ABS ACTA BIOLOGICA SLOVENICA
LJUBLJANA 2005 Vol. 48, Št. 1: 21-31

Sprejeto (accepted): 2005-09-27

The macrophytes of lake Velenjsko Jezero, Slovenia – the succession of macrophytes after restoration of the lake

Makrofiti Velenjskega jezera, Slovenija – sukcesija makrofitov po restavraciji jezera

Zdenka MAZEJ[1], Mateja EPŠEK[2]

[1] ERICo Velenje; Environmental Research and Industrial Co-operation Institute, Koroška 58, 3320 Velenje, Slovenia; Tel.: +386 3 898 19 58; fax: +386 3 898 19 42; E-mail: zdenka.mazej@erico.si
[2] Biotechnical Faculty, Department of Biology, Večna pot 111, 1000 Ljubljana, Slovenia

Abstract. The macrophyte vegetation in the artificial lake Velenjsko jezero has been monitored since 1996. The pH of the lake was around 12 up to 1994, when it was remediated. After that macrophytes started to colonize a large proportion of the littoral very quickly. The pioneer species, which appeared in the first survey year (1996), were *Chara* sp., *Nuphar lutea*, *Potamogeton crispus* and *Myriophyllum spicatum*. *Potamogeton crispus* was the dominant species till 1997. In the following years *Najas marina* and *Potamogeton filiformis* prevailed over other species in the lake. Since the beginning of the colonization, the species composition had become more heterogeneous and the quantitative relationships between the species varied enormously. In the year 2004, 9 species were detected in the lake. While species *Najas marina*, *Potamogeton filiformis, Potamogeton lucens, Potamogeton nodosus* show positive development progress, in the last years minor appearance of *Chara* sp., *Potamogeton crispus* and *Najas minor* was observed.

Key words: lake Velenjsko jezero, succession of macrophytes, species composition and distribution, relative plant mass, maximal depth colonization

Izvleček. Makrofite v umetno nastalem Velenjskem jezeru spremljamo od leta 1996. Vrednost pH jezerske vode je bila vse do leta 1994, ko so v Termoelektrarni Šoštanj uvedli zaprti krog transportne vode, okoli 12. Vrednost pH je po tem ukrepu hitro padla na vrednost okoli 8. Makrofiti so postopoma pričeli naseljevati litoralno območje jezera. Pionirske vrste v letu 1996 so bile *Chara* sp., *Nuphar lutea*, in *Potamogeton crispus*. *Potamogeton crispus* je bila dominantna vrsta vse do leta 1997. V naslednjih letih sta prevladali vrsti *Najas marina* in *Potamogeton filiformis*. Od začetka naseljevanja je prihajalo do velikih kvalitativnih in kvantitativnih sprememb v vrstni sestavi in razporeditvi makrofitov. V jezeru je leta 2004 uspevalo 9 vrst. Medtem ko kažejo vrste *Najas marina*, *Potamogeton filiformis, Potamogeton lucens* in *Potamogeton nodosus* pozitiven trend v razvoju, pa v zadnjih letih opažamo manjše pojavljanje vrst *Chara* sp., *Potamogeton crispus* in *Najas minor.*

Key words: Velenjsko jezero, sukcesija makrofitov, vrstna sestava, distribucija makrofitov, relativna rastlinska biomasa, maksimalna globina naselitve

Introduction

The succession of submersed macrophytes in lakes is a complex process. Once they are established, macrophytes have significant feedback effects on lake water quality and ecosystem health, and are an important consideration in lake management (JEPPESEN & al. 1998). In lakes where conditions favour development of high biomass of submerged aquatic vegetation over large areas, there is potential for large-scale reductions in water column concentrations of nutrients and phytoplankton, and increase transparency (JEPPESEN & al. 1998). Factors that influence the biomass and distribution of submersed macrophytes both among and within lakes have been well studied. These factors include substratum character and water depth (WEISNER 1991), transparency (HUTCHINSON 1975, NICHOLS 1992, MIDDELBOE & MARKAGER 1997, MAZEJ & GABERŠČIK 1999, VAN DUIN & al. 2001, BEST & al. 2001), water chemistry (PIP 1984, HASLAM 1987, PRESTON 1995, GERM & GABERŠČIK 1996, GERM & al. 2003), temperature (PIP 1989, ROONEY & KALFF 2000), bottom slope (NICHOLS 1992), water level fluctuation and wave action (PRESTON 1995, ANDERSSON 2001), filamentous and planktonic algae (URBANC-BERČIČ & al. 2002), grazing (JACOBSEN & SAND-JENSEN 1992, WEISNER & al. 1997) and intra- and inter- species competition among macrophyte species (FOX 1992, AGAMI & WAISEL 2002). The underwater light regime is one of the most important determinants of submerged aquatic vegetation (HUTCHINSON 1975, NICHOLS 1992, BEST & al. 2001, VAN DUIN & al. 2001). DUARTE AND KALFF (1986) asserted that within lakes, the morphometric variables of bottom slope and community exposure are both negatively correlated with macrophyte biomass. In lakes, which shelve rapidly, the density of plants on the shore of the lake falls very quickly. On the contrary, if the shore is shallow and slopes gently, the belt overgrown by aquatic plants can be very wide (NICHOLS 1992).

