ACTA BIOLOGICA SLOVENICA
LJUBLJANA 2008 Vol. 51, Št. 1: 3–11

Sprejeto (accepted): 27.10.2008

Seasonal changes in the contents of nutrients in five macrophyte species from the lake Velenjsko jezero (Slovenia)

Sezonske spremembe vsebnosti hranil v petih vrstah makrofitov iz Velenjskega jezera (Slovenija)

Zdenka MAZEJ[1*], Mateja GERM[2]
[1] ERICo d.o.o., Environmental Research and Industrial Co-operation, Koroška 58, 3320 Velenje, Slovenia; E-mail address: zdenka.mazej@erico.si (*corresponding author)
[2] Biotechnical Faculty, Department of Biology, Večna pot 111, 1000 Ljubljana, Slovenia

Abstract. The study was designed to depict the seasonal dynamic in relative abundance of macrophyte species, nutrient availability and their content in macrophytes to assess the capability of different species to store nutrients in nutrient rich lake Velenjsko jezero. The concentrations of total nitrogen and total phosphorus in the lake sediment, water and aboveground biomass of macrophytes (*Nuphar luteum*, *Najas marina*, *Najas minor*, *Potamogeton lucens* and *Potamogeton pectinatus*) were measured at three locations monthly from June to September 2004. Seasonal variability in the contents of total phosphorus in macrophyte tissues was high, but all examined species reached similar maximal concentration in the beginning of their growth. Later in the season, concentrations declined to a high degree. Seasonal variability in the contents of total nitrogen was smaller. Floating-leaved species *Nuphar luteum* was present in a low amounts and contained much more total nitrogen in its above-ground tissues than the submersed species. Because of different species life spans, differences in the content of nutrients among species were very high in particular month. *Nuphar luteum, Najas minor* and *Potamogeton lucens* were rarely present in the lake and they contributed less to storing nutrients in their biomass. *Potamogeton pectinatus* was commonly present in the early summer, but in August *Najas marina* prevailed by far and its growth had high effect on the concentration of nutrients in sediment and water. Therefore removing of 1 t dry weight of *Najas marina* biomass from the lake would contribute to removal of 2.7 kg of phosphorus and 28.2 kg of nitrogen from the lake.

Key words: lake, total nitrogen, total phosphorus, *Nuphar luteum* (L.) Sibth et Sm., *Najas marina* L., *Najas minor* All., *Potamogeton lucens* L. and *Potamogeton pectinatus* L.

Izvleček. V pričujoči raziskavi smo spremljali sezonske spremembe v abundanci makrofitskih vrst ter vsebnosti celotnega dušika in celotnega fosforja v sedimentu, vodi in v makrofitih (*Nuphar luteum*, *Najas marina*, *Najas minor*, *Potamogeton lucens* in *Potamogeton pectinatus*) Velenjskega jezera. Sezonska nihanja v vsebnosti TP v rastlinah so bila zelo velika, vendar so vse vrste v začetku svoje rasti dosegale podobne maksimalne vsebnosti TP, nato pa so koncentracije s časom večinoma pri vseh vrstah hitro upadale. Sezonska nihanja v vsebnosti TN v rastlinah so bila manjša. Največja maksimalna koncentracija celotnega dušika je bila izmerjena v nadzemnih tkivih v jezeru redko prisotne submerzne vrste s plavajočimi listi – *Nuphar luteum*. Maksimalne koncentracije v popolnoma potopljenih makrofitih (*Najas marina*, *Najas minor*, *Potamogeton pectinatus* in *Potamogeton lucens*) pa so bile zelo podobne. Zaradi različnega življenjskega cikla makrofitskih vrst, so bile sicer razlike med vrstami v določenem mesecu zelo velike. Prisotnost vrst *Nuphar luteum*, *Najas minor* in *Potamogeton lucens* je bila v jezeru redka, zato je bil njihov prispevek k zmanjšanju hranil v sedimentu in vodi jezera majhen. *Potamogeton pectinatus* je bila s svojo relativno zmerno prisotnostjo prevladujoča vrsta v jezeru spomladi, poleti pa je nad njo

močno prevladala vrsta *Najas marina*. Njena razrast je imela večji učinek na zmanjšano koncentracijo hranil v sedimentu in v vodi. Odstranitev 1 tone suhe biomase makrofita *Najas marina* v mesecu avgustu, bi prispevala k odstranitvi 2,7 kg fosforja in 28,2 kg dušika iz jezera.

