

CONTENT OF PHOTOSYNTHETIC PIGMENTS IN *Phragmites communis* (Cav.) Trin ex Steud., *Salvinia natans* L. (All.), *Utricularia vulgaris* L. AND *Ceratophyllum demersum* L. DURING THE SEASON IN THE AREA OF THE BARDAČA POND (REPUBLIKA SRPSKA)

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Abstract

Maksimović T., Lolić S., Kukavica B.: Content of photosynthetic pigments in *Phragmites communis* (Cav.) Trin. ex Steud., *Salvinia natans* L. (All.), *Utricularia vulgaris* L. and *Ceratophyllum demersum* L. during the season in the area of the Bardača pond (Republika Srpska). Ekológia (Bratislava), Vol. 42, No. 3, p. 201–208, 2023.

It is known that aquatic macrophytes are an important part of freshwater ecosystems, and that they play a different role in their structure and functioning. Their presence and distribution depends on water temperature and transparency, nutrient content, conductivity, pH, chemical composition and water circulation. Therefore, the goal of our research was to determine the influence and interrelationship of physicochemical parameters of water on the content of photosynthetic pigments in aquatic macrophytes of Lake Necik, in the Ramsar area of Bardača (Republic of Srpska). Content of total chlorophyll ($a + b$) during the growing season (June–October) ranged from 0.231 to 1.145 mg g⁻¹ FW in *Phragmites communis* Trin. ex Steud., from 0.061 to 0.541 mg g⁻¹ FW in *Salvinia natans* L. (All.), from 0.063 to 0.626 mg g⁻¹ FW in *Utricularia vulgaris* L. and from 0.063 to 0.443 mg g⁻¹ FW in *Ceratophyllum demersum* L. Research has shown that floating and submerged macrophytes have a lower ratio of chlorophyll a/b compared to emergent hydrophytes, which is most likely the result of stress caused by increased light intensity and temperature. Seasonal variations in the content of photosynthetic pigments indicated that the species *Phragmites communis* proved to be more tolerant to the stress caused by the influence of various abiotic factors, while *Salvinia natans* proved to be more sensitive. Spearman's correlation coefficient of the physicochemical parameters of water and the concentration of photosynthetic pigments of macrophytes showed a significant influence of certain abiotic factors (temperature, transparency and nutrients) on the content of pigments in the leaves of *Phragmites communis*, *Salvinia natans*, *Utricularia vulgaris* and *Ceratophyllum demersum* L.

Key words: aquatic macrophytes, chlorophyll, stress, physicochemical parameters of water, growing season.

Introduction

The swamp-marsh complex of Bardača is of exceptional importance for humans and natural diversity because this ecosystem is the habitat of rare and endangered representatives of flora and fauna, and it can rightfully be said that it is of inestimable importance. Given the fact that today, there are fewer and fewer natural wetlands, and that we are daily faced with the problem of the disappearance of drinking water, floods, and the disappearance of plant and animal species, the importance of wetlands is increasing primarily in water purification, protection from floods, and in filtration and the remedial role of dominant macrophytic species (Đurić et al., 2004; Maksimović et al., 2016, 2019, 2020a, b). Aquatic macrophytes, the most important constituents and main producers of aquatic ecosystems, are constantly exposed to various stress factors that often lead to physiological-biochemical changes in the leaves, including changes in the content of photosynthetic pigments (Nekrasova et al., 2003; Ronzhina et

al., 2004). In the case of aquatic plants, the full spectrum of light is accepted by emergent and floating aquatic plants, while submerged aquatic plants that live at greater depths absorb a smaller amount of visible radiation, which is also of variable quality. Therefore, essentially, in water basins, there is a great competition among plants for light, which especially refers to submerged plants. So, variation in the content of photosynthetic pigments as well as their representation is one of the ways of adaptation to different light conditions in the water layer (Lukina, Smirnova, 1988; Stevanović, Janković, 2001; Nekrasova et al., 2003; Ronzhina et al., 2004). Aquatic macrophytes are characterised by a lower concentration of photosynthetic pigments per fresh biomass (1–2 mg · g⁻¹ FW) compared to terrestrial plants (2–3 mg g⁻¹ FW) (Ronzhina et al., 2004). In their research, Nikolić et al. (2009), Horvatić et al. (2013), and Hreeb (2017) indicated that various physicochemical factors play a key role in the biosynthesis of photosynthetic pigments, and that certain abiotic factors (light, temperature, nutrients) significantly determine the pho-

