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Aquatic macrophytes of the mountain lake Krnsko jezero, Slovenia

Vodni makrofiti Krnskega jezera, Slovenija

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Abstract. The macrophyte vegetation in the mountain lake Krnsko jezero has been monitored since 1991. Five species of aquatic macrophytes, occupying different depths, were present in the lake. Changes in depth distribution were detected due to accelerated eutrophication caused by inputs of nutrients from the watershed. In the period between 1997 and 1998 repeated earthquakes additionally influenced the processes in the lake Krnsko jezero, by increased input of matter. The occasional phytoplankton blooms reduced water transparency and consequently disturbance to growth, development and distribution of anchored macrophytes occurred. In 1998 macrophytes spread down to 7.0 m, reaching the maximum at 5.8 kg DW m^{-2} at 2 m depth. The total primary production in the lake was estimated at 4991 kg organic matter per year out of which *Chara* and *Potamogeton* species presented 95.5 % and 0.6 %, respectively.

Key words: aquatic macrophytes, chlorophyll *a*, lake Krnsko jezero, mountain lake, nutrients, organic matter, primary production

Izvleček. Makrofite v Krnskem jezeru spremljamo od 1991 leta. V jezeru je prisotnih pet vrst podvodnih rastlin, ki uspevajo na različnih globinah. Zaradi pospešene evtrofikacije, ki je odraz povečanega vnosa nutrientov iz zaledja, se globina uspevanja spreminja. Med letoma 1997 in 1998 je bila serija potresov, zaradi česar se je vnos snovi iz zaledja povečal in dodatno vplival na procese v jezeru. Občasno cvetenje fitoplanktona je zmanjšalo prosojnost vode, kar se je odrazilo na rasti, razvoju in razporeditvi submerznih makrofitov. Tako so v letu 1998 makrofiti segali do globine 7 m, njihova največja biomasa je bila 5,8 kg suhe teže m^{-2} na globini 2 m. Celotna primarna produkcija organske snovi v jezeru je bila ocenjena na 4991 kg $leto^{-1}$, pri čemer je bil delež parožnic 95,5 %, delež dristavcev pa le 0,6 %.

Ključne besede: vodni makrofiti, klorofil *a*, Krnsko jezero, gorsko jezero, nutrienti, organska snov, primarna produkcija

Introduction

Mountain lakes, usually located in remote natural environment, are becoming interesting sites of ecological research for two reasons *inter alta*: they are relatively small and they are sensitive to different influences from the environment. The alpine lake Krnsko jezero is an eutrophic lake (GABERŠČIK & URBANC-BERČIČ 1996). In the last century some events had put an evident mark on this ecosystem. During the First World War the wider area was the centre of severe battles that had resulted in increased input of matter from the watershed. Latter on two species of fish were introduced in the lake; in late twenties *Salvelinus alpinus* (Linnaeus, 1758) and two decades latter *Phoxinus phoxinus* (Linnaeus, 1758) (BRANCELJ & al.1997). Other human activities, pasturing and mountaineering at most, presented an influential activity, the latter being intensified in the last decade. The influence of these activities had been closely studied in the nearby lake (BRANCELJ & al. 2000).

The first investigation of basic geographic and hydrobiologic characteristics was carried out in the late fifties (GAMS 1962), but no record on macrophytes was made until 1988 (BLAŽENČIČ & al. 1990). In 1996 the systematic research of 14 alpine lakes started as an addition to the previous 5-year monitoring. The study had revealed that the most abundant aquatic vegetation was in the lake Krnsko jezero (GABERŠČIK & URBANC-BERČIČ, 1996). Comparable studies to ours on primary production in mountain lakes was not found but in our case it was evident that macrophytes contributed a great deal to the production of the lake. Researches on lowland lakes, rich with aquatic vegetation showed, that macrophytes present an important factor maintaining the stability of the ecosystem (OZIMEK & al. 1990, RØRSLETT 1991, RASPOPOV & al. 1996).

The present study was carried out in order to evaluate the abundance and production of anchored macrophytes, related to the main trophic parameters and their contribution to the primary production of the lake.