Ključne besede: jezero, celotni dušik, celotni fosfor, *Nuphar luteum* (L.) Sibth et Sm., *Najas marina* L., *Najas minor* All., *Potamogeton lucens* L. in *Potamogeton pectinatus* L.

Abbreviations:

TP – total phosphorus, SRP – soluble reactive phosphate, TN – total nitrogen, Pot pec – *Potamogeton pectinatus* L., Pot luc – *Potamogeton lucens* L., Naj mar – *Najas marina* L., Naj min – *Najas minor* All., Nup lut – *Nuphar luteum* (L.) Sibth et Sm.

Introduction

Velenjsko jezero is more and more popular as a recreational resource, which increases the threat of its rapid eutrophication. The lake offers good conditions for the growth of macrophytes, which allowed for their rapid spread within only a few years. There is strong evidence that nutrient availability plays an important role in controlling the development and abundance of macrophytes (Carr & Chambers 1998). After 1997 the aquatic plant *Najas marina* L. prevailed in Velenjsko jezero, forming weed beds that covered larger areas in August and September. *Najas marina* is a summer-annual plant that is highly fertile and produces great quantities of seeds. Its presence in Velenjsko jezero disturbs swimmers, fisheries and other lake users.

Aquatic macrophytes are often suggested to be accumulators of contaminants and nutrients in surface waters (Wolverton & McDonald 1979). Nutrient absorption in submersed macrophytes occurs both from the water by foliage and from the sediments by root and rhizoid systems. The relative contribution of roots and shoots, at least to N and P uptake, depends on the sediment:water nutrient ratio (Carignan 1982). But Wetzel (2001) emphasized that under most circumstances, even in nutrient-rich waters, roots are the dominant sites of nutrient uptake and assimilation for aquatic plants, although some evidence is contradictory (e.g. Swanepoel & Vermaak 1977). Experimental analyses have demonstrated that most rooted submersed angiosperms obtain most of their phosphorus from the interstitial water of the sediments (e.g. Chambers & al. 1989; Carr & Chambers 1998), since the absorbable nutrient concentration is much higher in sediment pore water than in the water column (Carr & Chambers 1998). Because of that, the value of tissue analyses of element concentrations in aquatic macrophytes is suspect as an index of the fertility of the lake water.

Nutrient content of the water can be quite unrelated to plant growth of those species having ready access to the abundant nutrient in the sediment. The rooted plants can function as a "pump" of nutrients from the sediment; some of those nutrients can then be lost to the water during both active growth and decomposition (Wetzel 2001). Nutrient concentrations in macrophyte species differ greatly even among closely related species and within the same species from site to site (Kufel & Kufel 2002; Garbey & al. 2004). This can be explained by the fact that nutrient uptake and accumulation in macrophytes does not only depend on the physiological capacity of the species, but also on the nutrient concentration in water and sediment (Carignan 1982; Shardendu & Ambasht 1991; Fernández-Aláez & al. 1999) and on N and P reserves in the plant tissue (Taheruzzaman & Kushari 1989).

In the present study we attempted to depict the seasonal dynamics in relative abundance of macrophyte species, as well as nutrient availability and content in macrophytes, to assess the capability of different species to store nutrients in nutrient rich lake Velenjsko jezero. For this purpose we carried out a comparative analysis of nitrogen and phosphorus content of macrophyte species: the submersed annual species *Najas marina* and *Najas minor* All., the submersed perennial annual species *Potamogeton lucens* L. and *Potamogeton pectinatus* L. and the floating-leaved perennial species – *Nuphar luteum* (L.) Sibth et Sm.

Materials and Methods

Description of the site

Lake Velenjsko jezero is located in central Slovenia, in the Šalek Valley. It is situated at an altitude of 366 m, with a surface area of 135,000 m^2 and a maximal depth of 54 m. It is an artificial lake resulting from mining activity. The detailed description is available in Šterbenk (1999) and Mazej and Epšek (2005).

Presence and abundance of macrophytes

The distribution of macrophyte species over the entire littoral was assessed using a boat, depth meter, view box and sampling rake to choose sampling locations. After that, three sampling transects (L1, L2, L3) were chosen for comparative analyses on the south-eastern part of the lake, where macrophyte species richness was greatest. Each transect was 200±2 m in length. These transects were surveyed every month from June to September. Species abundance in each section was evaluated according to Kohler (1978) on a five level descriptor scale (1 – very rare, 2 – infrequent, 3 – common, 4 – frequent, 5 – abundant, predominant).

