ANALYSIS OF SEDIMENT FROM LOVRENŠKA JEZERA (LAKES) IN POHORJE

ANALIZA SEDIMENTA IZ LOVRENŠKEGA JEZERA NA POHORJU

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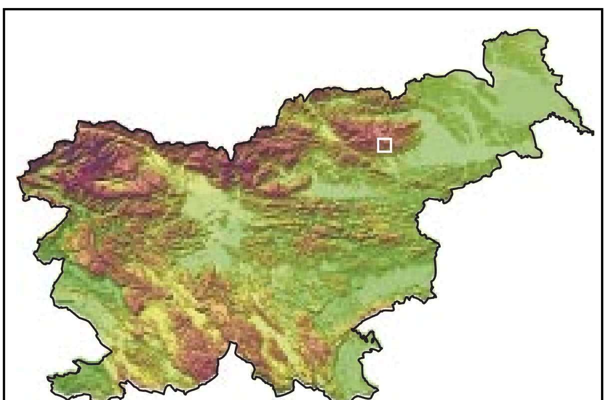
Lovrenška jezera (lakes) – a typical landscape on the top of the mountain ridge of the Pohorje (October 1998, photography Anton Brancelj)
Lovrenška jezera – značilna pokrajina na vrhu Pohorja (oktober 1998, fotografija Anton Brancelj)



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KEY WORDS: Cladocera, ^{137}Cs, diatoms, Lovrenška jezera (lakes), paleolimnology, Pohorje, *SCP*, spheroidal carbon particles ^{210}Pb.

The paper presents the results of sediment analyses done at a small moor lake on Pohorje. The changes in the plankton association of water fleas and diatoms whose remains accumulate in the sediment are a reflection of changing environmental factors. It was determined that the greatest dynamics of change occurred in the last 150 years, which coincides with the beginnings of industrialization. The age of the sediment has been determined by the analyses of the activity of the radionuclides ^{137}Cs, ^{210}Pb, and ^{241}Am, which showed that the sediment at the depth of 14 cm is about 100 years old. The presence of spheroidal carbon particles (SCP), a consequence of the use of fossil fuels, confirmed dating by radiunucleids.

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KLJUČNE BESEDE: Cladocera, ^{137}Cs, diatomeje, Lovrenška jezera, palaeolimnologija, Pohorje, *SCP*, kroglasti ogljikovi delci ^{210}Pb.

V prispevku so predstavljeni izsledki raziskave sedimenta v barskem jezercu na Pohorju. Spreminjanje planktonske združbe vodnih bolh in kremenastih alg, katerih ostanki se nabirajo v sedimentu, so odraz spreminjanja okoljskih dejavnikov. Največja dinamika sprememb je ugotovljena za zadnjih 150 let, kar sovpada z začetki industrializacije. To potrjujeta tudi analizi aktivnosti radionuklidov ^{137}Cs, ^{210}Pb in ^{241}Am, ki so pokazale, da je sediment na globini 14 cm star okoli 100 let in prisotnost kroglastih ogljikovih delcev (SCP), ki so posledica uporabe fosilnih goriv.

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1. Introduction

In the last several decades, we have witnessed an ever more accelerated changing of the natural environment. The reasons for this are quite clear and can be attributed especially to the human striving for new urban areas, expansion of industry, traffic connections, intensive farming, interventions of water-management schemes, and the need for new tourist areas. Some consequences of this activity are reflected more at the local level, while others can assume much greater, even global dimensions. The consequences appear primarily in two forms:

a) general pollution of the environmental elements air, water, and soil; and
b) changing of the global climate, especially as a consequence of emissions into the air.

