*T. oblonga* Lemm.	Euglenophyta
W2	*T. volvocina* (Ehr.) Ehr.	Euglenophyta
X2	*Chlamydomonas ampulla* Skvortz.	Chlorophyta
X2	*C. proboscigera* var. *conferta* (Korsh.) Ettl	Chlorophyta
X2	*C. heterogama* Gerlo.	Chlorophyta
X2	*C. incerta* Pasch.	Chlorophyta
X2	*C. lunata* Skvort.	Chlorophyta
X2	*Chloromonas tapeta* var. *vernalis* (Sku.) Ettl	Chlorophyta
X1	*Pseudoschroederia robusta* (Korsh.) Hege. & Schn.	Chlorophyta
Y	*Cryptomonas ovata* Ehr.	Cryptophyta
Y	*C. rostratiformis* Sku. ex Willén	Cryptophyta
Y	*Gymnodinium coronatum* Wolosz.	Dinophyta

occurred in HW at the second station. Biomass values were significantly different between LW and HW (df = 11, F = 3.01, $P < 0.05$). Phytoplankton biomass was positively correlated with temperature (R = 0.52, $P < 0.01$), EC (R = 0.39, $P < 0.01$), pH (

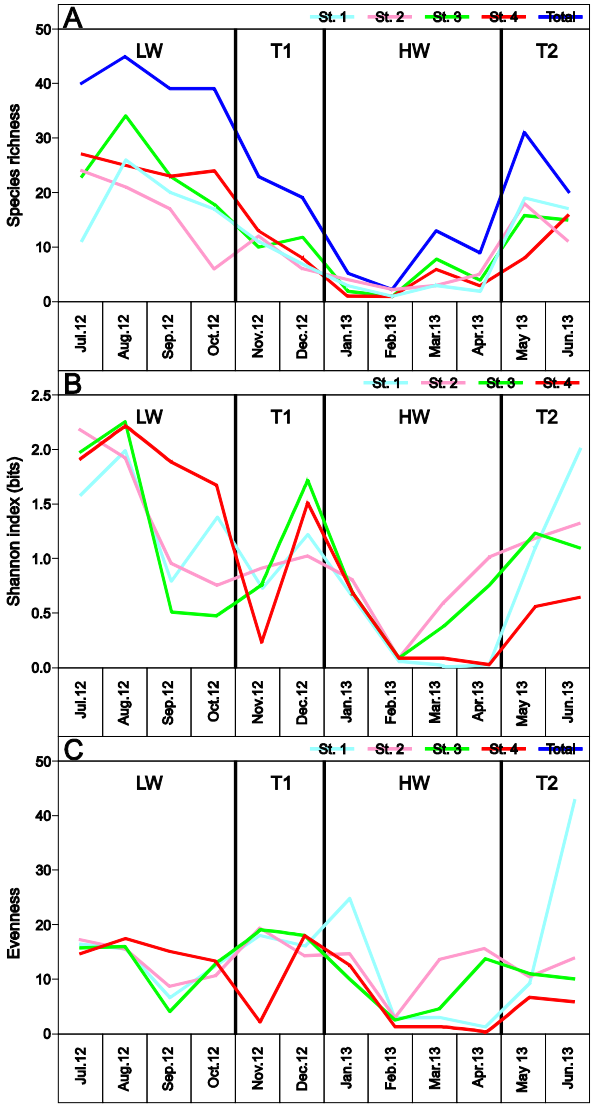

Fig. 4. Temporal variations of **A)** species richness, **B)** Shannon and Weaver diversity index (*H*) and **C)** evenness (*E*) at four sampling sites during low water (LW), transition from lake to riverine (T1), high water (HW) and transition from riverine to lake (T2) periods

R = 0.29, P < 0.05) and negatively correlated with water discharge (R = -0.37, P < 0.01), TP (R = -0.36, P < 0.05) and NO_2-N (R = -0.29, P < 0.05). Chlorophyll-*a* values were significantly different between LW and HW (df = 11, F = 4.02, P < 0.01). Chlorophyll-*a* values were positively correlated with EC (R = 0.38, P < 0.01) and temperature (R = 0.37, P < 0.05). Biomass and chlorophyll-*a* values were not correlated (P > 0.05).