Content of nutrients in water, sediment and macrophytes

Samples of water, sediment and macrophytes were taken from the three locations every month from June to September 2004. The sediment samples were collected from the top 5 cm of bottom sediments using a grab sampler. Samples of water were collected by hand from a boat by submerging precleaned PE bottles approximately 50 cm beneath the water surface. Plants were collected from the boat with a rake. The contents of total nitrogen (TN), total phosphorus (TP) and soluble reactive phosphate (SRP) in sediment were analysed by the standard methods: ISO 11261:1995, ISO 11263:1995 and ÖNORM L 1088:2005, while TN and TP in the water were determined according to the standard methods ISO 10304-2:1995 and ISO 6878:2004.

Above ground tissues of plants were washed carefully in the laboratory to remove sediment and periphyton. The specimens of different macrophyte species were analysed for nutrient content. Plant material was oven-dried at 75 °C to constant weight and ground to a fine powder by milling. TN in plants was determined by the standard method ISO 11261:1995, while TP was determined by EPA Method 3050B Mod Block.

Statistical analysis

Statistical procedures were performed using the Statistica software package (Statistica for Windows, version 7.0). After verifying the normality and homoscedasticidy of the variables (K-S and Liliefors test for normality), standard one-way analysis of variance (ANOVA; LSD test) was used to check the existence of significant differences between the locations regarding the contents of nutrients in water, sediment and macrophytes. The Spearman correlation coefficients between the content of nutrients in macrophytes and the contents of nutrients in water and sediment were calculated.

Results

Table 1: Abundance of different macrophyte species in Lake Velenjsko jezero in the year 2004 at the three selected transects. Each transect was 200±2 m in length. Five level descriptor scale of abundance was used: 0 – absent, 1 – very rare, 2 – infrequent, 3 – common, 4 – frequent, 5 – abundant, predominant (KOHLER 1978).

Tabela 1: Prisotnost in pogostost makrofitov na treh izbranih transektih Velenjskega jezera od junija do septembra 2004. Dolžina transektov je merila 200±2 m. Abundanca po KOHLER (1978) temelji na petstopenjski skali: 0 – odsotna, 1 – posamična, 2 – redka, 3 – pogosta, 4 – množična, 5 – prevladujoča).

	L1				L2				L3			
	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep
Nup lut	2	2	2	2	0	0	0	0	0	0	0	0
Pot pec	3	3	3	2	0	0	0	0	3	3	2	2
Pot luc	0	0	0	0	1	2	2	1	1	2	2	1
Naj mar	0	1	5	4	0	2	5	3	0	2	5	3
Naj min	0	0	0	0	0	0	2	2	0	1	2	2

The distribution pattern of the species was patchy, no species examined being found at all three chosen locations, with the exception of *Najas marina*, which in August overgrew almost the whole littoral (Tab. 1). *Potamogeton pectinatus*, *Najas minor* and *Potamogeton lucens* throve at two locations and *Nuphar luteum* at only one. We detected large seasonal changes in the presence and abundance of macrophyte species at the sampling locations due to their different life histories. The perennial spe-