Material and methods

Site description

The lake Krnsko jezero is located well bellow the timberline at the altitude of 1383 m. It is of glacial origin. Lake is the largest and the deepest in the Triglav National Park, covering the area of 49600 m^2. The lake is 17.6 m deep (Fig. 1). At the highest water level the total volume of 446700 m^3 of water accumulates in the lake. At heavy rains fluctuations of water level could be as high as 4 m, reaching the normal level within two days. The lake is ice covered usually from November to May. During the summer it is stratified, with late spring (after ice-cover melting) and late autumn homothermy. The nearby watershed is diverse, formed of stones, gravel, rocks, meadows and pastures. The wider area is geologically unstable and some severe earthquakes with soil avalanches have caused strong disturbances in watershed and increased the input of matter.

Water chemistry

The sampling of water for chemical analyses and chlorophyll *a* was carried out with Van Dorn sampler. Samples were collected on the vertical profile every 2.5 m (0 m, 2.5 m, 5 m, 7.5 m, 10.0 m, 12.5 m and above bottom) in monthly intervals in the ice-free period from May 1996 to the end of 1999. Electric conductivity was measured in laboratory at 25 °C with conductivity meter (MA 5950, Iskra, Slovenia) and concentration of oxygen was measured *in situ* with an oxygenmeter (WTW Oxi 320, Germany). To evaluate chemical variables analytical methods according to APHA (1992) were applied. All spectrophotometric measurements were performed with spectrophotometer Perkin Elmer (UV/VIS, Lambda 12). The temperature was measured with a thermistor (Iskra, Slovenia). Chlorophyll

a concentration was determined by photometry (Golterman & al. 1978, Wetzel & Likens 1995). Biomass of phytoplankton was calculated on the basis of chlorophyll *a* concentrations (Talling 1975). Transparency was estimated by means of Secchi disc. The physical and chemical data are presented as median, minimum and maximum of total measured values.

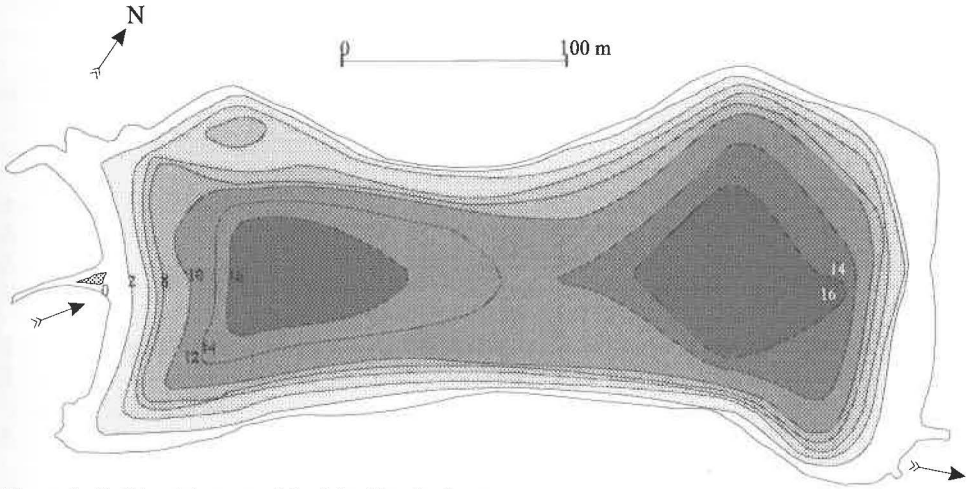

Figure 1: Bathimetric map of the lake Krnsko jezero

Slika 1: Batimetrična karta Krnskega jezera

Macrophyte survey

The survey of submersed vegetation was carried out from 1991 to 1999 along 20 permanent transects. The shore line was divided into the sections of different lengths, based on the uniformity of morphological characteristics (bathimetric map), water depth and substrate types. For graphic presentation the homogenous sections were additionally divided into the final 31 sections, with the length of 35±2 m (Fig. 2). Abundance of the observed macrophytes was estimated semi-quantitatively using a 5-level scale (1- present, 2 - rare, 3 - common, 4 - abundant, 5 - predominant) (Melzer 1992, Pall & Janauer 1995). The survey was made from the boat using depthmeter, view box and sampling rake. In September 1998, macrophyte community was surveyed by scuba-diving on six representative transects. The total biomass of macrophytes was collected in the area of 0.1 m^2 on the depths of 1, 2, 3, 4 and 7 m, washed thoroughly to remove periphyton, oven dried at 105 °C and weighted. The ratio of organic matter was determined by ignition at 550 °C following the method from APHA (1992).