Already for a longer time, environmental researchers have been trying to determine to what extent these changes have already progressed. The greatest changes in nature in the history of mankind occurred on two occasions. The first occurred when man passed from the hunting-gathering system to the farming-livestock breeding way of life. The second more intensive change occurred with the Industrial Revolution in the middle of the last century. To some extent, the changes caused by the transition to the farming-livestock breeding way of life could still be corrected, as it primarily involved slower, physical changes in the environment (clearing trees, burning off brush, erosion) that were also more or less localized. However, much bigger changes occurred in the course of the Industrial Revolution after 1850 when we can already speak of changes on a global scale that are linked with the use of the fossil fuels coal and oil. The consequences of this kind of activity also appear in the chemical changes of the environment with the increasing use of harmful and poisonous substances and with acidification.

Recent damage to the environment and its pollution can be quite well assessed, both quantitatively and qualitatively, by modern measuring techniques and observations. The problem arises when we attempt to determine when and under which past circumstances the changes occurred. In this case, it is necessary to find a suitable environment in which such changes have been recorded and also preserved. The water environment, primarily of lakes, is one such environment. In lakes, the processes of sediment accumulation occur in relatively non-disturbing circumstances, which enables the chronological recording of events in the lake and its immediate neighborhood. Therefore, lake sediments represent a time capsule or yearbooks that using appropriate methods we can »read« and thus reconstruct past events. The methodology is based on the assumption that the physical, chemical, and biological factors of a lake ecosystem change in accordance with changes in the environment, or with a certain time delay. What changes in the lake sediments is their physical composition (the ratio between organic and inorganic matter), the chemical composition (the composition of rocks and organic material), and their content as regards the remains of plants and animals (species present and their numbers). Among the analyses of the biological parameters that have been done so far, those best known have been the paleontological analyses of pollen that primarily show the vegetation changes in both the narrow and wider surroundings of the lakes.

Recently, paleolimnological methods have been developed that also make possible the reconstruction of events in a lake and its immediate neighborhood on the basis of the remains of plants and animals living in the lake itself (Battarbee & Kneen 1986; Birks 1998). Among these groups, those best preserved in the lake sediments are the tiny shells of the diatoms (Bacillariophyceae), and water fleas (Cladocera), which make possible an analysis of the changes. Furthermore, the method of analyzing radionuclides such as ^{210}Pb and ^{137}Cs makes it possible to determine the age of the lake sediments very preciously for a time period of 100–200 years from the present.

2. Material and methods

Over thirty years ago, a partial study of mountain lakes in Slovenia was done by Gams (1962). The data published then is still today the only written source for some of the lakes studied at that time. As regards the Lovrenška jezera (lakes) in Pohorje, the only available data is that published in his article. In 1998, *Zavod za spomeniško varstvo Maribor* (»Maribor Institute for the Protection of Monuments«), which for many years now has been preparing the professional basis for declaring the Pohorje region a landscape park, ordered an analysis study of the sediment in the fifth lake, the largest in this group of eleven moor lakes. The investigation was to determine precisely when these lakes were created and how life in them has changed relative to the intensive environmental changes of the last 150 years during the period of industrialization.

Samples were taken on November 19, 1998. A layer of ice 8 cm thick covered the lake; below it was about 1.2 m of water, and at the bottom, sediment composed primarily of dark layers of peat. We took the samples at the deepest point of the lake, which is 40 m long and 20 m wide.

Sampling was done with an adapted Kayak gravitational sampler (corer) equipped with a transparent Plexiglas pipe with a diameter of 6 cm and a length of 1 m. Four 65–70 cm long samples were taken. The pipes were hermetically sealed and prepared for transportation to the laboratory. At the same time, we also took zooplankton samples necessary for the analysis of the present community.

In the laboratory, we thinly sliced the core of the sediment transversally. We cut the upper 10 centimeters into slices 0.5 cm thick, and the rest of the sample, up to the length of 65 cm, into slices of 1 cm thickness. From each layer, we took a part intended for the determination of the age of the sediment; a part intended for the analysis of the remains of water fleas, diatoms, and SCP; and a sample intended for the determination of the sediment's composition (Lotter *et al.* 1998).