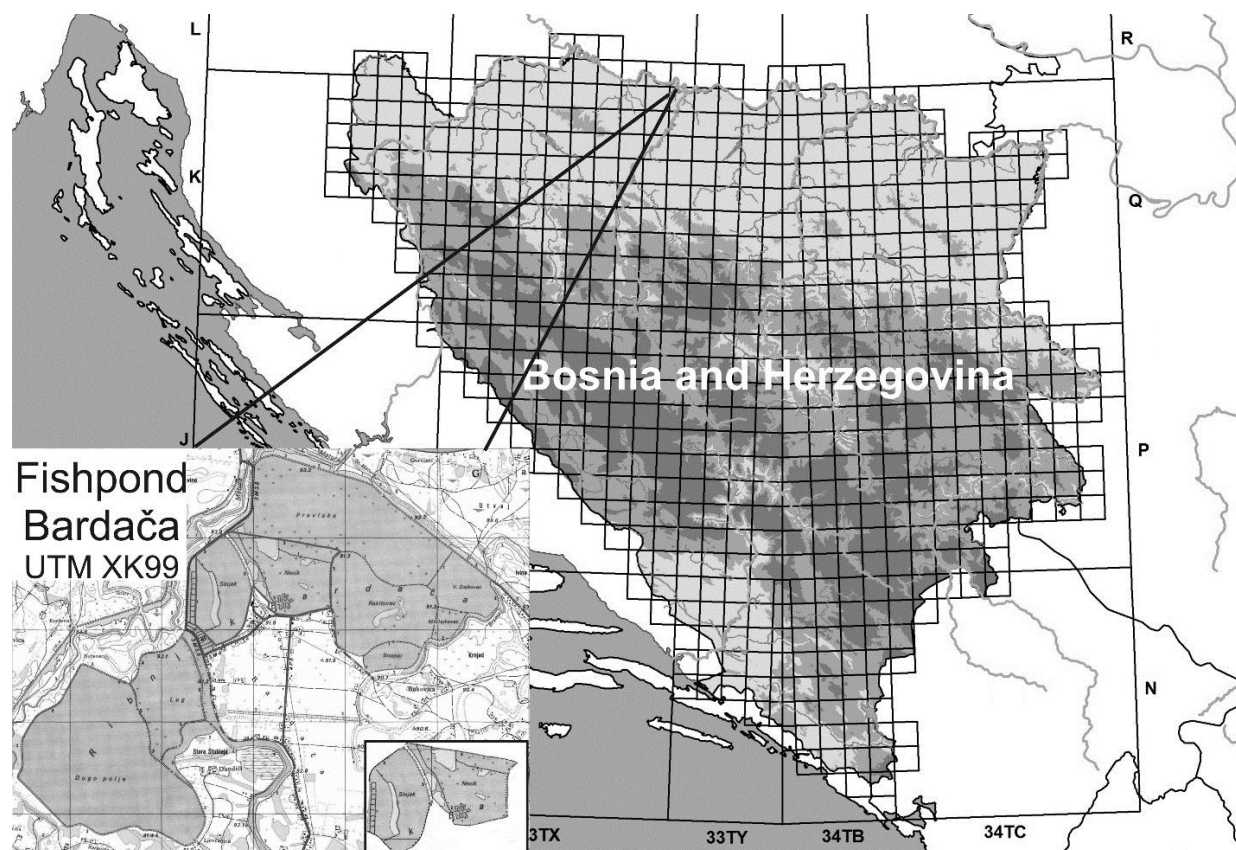


Fig. 1. Map of Bardača wetland (topographic map 1:25,000, Nova Gradiška (Razboj-Ljevcanski) 4-4, Military Geographic Institute 1977 (Military Geographic Institute).

tosynthetic pathway of aquatic macrophytes. On the other hand, Ronzhina et al. (2004) attributed the significant difference in the concentration of photosynthetic pigments among emergent, floating, and submerged leaves to their specific morphological and anatomical structure. Hreeb (2017) states in his research that the increase in the content of chlorophyll *a* in aquatic macrophytes and the increase in nutrients are one of the indicators of the state of water quality.

Previous investigations of the chemical composition of water, sediment, and dominant macrophytes in the area of the Bardača pond have shown that the investigated area is not burdened by the content of heavy metals (Maksimović et al., 2016, 2019), and that there was a pronounced phenomenon of eutrophication. They also reported that the pond basins belong to the eutrophic hypertrophic aquatic environment (Lolić et al., 2014). Since eutrophication has occurred due to the increased influx of nutrients, which is one of the main reasons for the degradation of aquatic ecosystems, it is very important to know their correlation with photosynthetic pigments. It is important to point out that eutrophication is an increasingly existing problem today, because not only does this process degrade the chemical quality of water, but also it changes the structure of aquatic communities and the consequent reduction in water quality. Therefore, the goal of research in this paper was to determine the content of photosynthetic pigments during the growing season in *Phragmites communis* Trin. ex Steud., *Sal-*

vinia natans L. (All.), *Utricularia vulgaris* L., and *Ceratophyllum demersum* L. and to determine the mutual correlation between the physical and chemical parameters of water and the concentration of photosynthetic pigments.