Results and Discussion

As the majority of lakes world-wide the lake Krnsko jezero is subjected to accelerated eutrophication due to diverse reasons. The disturbances to the lake were caused by the First World War, introduction of fish, traditional pasturing, earthquakes and mountaineering (Gaberščik & al. 1997). In the period between 1997 and 1998 after repeated earthquakes the sedimentation rate in the lake increased. The analyses of the material in the sediment traps revealed that the annual amount of gathered matter was increasing from 0.84 g DW m^{-2} in 1997, 1.01 g DW m^{-2} in 1998 to 3.68 g DW m^{-2} in 1999 (Muri &. al. 2002).

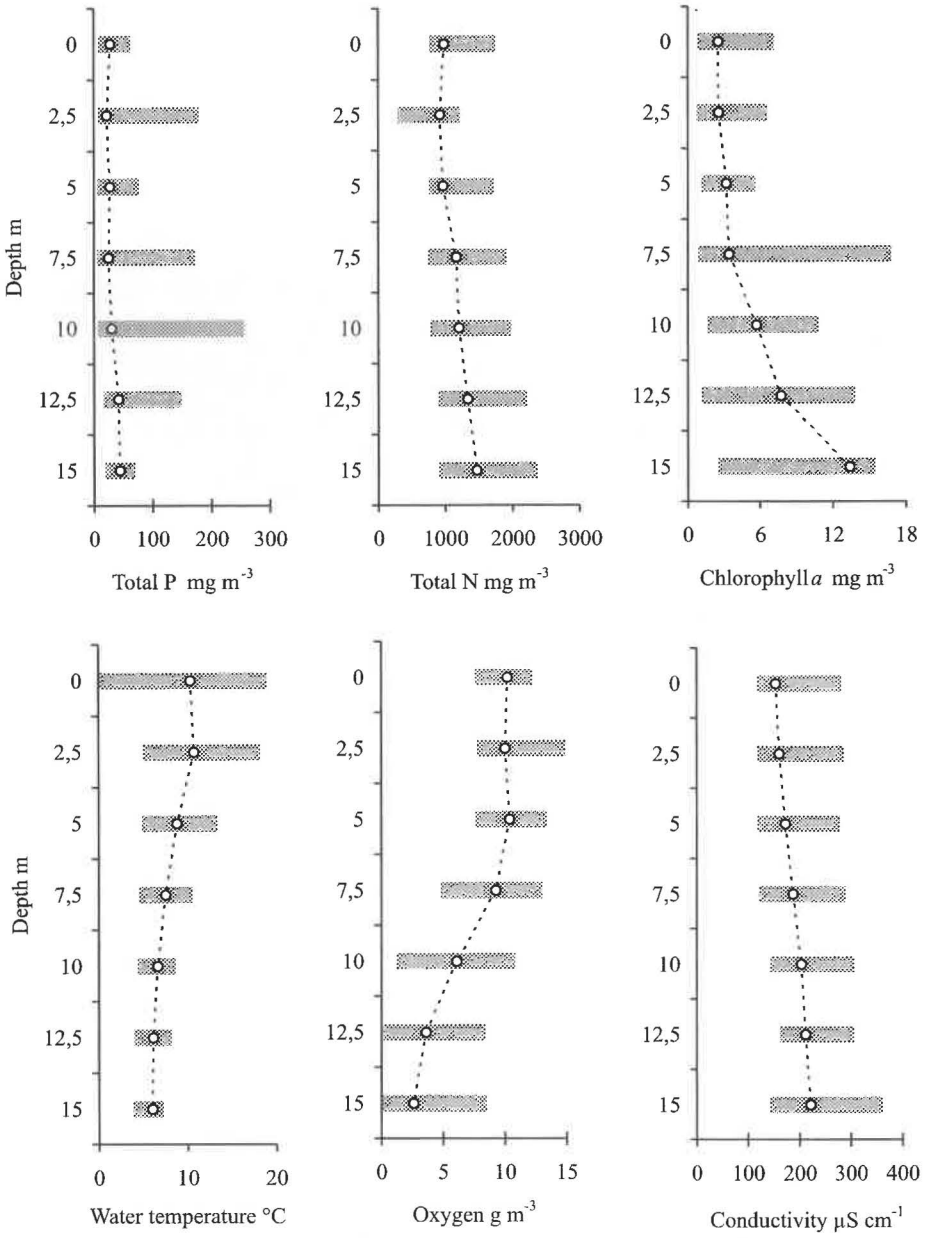

Figure 2: Main physical and chemical parameters measured in the depth profile of the lake Krnsko jezero in the period from 1996 to 1999. Median values, minima and maxima are presented.
Slika 2: Glavni fizikalni in kemični parametri merjeni na globinskem profilu v Krnskem jezeru, v obdobju od 1996 do 1999 leta. Pedstavljene so mediane, minimalne in maximalne vrednosti.