We measured the volume the sediment-composition samples and weighed them. We dried them overnight at a temperature of 105° C, and again weighed them to obtain their dry weight (DW), expressing it as a percentage of wet weight (ww). Afterwards, we ignited the samples at 520° C, and weighed the post-ignition remains. We expressed the loss of organic mass quantity as a percentage of the dry weight (loss-on-ignition – LOI).

We determined the age of the sediments based on two radioactive isotopes, ^{210}Pb and ^{137}Cs (Pennington *et al.* 1976). We froze the samples, lyophilized them, and, when they were dry, homogenized them. We weighed out portions into polyethylene ampoules. We determined the specific activity of ^{210}Pb and ^{137}Cs using high-resolution gamma-spectrometry (VLG). We measured individual samples for 28–41 hours in a pure Germanium (Ge) detector with a bore linked to a *Maestro* multichannel analyzing system. We measured the specific activity of ^{210}Pb at the energy of 46.5 keV, and of ^{137}Cs at the energy of 661.6 keV. We also determined values for ^{241}Am (59.5 keV).

For the analysis of water flea remains, we weighed the fresh samples and washed out the tinier particles of sediment through a small plastic mesh with openings of 40 μm, using the captured sediment with water flea remains for the purpose of determining species. With the aid of determining keys, we classified the remains to the species level and determined their number. This makes possible a qualitative and quantitative reconstruction of the changes in the lake (Brancelj *et al.* 1997).

For the determination of diatoms, we also used the fresh sediment, weighing it and then decomposing the inorganic and organic particles of the sediment using hydrogen peroxide so that only the tiny siliceous shells of diatoms remained in the sample. We added to the sample a known quantity of small latex pellets for quantitatively assessing the remains. We determined the species of the algae using determination keys (Krammer & Lange-Bertalot 1991).

As a supplementary method of determining the age of the sediment, we employed the method of determining the spheroidal carbon particles (SCP). These particles are created at high temperatures through the burning of fossil fuels (diesel fuel, coal, heating oil). The particles travel through the air, and the wind can carry them far from where they are released into the air. The first SCP's can be expected in the layers that coincide with the beginning of the use of fossil fuels and the Industrial Revolution after 1850, and the greatest concentrations can be expected in the layers corresponding to the 1970's. Rose (1994) improved the method of determination. We weighed out part of the sediment into polyethylene test tubes and decomposed the majority of the organic and inorganic matter using fluorine, nitrogen, and hydrochloric acid, so that mainly the carbon particles remained. Under the microscope, we counted the spheroidal particles of up to 50 µm and calculated their concentration per unit of dry sediment (the number of SCP/g DW).

3. Results

3.1. Fauna

Zooplankton was poorly represented in the lake since we sampled in winter when the lake was already frozen. We established the presence of only three species of water flea: the plankton species *Daphnia rosea* and two benthic species, *Chydorus sphaericus* and *Acantholeberis curvirostris.* All three species are typical of moor waters. This particularly applies for the species *Acantholeberis curvirostris*, which can be found only in acidified moor waters with low pH values.

3.2. Sediment

Throughout its entire depth, the sediment has a uniform dark brown color with various amounts of water. The specific gravity and dry weight increase with depth and increase greatly at the depth of 57 cm (Figure 1). At this depth, a larger quantity of siliceous sand occurs, which probably shows that we probably struck