Material and methods

Research area

The Bardača swamp-marsh complex is located in Bosnia and Herzegovina, in the northern part of Republic of Srpska (B&H) in the centre of the temperate zone (45° 08' north latitude and 17° 25' east longitude), at about 100 m above sea level, at the foot of Motajica mountains. It is located in the extreme northeast of the Lijevče field and is bounded by the Sava River from the north, the Brzaja and Vrbas rivers from the east, Matura from the west, while the Osorna-Borna-Ljevcanica perimeter canal (O-B-Lj) is located in the immediate vicinity on the south.

According to the Ramsar Convention, Bardača was declared a wetland of world importance in February 2007 due to its unique importance as a bird habitat. In the period of acquisition of this status, the wetland area of Bardača covered 2810 ha (810 ha of water and 2000 ha of terrestrial ecosystems) with a total of 11 artificial lakes (Đurić et al., 2004). Research was carried out at the Necik locality, which was an active pond during the sampling period (Fig. 1).

Table 1. Physical and chemical parameters of water in the locality Necik.

Parameters	June	July	August	September	October
Air temperature (°C)	24.80	27.50	25.10	27.40	17.5
Water temperature (°C)	25.40	29.60	26.40	25.70	15.60
pH	7.76	7.68	7.68	8.19	7.94
Electrical conductivity ($\mu\text{S cm}^{-1}$)	533	530	712	368	749
Turbidity (NTU)	53.80	58.20	45.60	57.10	56.00
Dissolved oxygen (mg L^{-1})	4.98	3.36	3.80	6.99	7.86
Saturation (%)	61.60	44.70	48.00	87.2	81.4
Ammonium nitrogen (mg L^{-1})	0.29	0.22	0.08	0.07	0.08
Nitrate nitrogen (mg L^{-1})	1.40	0.10	7.00	0.80	1.00
Nitric nitrogen (mg L^{-1})	0.081	0.051	0.038	0.012	0.014
Orthophosphates (mg L^{-1})	0.20	0.31	0.25	0.48	0.28
Sulphates (mg L^{-1})	28	24	33	38	36
Transparency (cm)	30	25	23	16	18
Depth (cm)	89	86	60	63	40

Methods

Seasonal sampling of plant material was carried out from June to October, once a month at the Necik site. Standard methods for aquatic plants were used for sampling plant material and preparing it for analysis (APHA, 1995). The collected plant material (*Phragmites communis* Trin. ex Steud., *Salvinia natans* L. (All.), *Utricularia vulgaris* L., and *Ceratophyllum demersum* L.) was delivered to the laboratory in containers with liquid nitrogen. The content of photosynthetic pigments (Chl *a*, Chl *b*, and carotenoids) in the leaves of aquatic macrophytes was determined spectrophotometrically in the acetone extract using standard methods (APHA, 1995), and the reading was performed using an ultraviolet-visible spectrophotometer (UV-VIS 1800 Shimadzu). Simultaneously, water samples were taken for the purpose of analysing the physical and chemical characteristics. Water and air temperature was determined with a mercury thermometer, while water transparency was determined using a Secchi disc. The oxygen concentration was determined using a Hach HQ30 flexi oximeter. A Eutech Cyberscan PC 10 pH meter was used to determine pH value and electrical conductivity, while a Eutech TN-100 turbidimeter was used to determine turbidity. The measurement of other water quality parameters, that is, ammonium ions (NH_4), nitrate (NO_3), nitrite (NO_2) and orthophosphate (O-PO_4), was performed using a HACH DR2800 spectrophotometer. The samples were always taken at the same profile points, and the measurements were made in a layer of water 30–50 cm below the surface. The samples were then transported on ice at a temperature of up to +4 °C and analysed within 24 h. All data were statistically processed in the Statistical Package for the Social Sciences (SPSS) program. The analyses were performed in three independent repetitions, and the analysed parameters were processed using the method of analysis of variance (ANOVA) of the factorial experiment. The LSD (least significant difference) test was used for the significance level $p < 0.05$ to compare the results and examine intergroup differences from the ANOVA analysis within the post hoc tests. All results are presented as means of three replicates $\pm$ standard error (SE). In addition, Spearman's

correlation coefficient was calculated between the content of photosynthetic pigments and the physicochemical parameters of water quality.