Many macrophytes are tolerant to pH values between 10 and 11; higher values are destructive (BOWES 1987). The pH of Lake Velenjsko jezero was around 12 until 1994, when reconstruction of the fly ash system and introduction of a closed loop water cycle was made at the Šoštanj Thermal Power Plant. The pH declined to around 8 and biota started to colonize the lake. Our study was focused on aquatic macrophytes, an important group of primary producers, which provide conditions necessary for fish, zooplankton and benthos in the littoral zones of lakes. Information on the distribution and species composition of aquatic vegetation is necessary for management and understanding of aquatic systems. We monitored the succession of species composition and abundance of submersed macrophytes after restoration measures in Lake Velenjsko jezero. Our method was based on direct field observations along transects that enabled identification of the main environmental factors influencing the appearance of macrophytes.

Materials and Methods

Description of the site

Velenjsko jezero is located in the Šalek Valley, at an altitude of 366 m, with a surface 135000 m^2 and a maximal depth of 54 m. It is an artificial lake resulting from mining activity. As a result of subsidence, whole settlements, meadows and fields submerged and flooded. Up to 1983 fly ash slurry from the Šoštanj Thermal Power Plant was transported by pipeline and emptied into Velenjsko jezero. It brought ash and calcium hydroxide to the lake, raising the pH of lake water to 12. Since 1983 the ash was used to build in embankments, but effluent with a pH around 12 remained the predominant polluter of the lake until 1994. After reconstruction of the fly ash system and a closed loop water cycle (October 1994), biota appeared in the lake again. It was recolonized by phyto- and zooplankton, fish, macrophytes and other organisms. The pH of the lake is now around 8. The lake shore is sparsely overgrown with emergent plants (e.g. *Typha latifolia* L., *Phragmites australis* (Cav.) Trin. Ex Steud., *Schoenoplectus lacustris* (L.) Palla [*Scirpus lacustris* L.]); the major part of the lake shore consists of bare areas, meadows and allotments. The littoral zone of the lake can be divided into three main regions: the fairly steep western and south-western unstable shoreline, a north-eastern marshy area, and the eastern and southern part of the lakeshore, which is used for sunbathing, walking, riding, bicycling and other recreational activities. Near the shore are allotments.

Macrophyte cover

The method of surveying the entire littoral from a boat, using depthmeter, view box and sampling rake, was applied in the years 1996, 1997, 1999, 2000, 2003 and 2004. In the year 2003 surveying of macrophyte community was carried out in detail. The littoral was checked every month from June to September. The shoreline was divided into 25 sections of the length 200±2 m. Species abundance in each section was evaluated according to KOHLER & JANAUER (1995) on a five level descriptor scale (1 – very rare, 2 – infrequent, 3 – common, 4 – frequent, 5 – abundant, predominant). The evaluated quantity of plants is interpreted as mass index (MI), which is with »real biomass« (PM) related with the function $PM = MI^3$. Obtained data has been processed by standard methodology, made in co-operation between the University teams of Hohenheim (Germany) and Vienna /Austria) (KOHLEER AND JANAUER 1995). The Internet based description of the methodology is accessible on the internet side www.midcc.at. From the data we can calculated two mass indexes; MMO is the Mean Mass Index of the individual species with respect to the survey transects they occur, MMT is the Mean Mass Index of individual species with regard to the full length of the lake shoreline. The distribution ratio »d« of each species stands for MMT^3/MMO^3. Nearly similar and high values of MMT and MMO (»d« value is near 1) reveal that a species is abundant and that it occurred in almost all sections – the distribution of the species is homogeneous.

$$MMT = \sqrt[3]{\frac{\sum_{i=1}^{n} MI_i^{\,3} * AL_i}{GL}} \qquad MMO = \sqrt[3]{\frac{\sum_{i=x}^{n} MI_i^{\,3} * AL_i}{\sum_{i=x}^{n} AL_i}}$$

MI_i = Mass Index of species in transect i
Al_i = length of transect i, where species occurred
GL = total length of lake shoreline