To analyze the relationship between the phytoplankton distribution and the environmental variables, we performed RDA using the biomass values of 14 FGs dominated among the phytoplankton assemblage. Initially the RDA was performed on the whole environmental and FGs datasets. The forward selection indicated that 9 of the 14 environmental variables significantly accounted for the variance in the FGs data. The results of RDA using only these 9 variables are presented in Figure 5. The eigenvalues of RDA axis 1 (0.24) and axis 2 (0.052) account for 29.2% of the cumulative variance in the FGs data. The FGs − environmental correlations of RDA axis 1 and 2 are high, and the first two axes account for 65% of the variance in the FGs − environmental relationships. These values are only slightly lower than those for the RDA with 14 environmental variables, indicating that the 9 variables provide a good representation of the major controlling gradients in the FGs data of

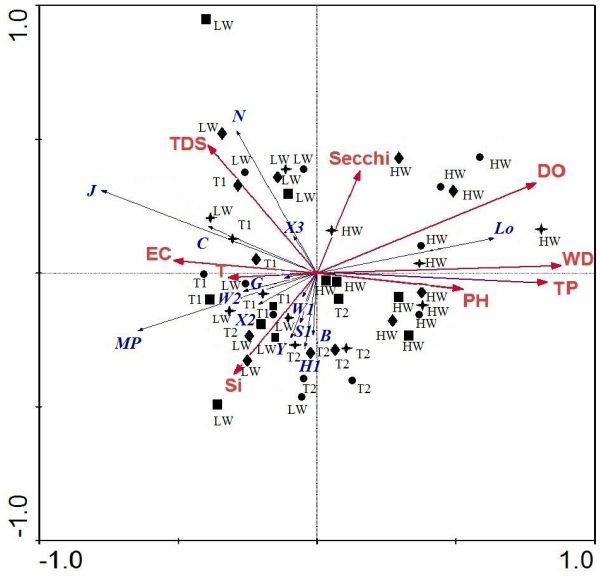

Fig. 5. Ordination of samples corresponding to different sampling stations and periods (♦: first station, ■:second station, ✦:third station, ●:fourth station, LW: low water, T1: transition from lake to riverine, HW: high water and T2: transition from riverine to lake), scores of phytoplankton biomass by functional groups and environmental variables (T: water temperature, DO: dissolved oxygen concentration, EC: specific conductance, TDS: total dissolved solid, WD: water discharge, Secchi: Secchi disk depth, Si: silica concentration, TP: total phosphorus concentration) along the first two redundancy analysis axes

NML. Axis 1 is strongly correlated with water discharges (R = 0.76), DO (R = 0.68), TP (0.54), pH (R = 0.45) and negatively correlated with EC (R = - 0.45), temperature (R = - 0.27) and Si (R = - 0.25). Axis 2 is positively correlated with TDS (R = 0.35) and Secchi disk visibility (R = 0.29). Groups **N, J, C, G, W2, X1, X2, W1, S1, B, Y, H1** and **MP** were associated with LW, T1 and T2. These groups were positively correlated with temperature, EC, TDS, and Si. The occurrence of the group **Lo** was linked mainly with HW where water discharges, Secchi disk, DO, TP and pH values were high. As a result of RDA, the second, third, and fourth stations were mainly linked with Si in T1 while the second station was linked with pH in HW. Moreover, the second station was mainly linked with the group **X2**, the third station with the group **Y** and the fourth station with **H1** and **S1** in T2.

During summer and early fall (LW), the functional group **MP** (*Oscillatoria* sp.*, Ulnaria ulna* and *Cocconeis placentula*) (on average 35% of the total biomass) dominated in phytoplankton. The contribution of the groups **N** (*Staurastrum cingulum*) (mean 30% of the total biomass) and **J** (*Coelastrum astroideum*, *Tetrastrum glabrum*, *Crucigeniella apiculata*) was also important at the beginning of this period (mean 20% of the total biomass). Also *Cyclotella meneghiniana* (group **C**), *Pseudoschroederia robusta* (group **X1**), *Trachelomonas intermedia* (group **W2**), *Euglenaria clavata* (group **W1**) *Eudorina elegans* (group **G**) contributed to the biomass in this period.