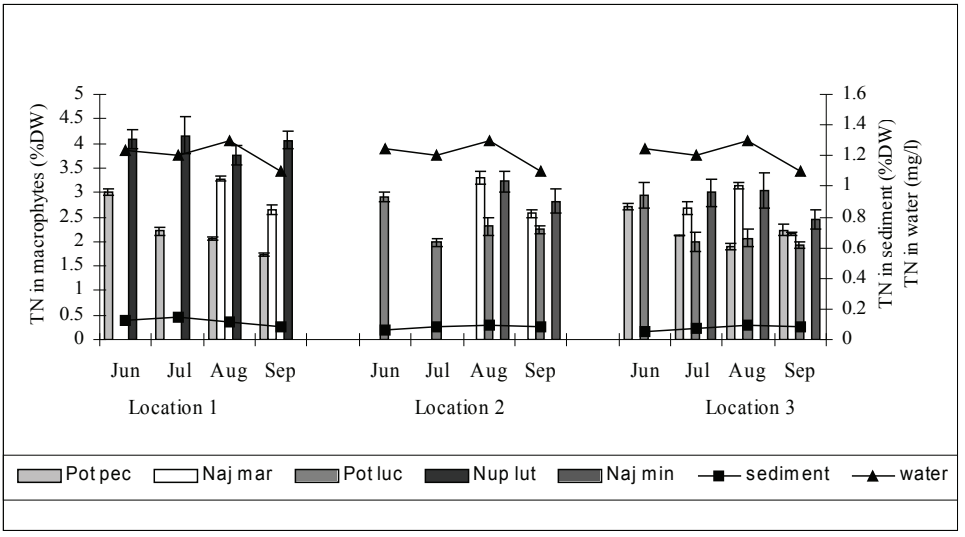

Figure 1: Total nitrogen (TN) content in above-ground tissue of five species of macrophytes (whole plant homogenate) – *Nuphar luteum*, *Potamogeton pectinatus*, *Potamogeton lucens*, *Najas minor* and *Najas marina* (in columns). Each value is the mean of three replicates. Lines represent the content of TN in sediment and TN in the water column during the summer growth season.

Slika 1: Vsebnost celotnega dušika (TN) v nadzemnih tkivih petih makrofitskih vrst – *Nuphar luteum*, *Potamogeton pectinatus*, *Potamogeton lucens*, *Najas minor* and *Najas marina* (v stolpcih). Vsaka vrednost je povprečje treh paralelk. Linije predstavljajo vsebnost TN v jezerskem sedimentu in v vodi.

cies *Nuphar luteum*, *Potamogeton lucens* and *Potamogeton pectinatus* started their vegetative growth earlier in the season. *Potamogeton pectinatus* prevailed in June and July, while in August *Najas marina* became the most abundant and overgrew almost all littoral. Annual species *Najas marina* and *Najas minor* had short life spans, appearing in the lake from July to September only.

The contents of TN, and especially of TP, in plants were higher at the beginning of their development (Figs. 1–2). Thus the comparison of different species regarding their content of nutrients was influenced by differences in phenological phase. Extreme values of TN stand out, the highest being 4.16% DW in *Nuphar luteum* in July (Fig. 1). This species was found only at the first location (L1). Concerning TP, the species *Nuphar luteum* (0.41% DW) and *Potamogeton pectinatus* (0.37% DW) from the first location (L1) and *Najas marina* (0.41% DW), *Najas minor* (0.42% DW) and *Potamogeton lucens* (0.38% DW) from the second location (L2) contained similar maximal concentrations at the beginning of their development (Fig. 2).

With respect to water and sediment, there were no significant differences in chemical characteristics in these two compartments between the three locations, except that the sediment of the first location contained a significantly higher amount of TP than the sediment from the third location ($p = 0.015$). Accordingly, *Potamogeton pectinatus* and *Najas marina* from the first location contained significantly higher average contents of TP than the same species from the third location – (*Potamogeton pectinatus* – $p = 0.034$, n=12 and *Najas marina* – $p = 0.002$, n=12). No significant differences were found