The Relative Plant Mass (RPM %) was used to calculate the quantitative significance of individual species in a section (PALL & JANAUER 1995).

$$RPM_x[\%] = \frac{\sum_{i=1}^{n}(PM_{xi} * L_i) * 100}{\sum_{j=1}^{k}\left(\sum_{i=1}^{n}(PM_{ji} * L_i)\right)}$$

PM_{xi} = MI_{xi}^3
RPM_x = relative plant mass of species x
MI_{xi} = for any transect i estimated mass of the species x
PM_{xi} = plant mass of species x in transect i
L_i = length of lake transect i
j = running index of the different species

Physical analyses of water:

Water transparency was measured with a Secchi disk. Temperature at 30 cm and pH were measured with a MultiLine P4.

Results

After restoration of the lake Velenjsko jezero, macrophytes, almost instantaneously, started to gradually overgrow large surface of the littoral. In the Tab. 1, presence and relative abundance of different macrophyte species in lake Velenjsko jezero for the period 1996 – 2004 is presented. The pioneer species that appeared in the year 1996 were *Chara* sp., *Nuphar lutea* (L.) Sibth. & Sm. and *Potamogeton crispus* L.. They colonized only a minor part of the littoral. Only three years later almost the whole littoral was overgrown and the species composition had become more heterogeneous. Changes in quantitative relationships between the species varied as well. *Potamogeton crispus* was the dominant species till 1997. In the following years *Najas marina* All. and *Potamogeton filiformis* Pers became the most abundant species in the lake.

Table 1: Presence and relative abundance of different macrophyte species in lake Velenjsko jezero for the period 1996 – 2004.
Presence: ♦ – present, – – not present. Relative abundance: a five level descriptor scale (1 – very rare, 2 – infrequent, 3 – common, 4 – frequent, 5 – abundant, predominant) (KOHLER & JANAUER 1995).
Tabela 1: Prisotnost in relativna abundanca posameznih makrofitskih vrst v Velenjskem jezeru v letih med 1996 in 2004.
Prisotnost: ♦ – prisotna – – ni prisotna. Relativna abundanca vrst: petstopenjska lestvica (1 = zelo redka; 2 = redka; 3 =zmerno zastopana; 4 = pogosta; 5 = prevladujoča vrsta) (KOHLER & JANAUER 1995).

Species / Year of survey	Abbrev.	1996*	1997			1999	2003			2004		
			Jun	Jul	Sept	Aug	Jun	Jul	Aug	Jun	Jul	Aug
Chara sp.	Cha sp	♦	1	-	-	-	-	-	-	1	1	1
Myriophyllum spicatum L.	Myr spi	-	2	2	2	2	2	1	2	2	2	2
Najas marina All.	Naj mar	-	-	-	3	4	1	3	4	-	2	4
Najas minor All.	Naj min	-	-	-	2	3	-	-	-	-	1	2
Nuphar lutea (L.) Sibth. Et Sm.	Nup lut	♦	1	1	1	1	1	1	1	1	1	1
Potamogeton crispus L.	Pot cri	♦	4	3	1	1	2	1	1	3	1	1
Potamogeton filiformis Pers.	Pot fil	-	1	-	-	1	2	3	3	3	3	3
Potamogeton lucens L.	Pot luc	-	-	-	-	2	1	2	2	1	1	2
Potamogeton nodosus Poir.	Pot nod	-	-	-	-	2	1	1	1	1	1	1

* Relative abundance of the species was not defined.

From the Fig. 1, where the distribution and relative abundance of different macrophyte species around lake Velenjsko jezero is presented for August 2003, it is evident that *Najas marina and Potamogeton filiformis* were the most abundant species in the lake in the late summer.

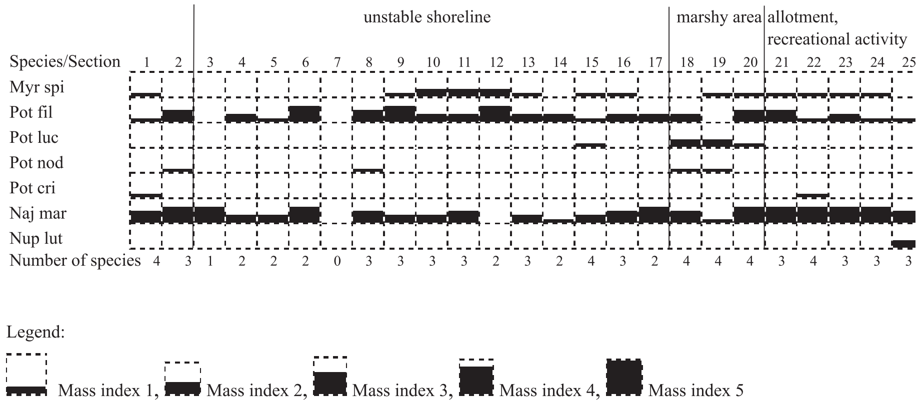

Figure 1. Distribution and abundance of different macrophyte species around lake Velenjsko jezero in August 2003. The Lake was divided into 25 section with the length of 200±2 m.
Slika 1: Distribucija in abundanca različnih makrofitskih vrst v Velenjskem jezeru avgusta 2003. Jezero smo razdelili na 25 transektov dolžine 200±2 m.