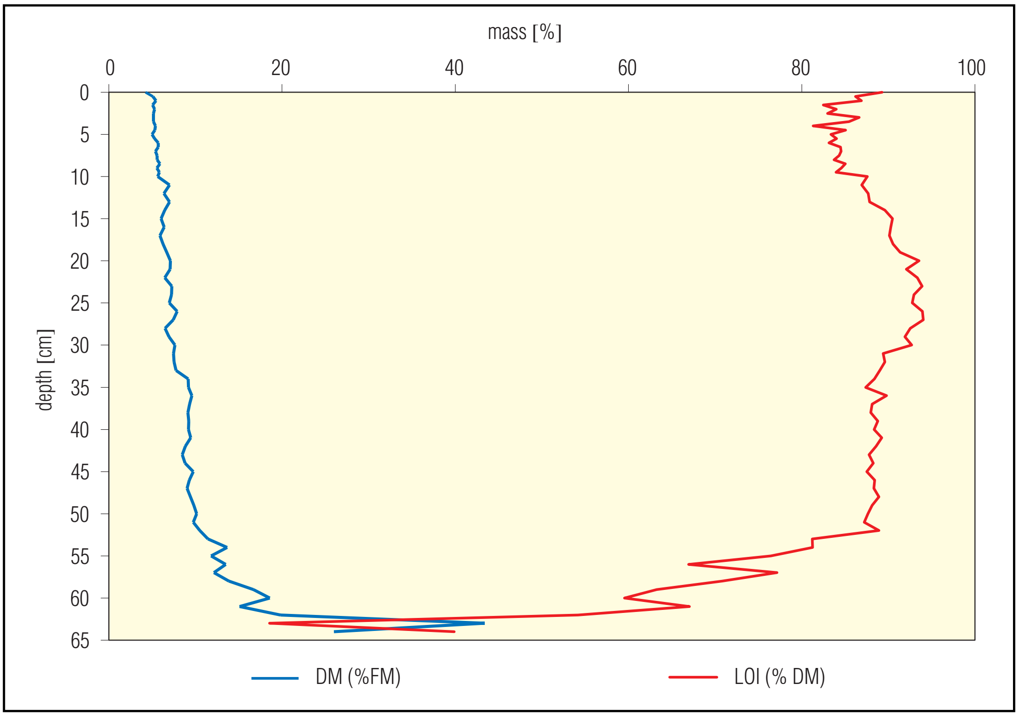

Figure 1. Content of dry matter (DM) as % of wet weight and organic matter as % of DW (loss-on-ignition = LOI) in sediment of the largest of the Lovrenška jezera (lakes).
Slika 1: Sestava sedimenta iz Lovrenškega jezerca; suha masa kot % sveže mase (FM) in organska masa kot % suhe mase (LOI).

the bedrock rot. The water content of the sediment is between 95% at the surface and about 88% at the depth of 70 cm. The case is similar with organic matter. In the upper 55 cm, there is between 80% and 95% organic matter in the dry matter, and then its proportion falls rapidly due to the siliceous sand mixed with the sediment.

3.3. Dating of the sediment

In the profile of the sediment, the specific activity of ^{210}Pb, ^{137}Cs, and ^{241}Am were measured, and based on the determined ^{210}Pb value, the age of the sediment was calculated for the upper 14 cm. The measurements showed that the highest content of ^{137}Cs is present in the upper layers, down to the depth of 4.5 cm, a consequence of the Chernobyl disaster in 1986. The increased content at the depth of 6 cm is in all probability the consequence of the atmospheric tests of nuclear weapons in the late 1950's and early 1960's. Oscillation of the ^{210}Pb content can be observed in the sediment; however, it is also clearly evident that the content of this radionuclide decreases with depth. Based on the data on the content of ^{210}Pb in individual layers of the depth profile, we determined their age and the speed of sedimentation. To do this calculation, we used three different software models (Shukla, 1996): the CRS, CIC, and ADE models. The difference between the models is that the CIC (Constant Initial Concentration) model considers the constant initial activity of ^{210}Pb, while the CRS (Constant Rate of Supply) model considers the constant rate of ^{210}Pb input. The ADE model considers the mixing and diffusion of ^{210}Pb in the sediment. In Figure 2, the age of individual sediment layers is shown, as calculated according to all three models. We believe that the CIC model gives a better estimate of the sediments' age, since the year 1959 (corresponding to the depth of 6 cm) calculated by the CIC model corresponds with the somewhat higher value for ^{137}Cs and