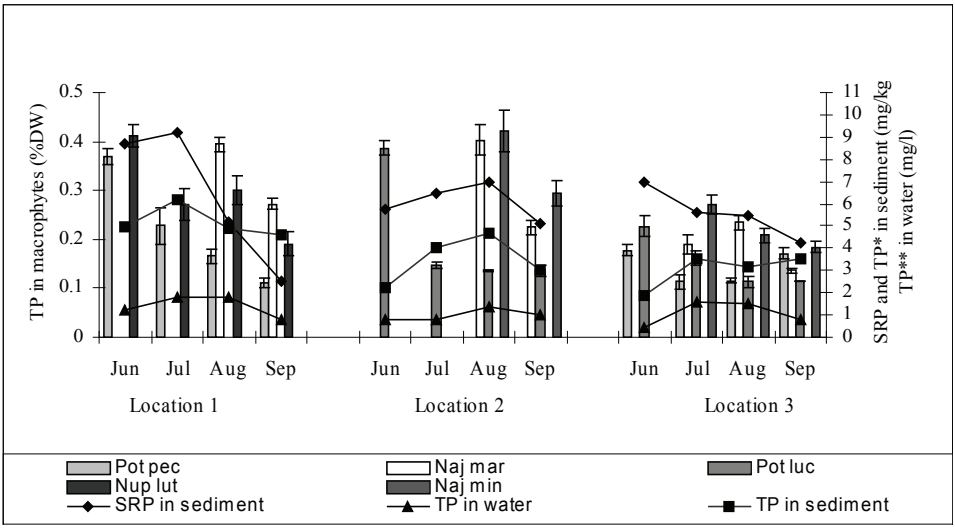

Figure 2: Total phosphorus (TP) content in above-ground tissue of five species of macrophyte (whole plant homogenate) – *Nuphar luteum*, *Potamogeton pectinatus*, *Potamogeton lucens*, *Najas minor* and *Najas marina* (in columns). Each value is the mean of three replicates. Lines represent the content of soluble reactive phosphorus (SRP) and TP in sediment and TP in the water during the summer growth season.
* Values of TP in sediment were in fact 100 times higher than is represented on the figure.
** Values of TP in water were in fact 100 times lower than is represented on the figure.

Slika 2: Vsebnost celotnega fosforja (TP) v nadzemnih tkivih petih makrofitskih vrst – *Nuphar luteum*, *Potamogeton pectinatus*, *Potamogeton lucens*, *Najas minor* and *Najas marina* (v stolpcih). Vsaka vrednost je povprečje treh paralelk. Linije predstavljajo vsebnost lahko dostopnega fosforja (SRP) in TP v jezerskem sedimentu in TP v vodi.
* Vsebnosti TP v sedimentu so bile 100 krat večje, kot je prikazano na sliki.
** Vsebnosti TP v vodi so bile 100 krat manjše kot je prikazano na sliki.

between different locations regarding concentrations of TN in macrophytes. Concentrations of SRP in the sediment, and TP and TN in water, drastically decreased in September, while content of TN in sediment remained constant.

Table 2: Correlation (Spearman coefficient) between the concentrations of nutrients in some macrophyte species and the concentrations in water and sediment.
Tabela 2: Korelacija (Spearmanov koeficient) med koncentracijo hranil v nekaterih makrofitskih vrstah in med koncentracijo hranil v vodi in sedimentu.

	Annual species				Perennial species					
	Naj mar (15)		Naj min (15)		Pot pec (24)		Nup lut (12)		Pot luc (24)	
	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP
Water (TN, TP) (12)	0.60*	0.42*	0.56*	0.43*	–0.3	–0.38	–0.88**	–0.15	–0.3	0.23
Sediment (TN, SRP) (12)	0.05	0.41*	–0.4	0.67*	–0.02	0.57*	0.41	0.47	0.01	–0.33

Level of statistical significance: *** $p<0.001$, ** $p<0.01$, * $p<0.05$
Numbers of replicates are in brackets.

Relationship between the content of nutrients in the macrophytes and in water and sediment was determined (Tab. 2). The contents of total phosphorus in *Najas marina* and *Najas minor* correlated positively with the contents of SRP and TP in sediment, while their contents of TN correlated positively with that in the water. Negative significant correlation was observed between the content of TN in *Nuphar luteum* and its content in water.

Discussion

Lake Velenjsko jezero can be classified as eutrophic on the basis of the level of total phosphorus (0.1 mg/L) and total nitrogen (1.34 mg/L) in the water (OECD 1982). Macrophytes of Velenjsko jezero showed no evidence of TP and TN limitation. The TN and TP contents in macrophytes were generally higher than the critical concentrations of 0.13 % for TP and 1.3 % for TN. The critical concentration of a nutrient in a plant has been defined as that concentration in plant tissues which permits the maximum yield (Gerloff & Krombholz 1966).

The variation in macronutrient concentration in macrophyte tissues was found to correlate with the growth form of the plant (Jackson & Kalff 1993; Fernández-Aláez & al. 1999). The macroalgae showed the lowest nutrient content, while an impoverishment in N was observed in emergent species (Fernández-Aláez & al. 1999). The lower N in tissues of emergent plants as related to submersed and rooted floating-leaved macrophytes is explained by their greater biomass, which means a greater proportion of non-nitrogenou supporting tissue (Fernández-Aláez & al. 1999). The above-ground tissues of *Nuphar luteum* contained much more TN than those of submersed species, in spite of the fact that the structure of floating leaves is similar to that of leaves of emergent species. Floating-leaved plants have a morphological adaptation to increase inorganic carbon and mineral acquisition, which enables their higher productivity (Boston & al. 1989). The floating and submersed leaves of *Nuphar luteum* enable it to exploit CO_2 from air and from water. Like emergent macrophytes, *Nuphar luteum* possesses operationally active transpiration-mediated root-pressure systems, which enable nutrient absorption and translocation from the roots to the foliage (Wetzel 2001). Maximum concentration of TP in *Nuphar luteum* did not differed from those of submersed species.