It can be seen from Fig. 2 that the quantitative relation among species during the growth season varied enormous. Species *Potamogeton filiformis* was dominant in June, while *Najas marina* was the predominant species in the lake in the late summer (RPM was 68.5% in August and 84.6% in September). Other species were much less abundant.

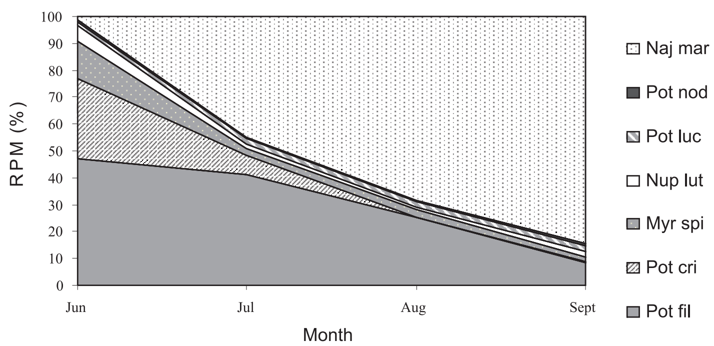

Figure 2. Relative plant mass (RPM %) throughout the season 2003 - Quantitative relation among species during the growth season.
Slika 2: Spreminjanje razmerja v relativni rastlinski biomasi (RPM %) med različnimi vrstami makrofitov od junija do septembra 2003.

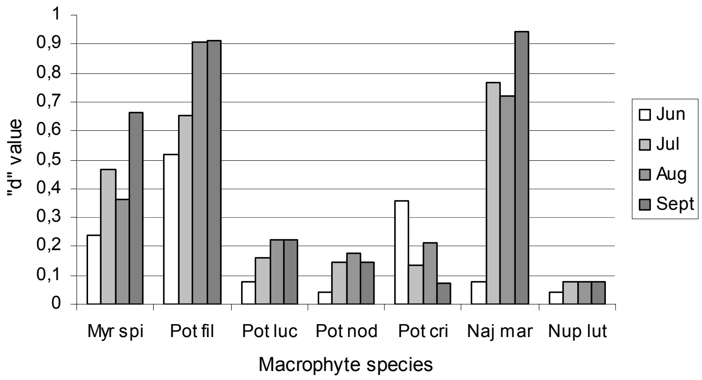

Figure 3. The distribution ratio - »d« values (the ratio between MMT[3] and MMO[3]) for different species throughout the season 2003.
Slika 3: Distribucijski kvocient - »d« vrednost (razmerje med MMT[3] in MMO[3]) za različne makrofitske vrste preko sezone 2003.

From the high »d« values, near 1 (Fig. 3) it is evident that *Najas marina* and *Potamogeton filiformis* overgrew most of the littoral in August and September, but the share of *Potamogeton filiformis* was much smaller than that of *Najas marina*. The RPM of *Potamogeton filiformis* was only 25.2 % in August and 8.2 % in September (Fig. 2).

Tab. 2 presents some physical characteristics of the water of lake Velenjsko jezero, in the years 1997, 2000, 2003 and 2004. The mean pH of the lake water was around 8 without any significant variations. The mean Secchi disk transparency (Zs) was the highest in 1997, but in the next years it decreased, while the mean temperature of the water increased.

Table 2: Mean physical and mean chemical characteristic of water in lake Velenjsko jezero averaged over the period May to September in the years 1997, 2000 and 2003; average value (minimum value/maximum value).
Tabela 2: Povprečni rezultati fizikalnih meritev in kemijskih analiz vode v Velenjskem jezeru v času od maja do septembra v letih 1997, 2000, 2003 in 2004; povprečje (minimalna/maksimalna vrednost).