With the beginning of the transition period from lake to riverine conditions (T1), members of the group **J** (*Actinastrum hantzschii*, *Desmodesmus communis*, *Tetraedron minimum*, *C. astroideum*) dominated over the others. Their contribution to the total biomass was higher compared to other groups and represented 60% in November 2012. Especially, *A. hantzschii* was important in the phytoplankton at the first three stations. Even though biomass of the group **MP** (*U. ulna*, *C. placentula, Gomphonema acuminatum*) decreased (10% of the total biomass) in November 2012, it increased again in December 2012 and represented 40% of the total biomass. In particular, the development of this group at the first station was more remarkable. Also *Chloromonas tapeta* var. *vernalis* (group **X2**), *Chlamydomonas heterogama* (group **X2**), *Cryptomonas ovata* (group **Y**), *Trachelomonas oblonga* (group **W2**) *P. robusta* (group **X1**), and *C. meneghiniana* (group **C**) were important components of algae during the T1 period.

Members of the group **Lo** (*P. lomnickii* var. *splendidum* and *Peridiniopsis cunningtonii*) dominated in the phytoplankton during HW. Their contribution to biomass was very high (on average 80.5% of the total biomass). However, biomass values were the lowest at the second station as a result of lesser development of *P. lomnickii* var. *splendidum* during HW. Furthermore, *Cyclotella ocellata* (group **B**) represented 38% of the biomass at the second station in January 2013.

With the beginning of the T2 period, members of the group **MP** (*U. ulna*, *Oscillatoria* sp.) began to increase quickly and reached 70.2% of the total biomass (except for the fourth station) in May 2013. However, *Phormidium* sp. (group **S1**) dominated in the phytoplankton at the fourth station and represented 87.9% of the total biomass in May 2013. It is worth noting that the abundance of species was different at different stations in the late T2 period (June 2013). *C. meneghiniana* (group **C**) and *Trachelomonas intermedia* (group **W2**) dominated at the first station while *C. placentula* and *Nitzschia palea* (group **MP**) (on average 69.1% of the total biomass) and *Chlamydomonas incerta* and *Chlamydomonas proboscigera* var. *conferta* (**X2**) (on average 26.2% of the total biomass) dominated at the second station, the group MP (on average 65% of the total biomass) and *C. ovata* (groups **Y)** at the third station, and *Dolichospermum sigmoideum* (group **H1**) (77.4% of the biomass) dominated at the fourth station. Moreover, members of **W1** (*E. clavata*) and **J** (*A. hantzschii*) contributed to the biomass at the first and the third station during this period.

DISCUSSION

The positive correlation between the depth of NML and the water discharges of the Sakarya River indicates that the floodplain lake is influenced by the river. RDA also supports the effect of water discharges on the phytoplankton distribution in NML. As a result of this impact, physical and chemical environments of NML were mainly determined by four different periods.

As it has been evidenced by other researchers, nutrient levels were low during LW (Furch and Junk 1993, Hein et al. 1996, Tockner et al. 1999) in other floodplains. Tockner et al. (1999) defined this period in which the autogenic processes are prevailing (e.g. sedimentation of autochthonous material, nutrient uptake and grazing) as the `biotic interaction phase'. During the isolation phase, most authors (Garcia de Emiliani 1997, Mihaljevic et al. 2009, Bovo-

Scomparin and Train 2008) found the dominance of Chlorophyta, Euglenophyta, Dinophyta and Cyanobacteria in floodplain lakes. However, biomass values were mostly contributed by Bacillariophyceae, Cyanobacteria, Charophyta and Chlorophyta (dominant species belong to groups **MP, N** and **J**) in our study.