Concentrations of nutrients in water column measured in a period from 1996 to 1999 varied to a great extent (Fig. 2). The median values of nutrients increased with depth, the total phosphorus ranging from 21 to 44 mg m^{-3} and the total nitrogen from 915 to 1463 mg m^{-3}. The concentrations of total phosphorus in the water column differed a lot, exhibiting the lowest variability in the bottom samples, due to releasing of phosphorus from the sediment under anaerobic conditions. The concentrations of total nitrogen and dissolved solids measured as electric conductivity showed less variability than total phosphorus.

The introduction of fish influenced the food web in the lake, and consequently only one zooplankton species, *Cyclops vicinus* (Uljanin 1875) was present. In the nearby lakes zooplankton was still diverse and up to 6 species could be found (Brancelj & al. 1997). The reduction of zooplankton diversity resulted further in the increase of chlorophyll *a* concentration and in lower water transparency (Tab. 1). During the monitoring Secchi depth varied in the range from 2.5 m to 11 m, median value being 4 m. The concentration of chlorophyll *a* as a measure of phytoplankton production was rather constant in the upper layers, reaching median value about 3 mg m^{-3}. The highest concentration was measured at the bottom layer (median value 13 mg m^{-3}), likely due to algal sedimentation, while the variability from 1 to 17 mg m^{-3} was determined at the depth of 7.5 m, where thermocline usually occurred.

Table 1: Data on minimal water tranparencies and maximal depth distribution of *Characeae* in the lake Krnsko jezero from 1994 to 1999; n = 3 - 6, * Blaženčič & *al.* (1990).
Tabela 1: Najnižje vrednosti prosojnosti vode in največja globina uspevanja parožnic (*Characeae*) v Krnskem jezeru v obdobju od 1994 do 1999 (n=3-6). Podatek * Blaženčič & al. (1990).

Year	1988	1991	1992	1993	1994	1995	1996	1997	1998	1999
Secchi depth (m)	-	-	-	-	-	4.2	3.5	3.0	2.5	2.5
Maximal depth distribution (m)	10.0*	8.0	8.0	8.0	8.0	7.0	7.0	7.5	7.0	7.5

By preventing the penetration of light, planktonic algae posed depth limits for anchored macrophytes. In spite of this phenomenon the littoral area of the lake Krnsko jezero is large. We defined it by the extension of macrophyte community (Wetzel 1990) on the basis of bathimetric map. In 1998 it presented about 19600 m^2, that is nearly 40 % of the projected lake area. Five species of submersed macrophytes i.e. *Chara delicatula* Ag., *Chara contraria f. capillacea* Mig., *Potamogeton alpinus* Balbis, *Potamogeton pusillus* L. and *Batrachium trichophyllum* Chaix. colonising different depths, were determined in the lake (Fig. 3). The community is considered as floral rich in comparison to other 13 Slovene alpine lakes (Gaberščik & Urbanc-Berčič 1996). This coincides with the data of northern European lakes elaborated by Rørslett (1991) which revealed that upland lakes exhibited proportionally fewer species than lowland sites.

During the monitoring the maximal depths colonised by macrophytes oscillated (Tab. 1) showing trend of gradual reduction. In 1988 *Chara delicatula* spread down to 10 m. The maximum depth of this species was 8 m from 1991 to 1994 and 7 - 7.5 m since then (Blaženčić & al. 1990, Gaberščik & Urbanc-Berčič 1996). The competition for light and nutrients with filamentous and planktonic algae was estimated to be the main reason for this feature. Blindow (1992a,b) found out that charophytes were sensitive to the reduction of light more than to the increase of total phosphorus, as it was indicated in the previous studies (Forsberg 1964). Lehmann & Lachavanne (1999) compared the relevance of two indices to refine changes in macrophyte community in Lake Geneva. They demonstrated that saprobic index based on organic matter inputs, was more closely related to subtle vegetation changes than index, based on nutrients load. Our survey indicated that increased inputs detected in sediment traps, originating from the disturbed watershed supposed to be a trigger for changing of submersed vegetation. Survey of 116 high mountain Pyrenean lakes, led by Gacia & al. (1994) pointed out two environmental variables, vegetation coverage of the catchment and altitude as the main factors that influence the distribution and composition