Year	Sechi disc transparency (m)	Temperature (°C)	pH	P-tot. (mg/l)	N-tot. (mg/l)
1997	5.9 (4.2/9.0)	19.8 (17.8/21.3)	8.3 (8.2/8.7)	0.24 (0.13/0.44)	2.0 (1.47/2.57)
2000	4.5 (3.2/5.0)	22.2 (19.8/25.4)	8.4 (8.2/8.8)	-	-
2003	4.6 (4.0/5.5)	23.4 (19.4/25.8).	7.8 (7.4/8.3)	0.1 (0.1/0.1)	1.3 (0.9/2.1)
2004	3.7 (3.0/4.5)	21.7 (19.0/23.7)	8.2 (8.1/8.2)	0.1 (0.1/0.1)	-

Most macrophyte species colonized only shallow part of the littoral in 1997 (Tab. 3). This year, species *Potamogeton crispus* reached the maximum depth of 3.5 m. Four species (*Najas marina* – Zc = 4.0 m, *Myriophyllum spicatum* – Zc = 4.0 m, *Potamogeton lucens* – Zc = 4.0 m and

Potamogeton filiformis – Zc = 5.5 m) colonized the deepest part of the littoral in the year 2003. From the data of the Table 3, negative relationship between Zs and maximum colonization depth (Zc) was calculated – correlation coefficient Zs/Zc: r = – 0.59, n= 14.

Table 3: Maximum colonization depth (Zc) of seven macrophyte species in 1997 and in 2003; Zs (mean Secchi depth).
Tabela 3: Največja globina uspevanja (Zc) sedmih makrofitskih vrst v letu 1997 in v letu 2003; Zs (povprečna Secchi-jeva globina).

	Zs = 5.9 m	Zs = 4.6 m
Chara sp.	0.5	-
Myriophyllum spicatum L.	3.0	4.0
Najas marina All.	2.0	4.0
Najas minor All.	1.5	-
Nuphar lutea (L.) Sibth. Et Sm.	2.0	2.0
Potamogeton crispus L.	3.5	3.0
Potamogeton filiformis Pers.	0.3	5.5
Potamogeton lucens L.	-	4.0
Potamogeton nodosus Poir.	-	2.0

Discussion

Lake Velenjsko jezero could be classified as meso-eutrophic according to the level of total phosphorus (OECD 1982, Mazej & Gaberščik 1999), what offered good conditions for quick colonization of macrophytes after restoration of the lake. Lake Velenjsko jezero, because of its original basin shape, has a steep slope in its littoral along the majority of the lakeshore. This is the reason why only a narrow area of shoreline is colonized by submersed macrophytes. Andersson (2001) asserted that the geomorphology of a lake basin is the primary factor affecting the structure of the interface zone between land and water. The steepness of the lake margins is decisive for sediment stability along slope gradients, which in turn influences the establishment of vegetation. The pioneer species, which colonized only a minor part of the littoral in the year 1996, were *Chara* sp., *Nuphar lutea* and *Potamogeton crispus* (Mazej 1998). Only three years later these species are not important components of the littoral vegetation anymore. *Chara* sp. disappeared from the lake when other macrophyte species overgrew the littoral in 1999, but it was detected in a very small quantity again in 2004. It is known that Charophytes are pioneers among macrophytes, and colonize a new habitat very quickly (Palma-Silva & al. 2002), but they are usually not competitive with angiosperms (Blindow 1992). *Nuphar lutea* has remained more or less at the same abundance at the same location throughout these years. Floating-leaved species may be expected to have a faster occupancy of areas with shallower water and smaller fetches, and the development of the floating-leaved macrophyte community may require years (Rea & al. 1998). It has been reported (Nichols & Show 1986, Bolduan & al. 1994, Jian & al. 2003) that *Potamogeton crispus* and *Myriophyllum spicatum* are very invasive species, which usually form a very dense population and establish large monospecific weed beds in many lakes. However, this was not the case in lake Velenjsko jezero. *Potamogeton crispus* was the dominant species till 1997. The life history of *Potamogeton crispus* differs from most other submersed plants. Biomass production of *Potamogeton crispus* often reaches its maximum in early summer, allowing it to avoid competition from other species in the habitat primarily because they are still in the dormant state (TOBIESSEN & SNOW 1984). Young plants of *Potamogeton crispus* and *Myriophyllum spicatum* overwinter, and then grow rapidly in the spring. In this respect, the two species are similar (BOLDUAN & al. 1994). By early summer plants undergo senescence processes and then remain dormant until autumn. It is known that *Potamogeton crispus* grows well in eutrophic lakes, at low temperature and very low light intensities, being an important primary producer in freshwater ecosystems, providing a good food source for herbivorous fishes (JIAN & al. 2003). Grazing by fish, birds and invertebrates may be an important factor that limits development of plants. Grazing sensitivity differs among submersed macrophytes (JACOBSEN & SAND-JENSEN 1992, WEISNER & al. 1997), and it has been proposed that selective grazing affects species composition and even succession (CRAWLEY 1983). It was ascertained that species of genus *Potamogeton* were significantly more heavily grazed by invertebrates (mean 4.2 % of leaf area) than non-*Potamogeton* species (mean 0.8 % of leaf area) (JACOBSEN & SAND-JENSEN 1992). The grazing experiments made by Weisner & al. (1997) also showed that non-*Potamogeton* species like *Chara* sp. and *Myriophyllum spicatum* were not significantly affected by grazing. There are no data in the literature about herbivory on the species *Najas marina*, but we assume that this species is not tasteful food for herbivores due to its fragility and its prickly shoots. Fragile shoots are easily broken and spread around by the help of current, wind and birds. It might be the reason, that *Najas marina* predominates over other species in lake Velenjsko jezero, including *Myriophyllum spicatum*. *Myriophyllum spicatum* and *Najas marina* usually appear together in various natural habitats, where they compete with each other. The result of studies (AGAMI & WAISEL 2002) showed that *Myriophyllum spicatum* was more sensitive to intraspecific competition than *Najas marina*, and additionally the competitive effects of *Najas marina* on *Myriophyllum spicatum* were stronger than vice versa.