Furtado (1998) registered the changes in concentrations of both nutrients (P and N) as a function of season, plant age and stage of vegetative development. Our results show great seasonal variability in the content of nutrients in macrophyte tissues in which fluctuations of the content of TP were most marked (Figs. 1–2). Seasonal variability in the contents of total phosphorus in macrophyte tissues

was high, but all examined species reached similar maximum concentration in the beginning of their growth. Later in the season, concentrations declined to a considerable degree. Seasonal variability in the contents of total nitrogen was smaller. The highest content of nutrients, especially phosphorus, at the beginning of the growth season is known as "luxury" uptake. Such a strategy may benefit the plant later, should nutrient concentrations diminish (Garbey & al. 2004), and allow the abundance of submerged plants to increase (Palma-Silva & al. 2002).

The rarely present floating-leaved species *Nuphar luteum* contained much more total nitrogen in its above-ground tissues than submersed species. Because of different species life spans, differences in the content of nutrients among species were very large in particular month. *Nuphar luteum*, *Potamogeton lucens* and *Potamogeton pectinatus* overwinter, and then grow rapidly in the spring. They are able to recycle and withdraw nutrients from their senescing parts or storage organs for reuse (Vitousek 1982) and so are less dependent on the nutrient concentration in their environment at the beginning of their growth, other than annual plants. Their growth in the lake was not significantly influenced on nutrient concentration in sediment and water. In contrast annual plants like *Najas marina* and *Najas minor*, are more dependent on the concentration of nutrients in their environment and required high levels for new growth in the summer, resulting in intensive growth. In July the soft sediment of the littoral is still not colonized and the amounts of nutrients in the water and sediment do not decrease before September. Both *Najas* species propagate from seeds that enable quick colonization of new habitats (Agami & Weisel 1986). Favourable nutrient conditions in summer offered *Najas marina* to overgrow almost the whole lake littoral in one month, reflecting the nutrient status of its environment. Concentrations of SRP in the sediment and TP in water drastically decreased in September, after the rapid expansion of *N. marina* in August. The content of TN in water also decreased drastically in September, while its content in sediment remained constant. Removing of 1 t dry biomass of *Najas marina* from the lake would contribute to removal of 2.7 kg of phosphorus and 28.2 kg of nitrogen from the lake.

Conclusions

1. Floating-leaved species *Nuphar luteum* contained much more total nitrogen in its above-ground tissues than submersed species.
2. Macrophytes showed great seasonal variability of TP content in their tissues. The stage of plant vegetative development appears to be an important factor, influencing the content of nutrients in plants. A high content of TP, very similar at all species, was detected in the initial phase of plant development. Because of different species life spans, differences in the content of nutrients among species were high in particular months.
3. While the development of four other species did not significantly influenced the nutrient concentration in sediment and water, rapid development of annual *Najas marina* had a significant effect on the concentration of nutrients in these two compartments. Therefore removal of at least part of the enormous biomass of this species in August would contribute to a high export of nutrients from Velenjsko jezero.

Acknowledgements

The authors are grateful to Prof. Dr. Alenka Gaberščik and Prof. Roger Pain for critical reading of the manuscript. This research was a part of the project financed by the Šoštanj Thermal Power Plant: "The role of macrophytes in maintaining the ecological balance of the Velenje Lake ecosystem" and of the project financed by the Slovenian Research Agency (ARRS), Ljubljana: "Determination of heavy metal pollution in the Šalek lakes by using bioindicators" No. L1-7144-1007. Additional support was

provided by the research program "Communities, relations and communications in ecosystems" (P1-0255), financed by Slovenian Research Agency (ARRS), Ljubljana. Parts of analyses were performed in the laboratory at National institute of Biology.

References

Agami M. & Waisel Y. 1986: The ecophysiology of roots of submerged vascular plants. – Végétale **24**: 607–624.

Boston, H. L., Adams, M. S., Madsen, J. D. 1989: Photosynthetic strategies and productivity in aquatic systems. Aquatic Botany **34**: 27–57.

Carignan R. 1982: An empirical model to estimate the relative importance of roots in phosphorus uptake by aquatic macrophytes. Canadian Journal Fisheries and Aquatic Sciences **39**: 243–247.