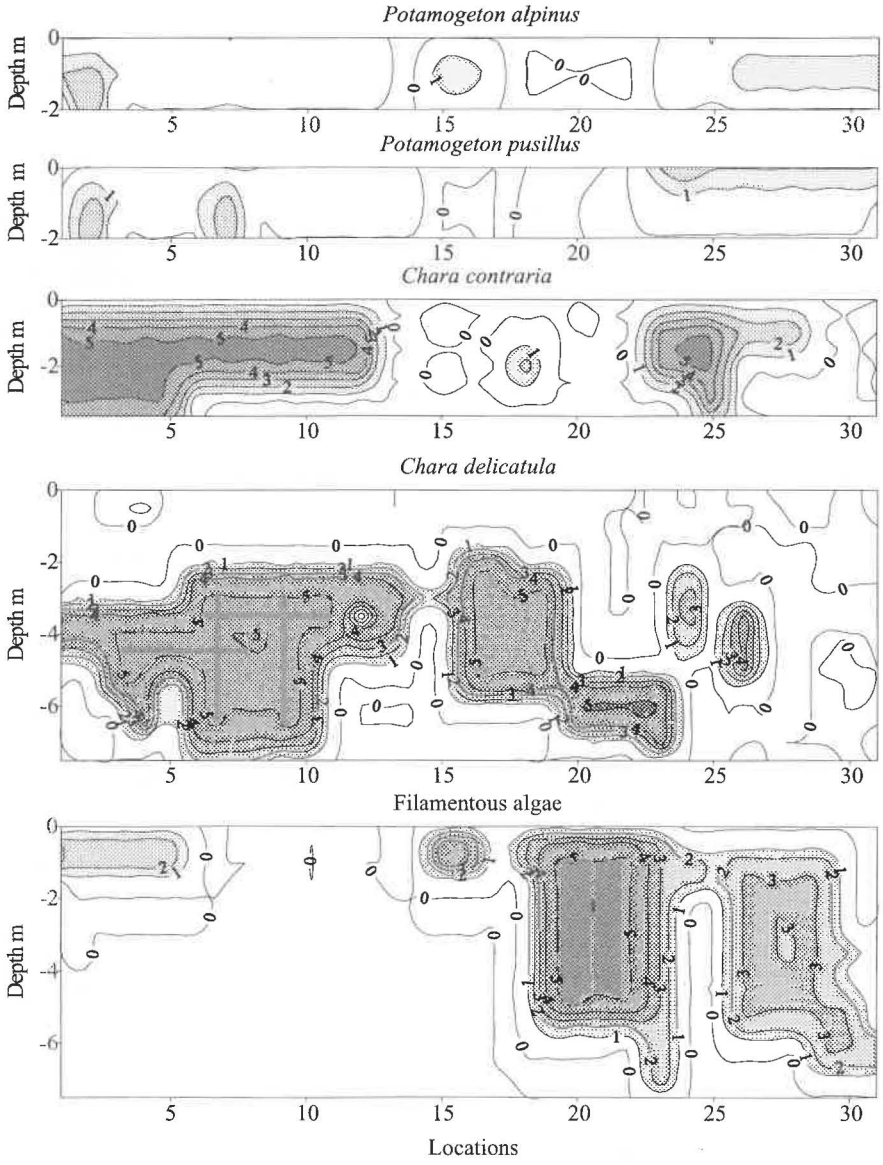

Figure 3: Depth distribution and abundance (rated from 1 to 5) of macrophytes in 31 sections (length 35±2 m) in the littoral of the lake Krnsko jezero in September 1998. Section 1 is to the right of the lake outflow (counter clockwise).

Slika 3: Globinska razporeditev in številčnost makrofitov, ocenjena od 1 do 5, na 31 odsekih litorala v Krnskem jezeru, september 1998. Odseki (1 je desno od iztoka) potekajo v obratni smeri urinega kazalca.

of macrophytes. These two determinants reflect potential inputs in whole while a nutrient availability in the water as a relevant variable for the primary producers, depends on the processes in lake, as well.