Results

During the investigated period, the maximum water temperature was obtained in summer (29.60 °C) and the minimum in autumn (17.60 °C) (Table 1). The pH value fluctuated from 7.68 in summer to 8.19 in October, and the water was slightly alkaline on average. Electrical conductivity values ranged from a minimum of 368 $\mu\text{S cm}^{-1}$ in September to a maximum of 712 $\mu\text{S cm}^{-1}$ in August. Ammonia and nitrite forms of nitrogen showed similar seasonal patterns, with higher values in summer and lower values in autumn. Nitrate values fluctuated more during the season; the highest value was obtained during August (7.0 mg L^{-1}) and the minimum value during July and September. In the period including May, September and October, the water was hypersaturated with dissolved oxygen, while in July and August, the concentration of dissolved oxygen in the water dropped significantly, so the water saturation was only 56.8%. Water transparency was maximum at the beginning of the season, while minimum transparency was recorded in autumn (Table 1).

A significantly high positive correlation was established between transparency and ammonia nitrogen ($r = 0.9775$) and nitrite ($r = 1.000$), while saturation was highly correlated with pH ($r = 0.975$) (Table 2). This study also found significant differences in the content of photosynthetic pigments during the season among different groups of macrophytes (emergent, submerged and floating).

The highest content of total chlorophyll (Chl *a* + *b*) during the season (June–October) was found in emergent leaves of *Phragmites communis* (0.231–1.145 mg g^{-1} FW), followed by submerged species of *Utricularia vulgaris* (0.063–0.626 mg g^{-1} FW) and *Ceratophyllum demersum* (0.063–0.443 mg g^{-1} FW), while twice lower content was found in floating *Salvinia natans* (0.025–0.541 mg g^{-1} FW) (Fig. 2A). The chlorophyll content was found to be maximum in the summer period, which is

Table 2. Correlation coefficients between physical and chemical parameters of water quality and concentration of photosynthetic pigments in the leaves of *Phragmites communis*, *Ceratophyllum demersum*, *Utricularia vulgaris* and *Salvinia natans* at Necik pond.

Parameter		Water temperature (°C)	pH	Electrical conductivity (μS cm ⁻¹)	Satura- tion (%)	Nitrate nitrogen (mg)	Ammonium nitrogen (mg L ⁻¹)	Nitric nitrogen (mg L ⁻¹)	Orthophos- phates (mg L ⁻¹)	Transparency (cm)
Water temperature (°C)		1.000								
pH		−0.667	1.000							
Electrical conductivity (μS cm ⁻¹)		−0.500	−0.205	1.000						
Saturation (%)		−0.700	0.975**	−0.100	1.000					
Nitrate nitrogen (mg L ⁻¹)		−0.300	−0.205	0.600	0.000	1.000				
Ammonium nitrogen (mg L ⁻¹)		0.051	−0.553	0.154	−0.616	0.103	1.000			
Nitric nitrogen (mg L ⁻¹)		0.200	−0.667	0.100	−0.700	0.200	0.975**	1.000		
Orthophosphates (mg L ⁻¹)		0.300	0.410	−0.600	0.300	−0.800	−0.667	−0.700	1.000	
Transparency (cm)		0.200	−0.667	0.100	0.700	0.200	0.975**	1.000**	−0.700	1.000
P. communis	Chl <i>a</i> + <i>b</i>	0.700	−0.718	−0.400	−0.800	−0.200	0.718	0.800	−0.200	0.800
	Chl <i>a</i> / <i>b</i>	−0.400	0.564	0.300	0.600	−0.100	−0.821	−0.900*	0.500	−0.900*
	Chl <i>a</i> + <i>b</i> / <i>Car</i>	−0.500	−0.154	0.500	−0.200	0.200	0.821	0.700	−0.700	0.700
	Car	0.600	−0.359	−0.700	−0.500	−0.500	0.564	0.600	0.100	0.600
C. demersum	Chl <i>a</i> + <i>b</i>	0.500	−0.821	0.000	−0.900*	−0.100	0.872	0.900*	−0.400	0.900*
	Chl <i>a</i> / <i>b</i>	−0.700	0.718	0.400	0.800	0.200	−0.718	−0.800	0.200	−0.800
	Chl <i>a</i> + <i>b</i> / <i>Car</i>	0.700	−0.667	0.100	−0.700	−0.300	−0.051	0.000	0.300	0.000
	Car	0.200	−0.667	0.100	−0.700	0.200	0.975**	1.000**	−0.700	1.000**
S. natans	Chl <i>a</i> + <i>b</i>	0.400	−0.564	−0.300	−0.600	0.100	0.821	0.900*	−0.500	0.900*
	Chl <i>a</i> / <i>b</i>	−0.100	0.205	0.200	0.400	0.600	−0.718	−0.600	0.000	−0.600
	Chl <i>a</i> + <i>b</i> / <i>Car</i>	0.500	−0.821	0.000	−0.900*	−0.100	0.872	0.900*	−0.400	0.900*
	Car	0.300	−0.205	−0.600	−0.300	−0.200	0.667	0.700	−0.200	0.700
U. vulgaris	Chl <i>a</i> + <i>b</i>	0.400	−0.564	−0.300	−0.600	0.100	0.821	0.900*	−0.500	0.900*
	Chl <i>a</i> / <i>b</i>	−0.700	0.718	0.400	0.800	0.200	−0.718	−0.800	0.200	−0.800
	Chl <i>a</i> + <i>b</i> / <i>Car</i>	0.667	−0.816	−0.051	−0.718	0.462	0.368	0.564	−0.462	0.564
	Car	0.400	−0.564	−0.300	−0.600	0.100	0.821	0.900*	−0.500	0.900*