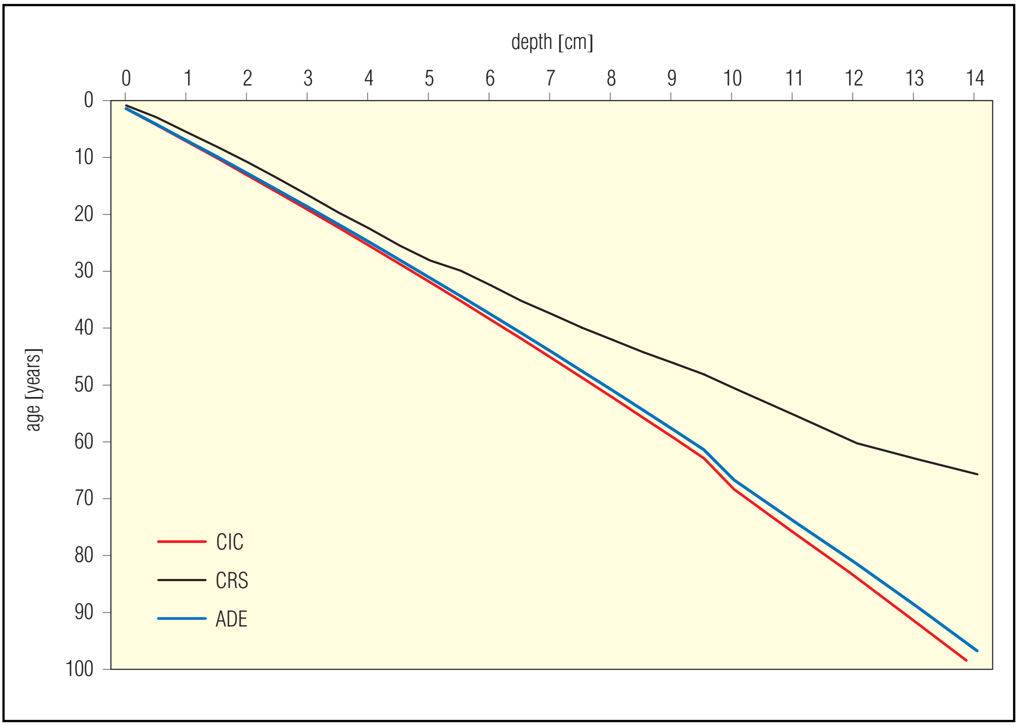

Figure 2. Age of sediment in the Lovrenška jezera (lake) to the depth of 14 cm based on concentrations of ^{210}Pb. CIC (Constant Initial Concentration) methodology get the best results.
Slika 2: Starost sedimenta v zgornjih 14 cm, izračunana na osnovi koncentracij ^{210}Pb. Metoda CIC (Constant Initial Concentration), ki upošteva konstantno začetno aktivnost 210Pb je dala najboljše rezultate.

the presence of ^{241}Am (nuclear tests of the 1960's). In addition, the sedimentation is uniform throughout the analyzed profile, amounting to 1.8 mm per year. The ADE model gives similar results. According to these calculations, the sediment at the depth of 14 cm is therefore approximately 100 years old. According to the CRS model, the sediments at the depth of 14 cm are around 30 years younger; however, according to this model, the sedimentation changes greatly across the profile, which is contrary to the physical characteristics of the sediment (proportions of dry mass and post-ignition remains).