In 1998, when a detailed survey was made by scuba-divers, the maximum biomass of macrophytes was determined between the depths of 2 and 3 m (the estimation of abundance was 5) even though the continuous stands of stoneworts spread to the depth of 7.5 m (Fig. 3). Plants were extremely elongated reaching the length up to 1 m at the depth of 3 m. The prevailing species in the lake were *Chara delicatula* and *Chara contraria f. capillacea*. In 1998 their share per lake was 2700 and 2068 kg of organic matter, respectively. The former reached up to 3 kg DW m^{-2} on the depth of 3 m. The highest dry weight 5.8 kg m^{-2} of *Chara contraria f. capillacea* was determined on the depth of 2 m (Fig. 4).

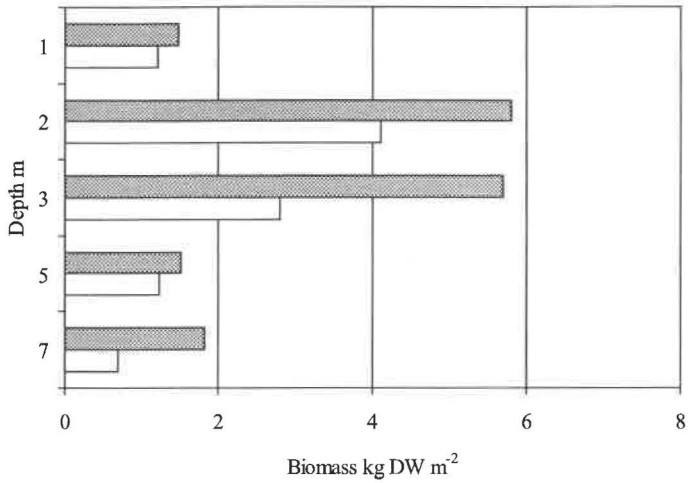

Figure 4: Depth distribution of macrophytes biomass in September 1998 (white column – average, grey column – maximum value). Figures present the values calculated from the macrophytes' samples obtained by scuba diving on 6 transects.
Slika 4: Globinska razporeditev biomase makrofitov v septembru 1998 (bel stolpec so povprečne, siv stolpec maximalne vrednosti). Številke predstavljajo biomaso, preračunano iz vzorcev makrofitov, zbranih s pomočjo potapljačev na 6 transektih.

Both species contributed a lot to the total dry weight which was determined at 17537 kg. The value corresponds to 4991 kg of organic matter. Converted to energy content it means that about 10^8 KJ were integrated in the ecosystem from solar energy. With such a production the lake reaches the level of fertile ecosystems (Ozimek & al. 1990). The predominance of stonewort species which function as a stabiliser of the sediment is beneficial for the system resilience concerning inputs from the watershed i.e. nutrients, as well as particulate matter. The other two submersed macrophytes *Potamogeton alpinus* and *Potamogeton pusillus* were not abundant and their biomass presented a negligible share of 21 and 33 kg DW per lake in 1998 (Fig.5) but having the highest organic content (Fig. 6). In spite of low production pondweeds present a factor stabilising the shallow, sensitive parts of the littoral and promoting sedimentation of fine particles. The macrophytic biomass distribution in the lake Krnsko jezero reflects the characteristics of the lake, i.e. basin configuration, high availability of nutrients, water level fluctuations and modest light conditions. Stoneworts that have lower light demands for photosynthesis (Blindow 1992a,b) express a competitive advantage over higher submersed plants. Occasionally, when the runoff of nutrients from the watershed was increased, the biomass of filamentous and planktonic algae increased. Even though planktonic algae presented a minor share in the primary production of the lake, they affected macrophytes (Lachavanne 1985, Hough & al. 1989). Calculated

to the whole lake volume their average concentration would be 4 mg m^{-3}, which is equivalent to the production of 92 kg organic matter per lake, presenting 1.8 % of the lake primary production (Fig. 5). In 1998, nearly the same share of primary production was contributed from filamentous algae. They

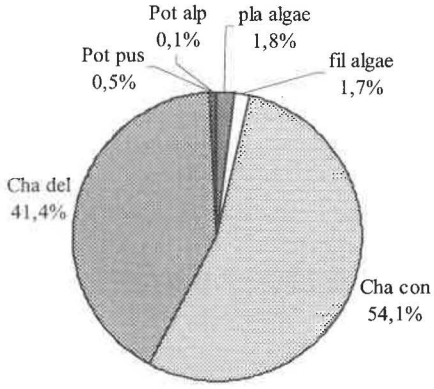

Figure 5. Partition of total organic matter among different primary producers in the lake Krnsko jezero in September 1998 when the total primary production was estimated to 4991 kg DW of organic matter. Periphyton biomass is excluded.
Slika 5: Delež organske snovi med različnimi primarnimi producenti v Krnskem jezeru, september 1998. Celotna primarna produkcija je bila ocenjena na 4991 kg suhe organske snovi brez biomase perifitona.