Note: * - significance more than 95%.

characterised by a period of active growth as well as increased nutrient content and temperature, while a significant decrease (2–3 times) was recorded with age in the studied macrophyte species (Fig. 2A).

The value of carotenoids was the highest in reed (0.062–0.314 mg g⁻¹ FW), while the lowest value was observed in *S. natans* (0.018–0.120 mg g⁻¹ FW) (Fig. 2C). The Chl *a*/*b* content also changed during the season from 1.51 for *S. natans* to 2.96 for

Phragmites communis, where it was significantly lower at the beginning of the season and increased with age in all investigated macrophyte species (Fig. 2C).

A different trend was recorded for the ratio of Chl *a* + *b*/*Car*. A higher Chl *a* + *b*/*Car* at the beginning of the season (June–July) was characteristic for all investigated macrophyte species, with a significant decrease found towards the end of the vegetation period (Fig. 2D).

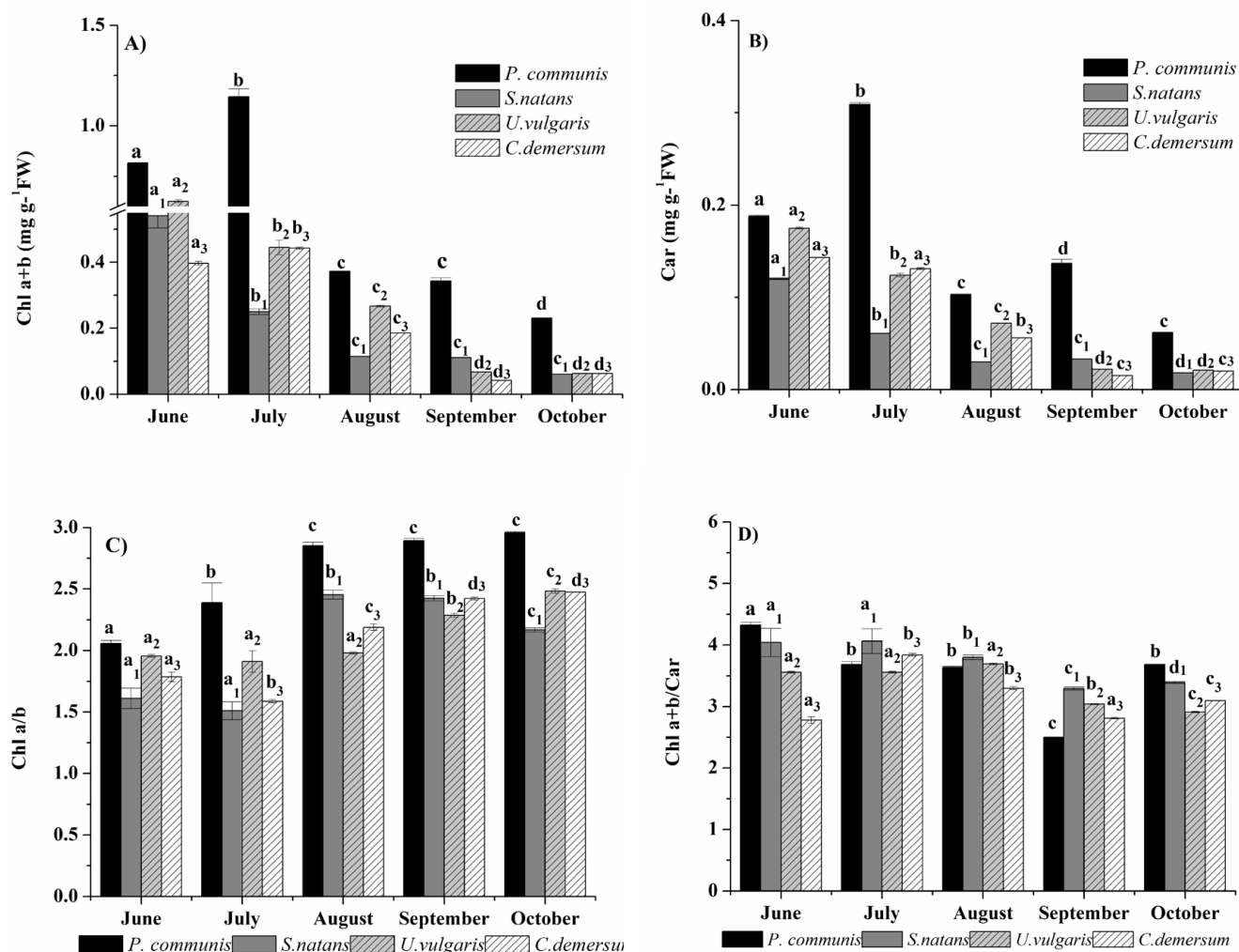


Fig. 2. Seasonal variations in the total chlorophyll content (Chl a + b) mg g⁻¹ FW (A), carotenoid content (Car) mg g⁻¹ FW (B), chlorophyll a and b rates (Chl a/b) (C) and total chlorophyll to carotenoid ratio (Chl a + b/Car) (D) in emergent, floating and submerged species in the Necik fishpond area. The values are expressed as mean of three repetitions ± standard error (SE). Different small letters indicate statistical significance between months according to LSD test ($p < 0.05$).