NML shifted from a closed to a more open system with the onset of flooding (T1). The increased levels of nutrients during this period indicated that the river water serves as a major source of nutrients, which is characteristic of floodplains (Junk 1982, Furch and Junk 1997, Weilhoefer and Pan 2007). In the Danubian floodplains, Riedler (1997) and Tockner et al. (1999) found a significant positive relationship between algal biomass and the increasing inundation. However, Garcia de Emiliani (1997), Ibañez (1998), Zalocar de Domitrovic (2003) and Mihaljevic et al. (2009) found an inverse relationship between algal biomass and flooding. Moreover, Salmaso and Zignin (2010) stated that the intensity of discharge affected the phytoplankton biomass, and the phytoplankton development was limited by the high flushing rate. In the present study, algal biomass and chlorophyll-*a* concentration did not increase despite the increased nutrient concentrations, probably due to the dilution effect by both the flooding and the increased water flux. Thus, flooding in the T1 period seems to be a disturbance factor (Reynolds et al. 1993). While the discharge increased, small-sized organisms (from the group **J)** which compensated for dilution effects with their growth rate and maintained their biomass (Garcia de Emiliani 1997), maintained and contributed to the biomass in our study. Afterwards, there was an increase in the group **MP** of diatoms during the second part of this period. Denser development of the group **MP** might have decreased the Si values at the first station, and as a consequence, Si values were different from other stations. It is commonly observed that typical, constant phytoplankton species of rivers develop in floodplain lakes during the flood (De Oliveira and Calheiros 2000, Mihaljevic et al. 2009). However, dominant phytoplankton species (*Pseudanabaena catenata* Lauterborn) of the Sakarya river did not maintain their growth in NML during the inundation (Küçük 2012).

Under the conditions of HW, the dilution effects were expressed as a greater Secchi depth and consequently the mean phytoplankton biomass was significantly lower compared to LW. Following the definition presented by Sommer et al. (1993), an equilibrium phase was established in the period of January-April 2013, under conditions of a long-lasting HW. Thus, the diversity and evenness had minimum values during this period. The presence of **Lo** species (*Peridinium* and *Peridiniopsis*) during long-lasting HW could be related to nutrient enrichment (especially PO_4), resulting in slow, gradual growth of this group (Zalocar de Domitrovic 2003). Similar to our results, *P. lomnickii* var. *splendidum* dispersed in ponds of Europe and the maximum abundance was observed in winter (Huber-Pestalozzi 1976). Even though in our study Dinophyta was dominant during HW, it was found during low-water periods or late autumn periods in several floodplain lakes (Garcia de Emiliani 1997, Zalocar de Domitrovic 2003, Mihaljevic et al. 2009). RDA revealed the difference at the second station in terms of pH values. High biomass values of *P. lomnickii* var. *splendidum* and, as a result, high photosynthetic activity may increase pH values of others except the second station during this period. Similar observations were reported in Lake Kinneret, where high photosynthetic activity of the dinoflagellate *Peridinium gatunense* increased the pH value (Berman-Frank et al. 1994).

The T2 period coincided with spring mixing and decreased water levels, and represented a turbid environment for the development of phytoplankton. Increased temperature and sufficient nutrients stimulated the growth of low-light-adapted cyanobacteria (groups **MP, S1** and **H1**) as well as other turbid-environment-adapted species (groups **X2, Y** and **C**) (Reynolds et al. 2002, Padisák et al. 2009). Dense Cyanobacteria development (Groups **H1** and **S1**) at the fourth station might result from low Secchi disk values rather than other stations.

In conclusion, this investigation show that the water chemistry and the composition and abundance of the phytoplankton in NML show significant temporal fluctuations in response to the hydrosedimentological regime of the Sakarya River rather than the climatologic changes as typical of temperate lakes. LW, T1 and T2 periods selected the species tolerant to mixing and turbidity (Reynolds et al. 2002, Padisák et al. 2009), while long-lasting potamophase (HW) forced phytoplankton communities toward equilibrium. RDA revealed that there are some differences between stations in terms of Si, pH values and the distribution of FGs. These differences may result from a different depth or different response rate to inundation. A long-term limnological investigation of phytoplankton is necessary to completely explain the differences

between stations and the interactions between the Sakarya River and the isolated floodplain lake (NML).

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