3.4. Spheroidal carbon particles (SCP)

We established the concentration of SCP in six samples taken in the region between the surface (0–0.5 cm) and the depth of 19–20 cm. The presence of SCP indicates the level of pollution of a selected location by airborne pollutants; additionally, we used the data gathered this way in establishing the age of the sediment. The method is effective for the period of the last 150 years, when these particles began appearing with the use of fossil fuels. The analysis showed that the highest concentration of 40,000 SCP/g DW occurs at the depth of 2.5 cm, while the lowest examined layer at the depth of 20 cm had a concentration of 6,000 SCP/g DW (Figure 3). We also estimated the size of the particles and ranked them in three classes: below 5 µm, from 5 to 20 µm, and from 20 to 50 µm. Particles of the middle class dominate, but there are a great many large particles, which indicates a close source of pollution.

3.5. Diatom remains

In the sediment, we found the remains of 27 different diatom taxons (Table 1). The most frequently occurring was the species *Eunotia tenella*, which had around 300 remains/µg of dry matter in the upper layer

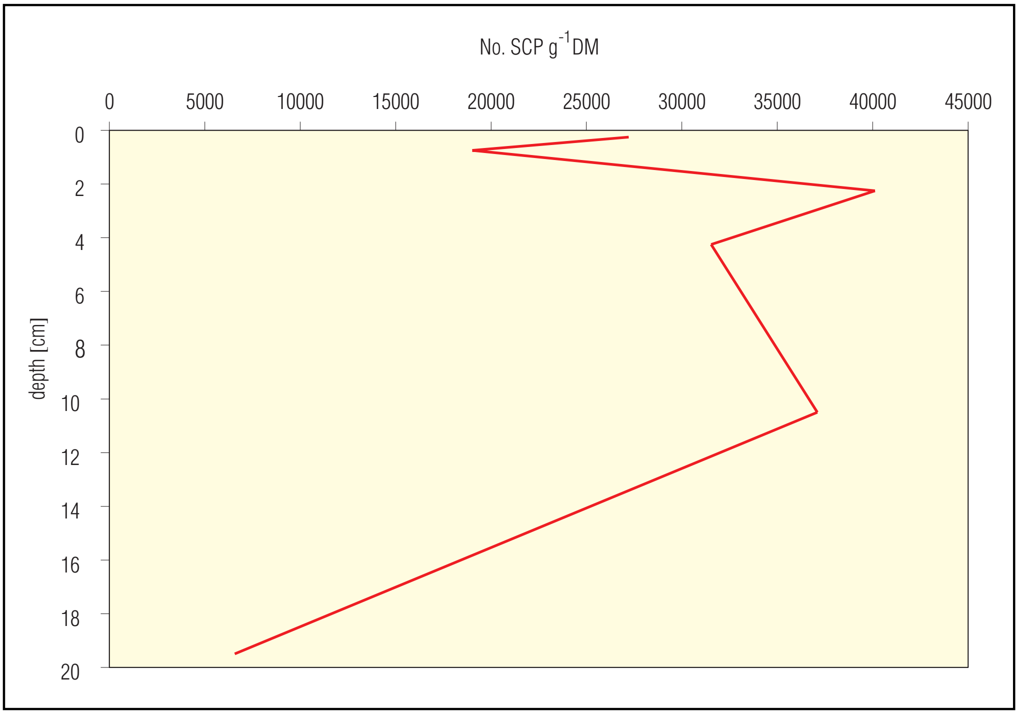

Figure 3. Spheroidal carbon particles (SCP) concentrations in sediment of the Lovrenška jezera (lake) from 0 to 20 cm (no. of SCP/g DW).
Slika 3: Koncentracija kroglastih ogljikovih delcev – SCP v vzdolžnem profilu sedimenta Lovrenškega jezerca na Pohorju (št. SCP/g DW).