The concentration of Chl a + b for the species *Utricularia vulgaris*, *Ceratophyllum demersum* and *Salvinia natans* was significantly positively correlated ($r = 0.90$) with nitrite content and transparency, while it was negatively correlated with pH, saturation and orthophosphate content (Fig. 2A, Table 2). In *Phragmites communis*, the concentration of Chl a + b was positively correlated with temperature, ammonium nitrogen content, nitrite and transparency, while it was negatively correlated with pH, electrical conductivity, saturation, nitrate content and orthophosphates (Table 2). A significant negative correlation was found in the Necik site between the ratio of Chl a/b and nitrite and transparency for the species *P. communis*. In the submerged species *Utricularia vulgaris* and *Ceratophyllum demersum*, a significantly high positive correlation of Car concentration with ammonia nitrogen, nitrites and transparency was found (Table 2). In the floating species *Salvinia natans*, the Car concentration was significantly positively correlated with nitrite content and

transparency, while it was significantly negatively correlated with saturation (Fig. 2B, Table 2).

Discussion

Photosynthetic pigments, especially chlorophylls, are indicators of photosynthetic activity, growth, development and yield of plants (Nikolić et al., 2009; Dar et al., 2013; Maksimović et al., 2020b). Changes in the concentration of photosynthetic pigments are important indicators of the physiological status of plants. The decrease in chlorophyll concentration is more pronounced when plants are exposed to stressful conditions (low/high temperatures, low/high light intensity, heavy metals, etc.) (Dar et al., 2013; Ivanković et al., 2011; Hreeb, 2017) or during leaf senescence (Sheikh et al., 2017), which was also observed in our research. It is known that the basic nutrients necessary for the growth of aquatic macrophytes are nitrogen and phosphorus.