Light availability affects both the biomass and community structure of phytoplankton and submersed vegetation (VAN DUIN & al. 2001, BEST & al. 2001). Although a significant positive correlation between Secchi disc transparency and the maximum colonization depth of macrophytes has been found in several studies (HUTCHINSON 1975, CHAMBERS & KALFF 1985, NICHOLS 1992, MIDDELBOE & MARKAGER 1997, MAZEJ & GABERŠČIK 1999), our study showed that transparency was not the main factor which determined the depth distribution of macrophytes in lake Velenjsko jezero. The maximum colonisation depth of macrophytes is usually ascribed to light attenuation in the water column and the minimum light requirement for growth (BLINDOW 1992), although other parameters such as surface irradiance, hydrostatic pressure, water colour, temperature, grazing pressure, substrate type and epiphyte loading can also affect maximum colonization depth (SAND-JENSEN 1989, VAN DUIN & al. 2001). Tall macrophytes (caulescent angiosperms and charophytes) compensate for light limitation by shoot growth towards the water surface, so maximum colonization depth is therefore independent of transparency (MIDDELBOE & MARKAGER 1997). Although mean Secchi disc transparency was higher in 1997 than in 2003, the maximum colonization depth of macrophytes (*Potamogeton crispus*) was only 3.5 m in 1997 and 5.5 m in 2003 (*Potamogeton filiformis)*. The results of ROONEY AND KALFF (2000) showed that angiosperms colonized deeper parts during years characterized by an early warming of the water, independent of underwater irradiance. The year 2003 was very warm with high May air temperatures. The average temperature of lake water was 3.6 °C higher than that in 1997. Since the majority of plants reproduce asexually, an earlier start to the growing season allowed plant communities more time for colonization.

Conclusion

The lake Velenjsko jezero has offered good conditions for development of macrophytes in less than ten years. In this short period, species composition and the quantitative relationships between the species varied enormously. Therefore further changes are expected in the coming years. We assume that plant interactions might constitute the main controlling factor regulating the distribution of macrophytes and coming projects should be oriented in studying plant interaction in grater detail.

Povzetek

Do leta 1983 je bilo Velenjsko jezero odlagališče pepela iz termoelektrarne Šoštanj. Od leta 1983 naprej so s sedimentacijo ločevali pepel od transportne vode. Pepel so odlagali na deponijo, vodo pa še naprej črpali v jezero, kjer se je pH dvignil na okoli 12 in iz jezera so izginile vse oblike življenja. Že eno leto po uvedbi zaprtega kroga transportne vode leta 1994, kjer vodo črpajo nazaj in jo ponovno uporabijo, se je pH na površini jezera zmanjšal na 9, leta 1997 pa pH vode po celotnem globinskem profilu ni presegal 8,7 in vanj se je po daljšem obdobju spet začelo vračati življenje.