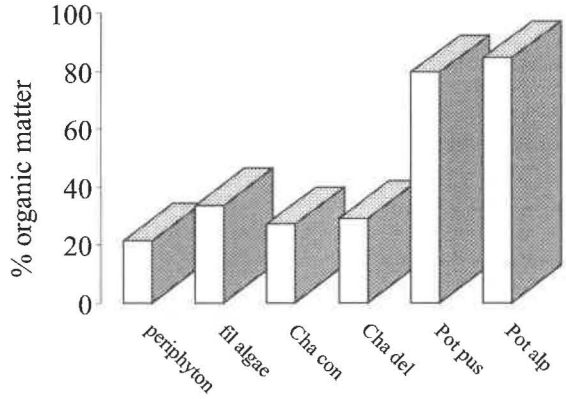

Figure 6: The ratio of organic matter in the biomass of different primary producers from the lake Krnsko jezero.
Slika 6: Razmerje organske snovi v biomasi različnih primarnih producentov v Krnskem jezeru.

appeared mainly in the shallow water competing with pondweeds. On the sites with steep slopes where the conditions for anchoring were not favourable, higher plants and stoneworts were scarce. On these locations filamentous algae were not in a position of direct competitors (locations from 18 to 30 on Fig. 3).

Conclusions

In the lake Krnsko jezero accelerated eutrophication resulted in high primary production that presented very high absorbance of solar energy into the lake. In 1998, littoral presented 40 % of a

projected lake area and was densely colonised with macrophytes. The major share of biomass belonged to charophyte species (95.5%) while planktonic and filamentous algae contributed 3.5%, only. In spite of this minority they presented an influential competitor to stonewort for light. Reduction of light penetration was a feature which have been measured in the last years. Successful competition of filamentous algae for nutrients was evident in the shallowest parts, with exception of the locations with steep slopes and unsuitable substrates for stoneworts and higher plants to anchor. The colonisation of littoral with anchored macrophytes increases the ecosystem resilience, by stabilising the erosion zone which overtakes function of a sedimentation zone.

In spite of different influences from the watershed, the direct impact of a single disturbance was difficult to define on a temporal scale, but the consequences of integral impact resulted in reduction of water transparency, enhanced appearance of filamentous algae and shrinking of littoral zone. Those features indicated the eutrophication in lake Krnsko jezero and showed trend of accelerated succession in a remote mountain lake ecosystem.

Povzetek

Pospešena evtrofikacija Krnskega jezera se odraža v visoki primarni produkciji, kar pomeni zelo visoko vezavo sončne energije v jezeru. Litoral je v letu 1998 zavzemal kar 40 % jezerske površine, ki je bila gosto poseljena z makrofiti. Večinski delež biomase je pripadel parožnicam (95,5%), medtem ko je bil delež planktonskih in nitastih alg samo 3,5%. Kljub podrejenemu deležu so bile alge vpliven kompetitor za svetlobo, katere intenziteta se je v jezeru zmanjševala. Uspešnost nitastih alg v tekmovanju za hranila je bila očitna predvsem v plitvejših predelih, z izjemo odsekov na strmih bežinah, kjer je bil substrat neprimeren za zakoreninjenje parožnic in višjih rastlin. Poselitev litorala z makrofitskimi vrstami, ki se zakoreninijo, povečuje elastičnost ekosistema, saj te vrste s koreninskim sistemom stabilizirajo potencialne erozijske cone, ki tako postanejo sedimentacijske cone.

Kljub očitnim vplivom iz zaledja je neposreden vpliv posamezne motnje tako časovno kot prostorsko težko razločiti. Vendar pa so posledice vseh motenj določljive in prepoznane kot znižanje prosojnosti vode, kot povečano pojavljanje nitastih alg in kot krčenje litoralne cone. Vsi ti pojavi, ki so prepoznani kot odraz pospešene evtrofikacije, so v Krnskem jezeru časovno zgoščeni in kot taki dober prikaz sukcesijskih procesov v oddaljenem gorskem jezerskem ekosistemu.

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