So, their presence in the soil and water is directly dependent on the content of photosynthetic pigments (Nikolić et al., 2009; Dar et al., 2013; Maksimović et al., 2020b). The maximum content of photosynthetic pigments in the investigated macrophyte species was found during the summer period (Fig. 2), which is characterised by high temperature, reduced oxygen content and moderate concentration of nutrients (Table 2). This is confirmed by a significant positive correlation between the concentration of total chlorophyll and temperature; with an increase in temperature, the concentration of total chlorophyll increased. The summer drop in the content of nutrients (nitrite, ammonia, phosphate) is attributed to a higher photosynthetic activity of macrophytes, especially submerged ones that absorb nutrients with their entire surface and thus leave small amounts of such substances in the water. Dar et al. (2013), who monitored the content of photosynthetic pigments during different seasons in different groups of aquatic plants, also reported similar results. A significantly high positive correlation found between the concentration of total chlorophyll, carotenoids of floating and submerged plants and nitrite can be explained by the dependence of the photosynthesis process on their supply (Wetzel, 2001), as well as their importance in the development of this species. Light intensity is recognised as a limiting factor for the dynamics and growth of aquatic plants, and the change in light intensity and quality is the main factor that determines photosynthetic activity and the content of photosynthetic pigments (Balali et al., 2012), which is the reason for the high positive correlation between transparency and total chlorophyll concentration of submerged and floating plants in Lake Necik. It is known that many types of aquatic macrophytes can efficiently use all forms of nitrogen from the aquatic ecosystem (Jampeetong, Brix, 2008; Saeed, Sun, 2012), which has a practical value in removing it from water, reducing the process of eutrophication, which is probably one of the causes of low concentrations recorded during summer in the researched area. The results obtained in this study showed that there is a clear trend in the reduction of the concentration of photosynthetic pigments in the leaves of (emergent, submerged and floating) macrophytes sampled in the period August–October at the Necik site. The lower content of photosynthetic pigments in macrophytic species at the end of the season is the result of the ageing process (Ronzhina et al., 2004) as well as adaptation to lower water temperatures (Dar et al., 2013), which we also noted in our research.

Jampeetong and Brix (2008) stated in their research that the main source of growth for *Salvinia natans* in natural conditions is NH_4^+ , and that plants use NO_3^- when NH_4^+ concentrations are low. The high positive correlation between total chlorophyll concentration and ammonia and nitrite nitrogen is probably the result of available nutrients in the aquatic environment and different uptake by aquatic macrophytes.

Aquatic macrophytes are characterised by a low concentration of pigments per fresh biomass ($1\text{--}2\text{ mg g}^{-1}$) compared to terrestrial plants ($2\text{--}3\text{ mg g}^{-1}$) (Ronzhina et al., 2004), and we also obtained similar results in this study. Some authors (Nikolić et al., 2009; Dar et al., 2012, 2013; Horvatić et al., 2013) emphasise in their research that there is a direct connection between the content of photosynthetic pigments of macrophytic species and various abiotic factors primarily (light intensity, temperature, nutrients, transparency), which is in line with our research. Different authors (Nekrasova et al., 2003; Dar et al., 2012; Horvatić et al., 2013) found that the content of photosynthetic pigments

varies significantly during the seasons and with the phases of plant development, and they are also an indicator of the dynamics of bioproduction of the analysed species (Nikolić et al., 2009), which is similar to the results obtained in this paper. Maksimović et al. (2020b), in their research in the area of the Bardača pond, found a lower content of total chlorophyll and carotenoids in the leaves of *S. natans*, followed by *Utricularia vulgaris* and *Salvinia natans*, while the highest content of photosynthetic pigments was found in the emergent leaves of *Phragmites communis*.

The highest concentration of total chlorophyll was obtained in the emergent leaves of *P. communis*, which was to be expected due to the similar anatomy with the leaves of terrestrial plants (Lukina, Smirnova, 1988). Unlike emergent and submerged species, the leaves of floating plants are positioned vertically away from direct solar radiation, and as a result, the leaves overlap, reducing the inflow of solar energy, which results in a lower concentration of photosynthetic pigments (Stevanović, Janković, 2001). Leaves of submerged plants are directly exposed to stress factors imposed by the water environment (Nekrasova et al., 2003). The increased surface area of submerged leaves in relation to their volume (development of striated, banded or lanceolate, usually very thin leaves) is also the best form of adaptation to efficiently carry out photosynthesis in conditions of weakened light (Ronzhina et al., 2001, 2004). The results obtained in this study were in agreement with those of other researchers (Ronzhina et al., 2004; Dar et al., 2013; Maksimović et al., 2020b), who reported a higher content of photosynthetic pigments in submerged compared to floating leaves.

As the leaves of emergent and floating plants develop in conditions of intense light and receive the full light spectrum, they are characterised by an increased ratio of chlorophyll *a* to chlorophyll *b* (Lukina, Smirnova, 1988; Ronzhina et al., 2004), which was also noted in our study. Unlike them, the leaves of submerged plants receive a small amount of visible radiation, of altered quality (Lukina, Smirnova, 1988; Ronzhina et al., 2004), which is one of the reasons for the existence of such large differences. Studies on the carotenoid composition of heliophyte leaves found that leaves exposed to strong solar radiation have higher amounts of xanthophyll cycle components as well as *b*-carotene than leaves in the shade (Demmig-Adams, Adams, 1992). In these conditions, where the light intensity is not only reduced, but also qualitatively changed in chloroplasts, the concentration of chlorophyll *b* increases, which fills the absorption spectrum of chlorophyll; energy is transferred to chlorophyll *a*, which ensures the process of photosynthesis, leading to a different trend of the ratio *a/b* of the investigated macrophyte species (Fig. 2C). Similar results were reported by Lukina and Smirnova (1988). The content of carotenoids in all three studied macrophyte species also varied seasonally: increased values were recorded at the beginning of the season in young, more physiologically active leaves, with a maximum recorded during the period June–July, while the content of carotenoids was reduced by 80% by the end of the research period (Fig. 2B). In relation to the species, the carotenoid content was the highest in emergent leaves and the lowest in floating leaves. The obtained values for the carotenoid content were close to the values obtained by Horvatić et al. (2013) in the leaves of submerged, floating and emergent leaves in the Baranja channel. Reduced concentrations of carotenoids can be associated with ageing and extinguishing of the basic photosynthetic function, while increased concentrations at the beginning of the