Vrstno sestavo in razporeditev makrofitov v Velenjskem jezeru spremljamo bolj ali manj redno že od leta 1996. Makrofiti so pričeli po sanacijskih ukrepih zelo hitro naseljevati prazen litoral, saj so bile nudene ugodne razmere – dosti hranil, podlaga za ukoreninjenje in ugodne svetlobne razmere. Velenjsko jezero je nastalo z ugrezanjem, zaradi česar se njegova obala na mnogih mestih zelo hitro spusti v globino. To je tudi razlog, zakaj je z makrofiti poraščen le ozek pas litorala. Pionirske vrste, ki so se pojavile v prvem letu raziskav (1996) so bile *Chara* sp., *Nuphar lutea* in *Potamogeton crispus*. *Potamogeton crispus* je bila dominantna vrsta do leta 1997. V naslednjih letih pa sta vrsti *Najas marina* in *Potamogeton filiformis* prevladali nad ostalimi vrstami v jezeru. *Chara* sp. je bila prisotna v zelo majhni količini v jezeru le v letih 1996 in 1997, v naslednjih letih pa je v občasnih pregledih litorala nismo več zasledili. Zopet pa smo jo našli na istem mestu v letu 2004. V vseh teh letih je prihajalo do spremenjenega kvantitativnega in kvalitativnega razmerja med vrstami. V prvih letih so makrofiti naselili predvsem del med čolnarno in pritokom Sopote, medtem ko je bil del ob deponiji neporaščen. V naslednjih letih so se makrofiti razširili tudi v ostala območja litorala, zmanjšala pa se je njihova pojavnost tam, kjer se kaže večji vpliv zaledja – ob nasipu in na območju pešpoti pod vrtičkarskim naseljem »Kinte-Kunte«. Od leta 1996 pa do leta 2004 je število vrst iz 3 naraslo na 9. Medtem ko kažejo vrste *Najas marina*, *Potamogeton filiformis, Potamogeton lucens* in *Potamogeton nodosus* pozitiven trend v razvoju, pa v zadnjih letih opažamo manjše pojavljanje vrst *Chara* sp., *Myriophyllum spicatum*, *Potamogeton crispus* in *Najas minor.*

Le nekaj let je minilo od naselitve prvih makrofitov v jezeru, zato lahko pričakujemo, da bo prišlo v naslednjih letih še do določenih sprememb in sicer tako v vrstni sestavi makrofitov kot tudi v razporeditvi le-teh.

Aknowledgements

Authors thank to Prof. Dr. Alenka Gaberščik and Dr. Mateja Germ for valuable comments on the manuscript.

stevilka 1_05.qxp 13.12.2005 12:32 Page 30

References

AGAMI M. & Y. WAISEL 2002: Competitive relationships between two water plant species: *Najas marina* L. and *Myriophyllum spicatum* L.. Hydrobiologia **482**: 197-200.

ANDERSSON B. 2001: Macrophyte development and habitat characteristics in Sweden's large lakes. Ambio **30** (8): 503-513.

BEST E. P. H., C. P. BUZZELLI, S. M. BARTELL, R. L. WETZEL, W. A. BOYD, R. D. DOYLE & K. R. CAMPBELL 2001: Modelling submersed macrophyte growth in relation to underwater light climate: modelling approaches and application potential. Hydrobiologia **444**: 43-70.

BLINDOW I. 1992: Long- and short-term dynamics of submerged macrophytes in two shallow eutrophic lakes. Freshwater Biology **28**: 9-14.

BOLDUAN B. R., G. C. VAN EECKHOUT, H. W. QUADE & J. E. GANNON 1994. *Potamogeton crispus* – The Other Invader. Lake and Reserv. Manage. **10** (2): 113-125.

BOWES G. 1987: Aquatic plant photosynthesis: strategies that enhance carbon gain. In: CRAWFORD R. M. M. (ed.): Plant Life in Aquatic and Amphibious Habitats, spec. publ. No. 5. Br. Ecol. Soc., Blackwell Sci. Pub. Oxford, pp. 79-98.

CHAMBERS P. A. & J. KALFF 1985: Depth distribution and biomass of submersed aquatic macrophyte communities in relation to Secchi depth. Can. J. Fish. Aquat. Sci. **42**: 701-709.

CRAWLEY M. J. 1983: Herbivory. The dynamics of animal-plant interactions. Blackwell, Oxford.

FOX A. M. 1992: Macrophytes. In: CALOW P. & E. P. GEOFFREY (eds.): The Rivers Handbook. Volume 1. pp. 216-346.

GERM M. & A. GABERŠČIK 1999: The distribution and abundance of macrophytes of the lowland Ižica river (Slovenia) = Razporeditev in pogostost makrofitov v nižinski reki Ižici. Acta biol. slov. **42** (4): 3-11.

GERM M., M. DOLINŠEK & A. GABERŠČIK 2003: Macrophytes of the river Ižica – comparison of species composition and abundance in the years 1996 and 2000. Arch. Hydrobiol., Suppl. **147** (1-2): 181-193.

HASLAM S. M. 1987: River Plants of Western Europe. The macrophytic vegetation of watercourses of the European Economic Community. Cambridge University Press, Cambridge, New York, New Rochelle, Melbourne, Sydney.