Carr G. M. & Chambers P. A. 1998: Macrophyte growth and sediment phosphorus and nitrogen in a Canadian prairie river. Freshwater Biology **39**: 525–536.

Chambers, P. A., Prepas E. E., Bothwell M. L. & Hamilton H. R. 1989: Roots versus shoots in nutrient uptake by aquatic macrophytes in flowing waters. Canadian Journal Fisheries and Aquatic Sciences **46**: 435–439.

Fernández-Aláez M., Fernández-Aláez C. & Bécares E. 1999: Nutrient content in macrophytes in Spanish shallow lakes. Hydrobiologia **408/409**: 317–326.

Furtado A. L. S. 1998: Ash free dry weight, organic carbon, nitrogen and phosphorus content of *Typha domingensis* Pers. (Thyphaceae) and aquatic macrophyte. Verhandlungen – Internationale Vereinigung für Limnology 26: 1842–1845.

Garbey C., Murphy K. J., Thiébaut G. & Muller S. 2004: Variation in P-content in aquatic plant tissues offers an efficient tool for determining plant growth strategies along a resource gradient. Freshwater Biology **49**: 346–356.

Gerloff G. C. & Krombholz P. H. 1966: Tissue analysis as a measure of nutrient availability for the growth of angiosperm aquatic plants. Limnology and Oceanography **11**: 529–537.

International standard ISO 11261:1995. Soil quality – Determination of total nitrogen – Modified Kjeldahl method. Brussels, Belgium.

International standard ISO 11263:1995. Soil quality – Determination of phosphorus – Spectrometric determination of phosphorus soluble in sodium hydrogen carbonate solution. Brussels, Belgium.

International standard ISO 10304–2: 1995. Water quality – Determination of dissolved anions by liquid chromatography of ions – Part 2: Determination of bromide, chloride, nitrate, nitrite, orthophosphate and sulfate in waste water. Brussels, Belgium.

International standard ISO 6878:2004. Water quality – Determination of phosphorus – Ammonium molybdate spectrometric method. Brussels, Belgium.

Jackson L. J. & Kalff J. 1993: Patterns in metal content of submerged aquatic macrophytes: the role of plant growth form. Freshwater Biology **29**: 351–359.

Kohler A. 1978: Methoden der Kartierung von Flora und Vegetation von Süßwasserbiotopen. Landschaft und Stadt **10**: 78–85.

Kufel L. & Kufel I. 2002: *Chara* beds acting as nutrient sinks in shallow lakes – a review. Aquatic Botany **72**: 249–260.

Mazej Z. & M. Epšek 2005. The macrophytes of lake Velenjsko Jezero, Slovenia – the succession of macrophytes after restoration of the lake. Acta Biologica Slovenica **48**: 21–31.

OECD 1982: Eutrophication of waters, monitoring, assessment and management. Paris.

ÖNORM L 1088: 2005. Chemische Bodenuntersuchungen. Bestimmung von pflanzenverfugbarem Phosphat und Kalium nach der Doppel-Lactat (DL)-Methode. Wien, Austria.

Palma-Silva C., Albertoni E. F. & Estevas F. A. 2002: Clear water associated with biomass and nutrient variation during the growth of a Charophyte stand after a drawdown, in a tropical coastal lagoon. Hydrobiologia **482**: 79–87.

Shardendu & Ambasht R. S. 1991: Relationship of nutrient in water with biomass and nutrient accumulation of submerged macrophytes of a tropical wetland. New Phytology **117**: 493–500.

Šterbenk E., 1999. Šalek Lakes. Pozoj Velenje.

Swanepoel J. H. & Vermaak J. F. 1977: Preliminary results on the uptake and release of ^{32}P by *Potamogeton pectinatus*. Journal of the Limnological Society of Southern Africa **3**: 63–65.

Taheruzzaman Q. & Kushari D. P. 1989: Evaluation of some common aquatic macrophytes cultivated in enriched water as possible source of protein and biogas. Hydrobiologia **23**: 207–212.

Vitousek P. M. 1982: Nutrient cycling and nutrient use efficiency. American Naturalist **119**: 553–572.

Wetzel R. 2001: Limnology, 3rd edition. Academic Press, New York, USA.

Wolverton B. C. & McDonald R. C. 1979: Upgrading facultative wastewater lagoons with vascular aquatic plants. J. Water Poll. Control Fed. **51**: 305–313.