season are the result of increased light intensity and temperature, when carotenoids have a protective role in extinguishing triplet chlorophyll and singlet oxygen (Karuppanapandian et al., 2011). The Chl *a* + *b*/carotenoids ratio varied significantly seasonally and in relation to the investigated species. This ratio depends and varies primarily in different light conditions (Ronzhina et al., 2004). It was maximal at the beginning of the season (*P. communis* and *Salvinia natans*) and decreased significantly as the plants aged (Fig. 2D). Reduced ratio *a* + *b*/carotenoids in submerged and floating leaves compared to emergent and floating ones during the season is probably the result of the influence of various abiotic factors as well as the anatomical and morphological characteristics of the researched species itself.

The increase in the ratio concentration is a protective mechanism of the leaves to reduce damage to the photosynthetic apparatus not only by dispersing excess energy, but also by directly removing singlet oxygen (Gill, Tuteja, 2010). Demmig-Adams and Adams (1992) stated in their research that heliophyte leaves contain larger amounts of carotenoids than shade leaves, which represents a type of protection against photooxidation in conditions of high solar radiation. Increased *a* + *b*/carotenoids ratio in floating leaves is probably a way of resistance to stressful conditions caused by increased temperature and light.

Conclusion

The results obtained in this study showed that the investigated macrophyte species (emergent, floating and submerged) have different seasonal trends in the content of photosynthetic pigments. The influence of certain abiotic factors (content of nitrates, ammonia nitrogen, nitrites, as well as temperature and transparency) is confirmed by significant correlations with photosynthetic pigments, and thus provides important information about the physiological status of aquatic macrophytes in natural conditions as well as the mutual influence of different stress factors on the content of photosynthetic pigments. Changes in concentrations of photosynthetic pigments between different macrophyte species are also the result of different morpho-anatomical adaptations in aquatic ecosystems. Such a study is a potential model for future research, although aquatic plants can serve as potential bioindicators of the ecological status of surface waters.

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Collected material



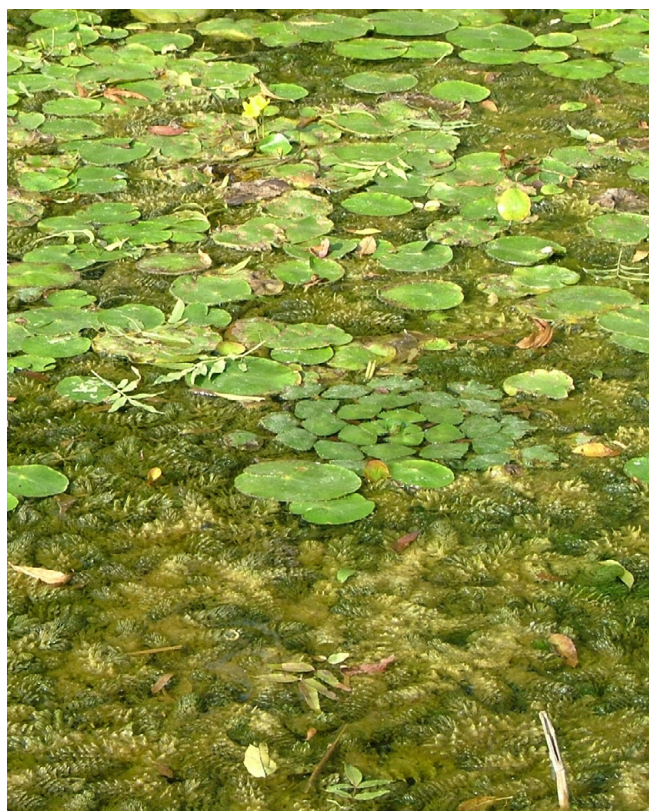
Phragmites communis



Salvinia natans



Utricularia vulgaris



Ceratophyllum demersum