JACOBSEN D. & K. SAND-JENSEN 1992: Herbivory of invertebrates on submerged macrophytes from Danish freshwaters. Freshwater Biology **28**: 301-308.

JEPPESEN E., MA. SONDERGAARD, MO. SONDERGAARD & K. CHRISTOFFERSEN (Eds.) 1998: The structuring role of submerged macrophytes in lakes. Springer Press, New York.

JIAN Y., B. LI, J. WANG & J. CHEN 2003: Control of turion germination in *Potamogeton crispus*. Aquatic Botany **75**: 59-69.

KOHLER A. & G. A. JANAUER 1995: Zur Metodik der Untersuchungen von aquatischen Makrophyten in Flussgewasseren. In: LANDSBERG, H. & H. KLAPPER, (Eds.): Hollandbuch Angewandte Limnologie, Ecomed Verl., Landsberg /Lech, pp. 1-22.

MAZEJ Z. 1998: Macrophytes in the different types of lakes: species composition and species vitality. Master of science thesis, Ljubljana, 104 pp.

MAZEJ Z. & A. GABERŠČIK 1999: Species composition and vitality of macrophytes in different types of lakes. Acta biologica Slovenica **42** (3): 43-52.

MIDDELBOE A. L. & S. MARKAGER 1997: Depth limits and minimum light requirements of freshwater macrophytes. Freshwater Biology **37**: 553-568.

NICHOLS S. A. & B. H SHAW 1986: Ecological life histories of the three aquatic nuisance plants, *Myriophyllum spicatum*, *Potamogeton crispus*, and *Elodea canadensis*. Hydrobiologia **131**: 3-21.

NICHOLS S. A. 1992: Depth, substrate and turbidity relationship of some Wisconsin Lake plants. Wisconsin Academy of Sciences, Arts and Letters 59, 97-118.

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

PALL K. & G. A. JANAUER 1995: Die Makrophytenvegetation von Flußstauen am Beispiel der Donau zwischen Fluß-km 2552.0 und 2511.8 in der Bundesrepublik Deutschland. Arch. Hydrobiol. Suppl. **101** (Large Rivers 9) (2): 91-109.

PALMA-SILVA C., E. F. ALBERTONI & F. A. ESTEVES 2002: The role of Charophytes primary production in a coastal lagoon subjected to human impacts (RJ, Brasil). Acta. Limnol. Bras. **14** (1): 59-69.

PIP E. 1984: Ecogeographical tolerance range variation in aquatic macrophytes. Hydrobiologia **108**: 37-48.

PIP E. 1989: Water temperature and freshwater macrophyte distribution. Aquatic Botany **34**: 367-373.

PRESTON C. D. 1995: Pondweeds of Great Britain and Ireland. Botanical society of the British Isles, London.

SAND-JENSEN K. 1989: Environmental variables and their effect on photosynthesis of aquatic plant communities. Aquatic Botany **34**: 5-25.

REA E. T., D. J. KARAPATAKIS, K. K. GUY, I. J. E PINDER & H. E. MACKEY JR. 1998: The relative effects of water depth, fetch and other physical factors on the development of macrophytes in a small southeastern US pond. Aquatic Botany **61**: 289 – 299.

ROONEY N. & J. KALFF 2000. Inter-annual variation in submerged macrophyte community biomass and distribution: the influence of temperature and lake morphometry. Aquatic Botany 68, 321-335.

TOBIESSEN P. & P. D. SNOW 1984: Temperature and light effects on the growth of *Potamogeton crispus* in Collins Lake, New York State. Can. J. Bot. **62**: 2822-2826.

URBANC-BERČIČ O., A. GABERŠČIK, M. ŠIŠKO & A. BRANCELJ 2002: Aquatic macrophytes of the mountain lake Krnsko jezero, Slovenia. Acta Biologica Slovenica **45** (2): 25-34.

VAN DUIN E. H. S., G. BLOM, F. J. LOS, R. MAFFIONE, R. ZIMMERMAN, C. F. CERCO, M. DORTCH & E. P. H. BEST 2001: Modeling underwater light climate in relation to sedimentation, resuspension, water quality and autotrophic growth. Hydrobiologia **444**: 25-42.

WEISNER S. E. B. 1991: Within-lake pattern in depth penetration of emergent vegetation. Freshwater Biol. **26**: 133-142.

WEISNER S. E. B., J. A. STRAND & H. SANDSTEN 1997: Mechanisms regulating abundance of submerged vegetation in shallow eutrophic lakes. Oecologia **109**: 592-599.