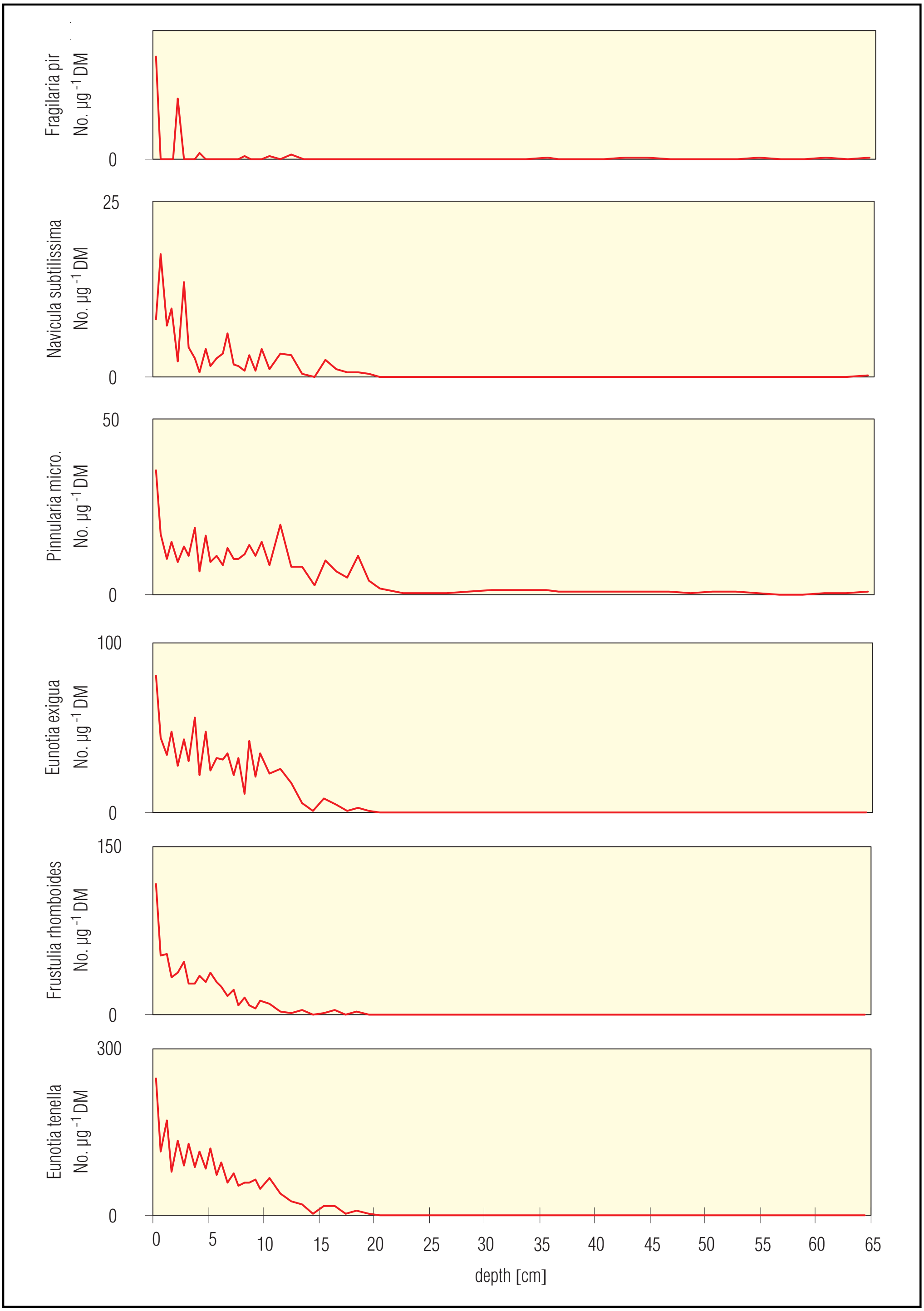

Figure 4. Distribution of the six most frequent species of diatoms in the sediment profile of the Lovrenška jezera (lake) (number of valves/µg DW).
Slika 4: Razporeditev šestih najpogostejših vrst kremenastih alg v profilu sedimenta iz Lovrenškega jezerca na Pohorju (število ostankov/µg DM).

of the sediment. The presence of other species was much smaller: only a few valves/µg of dry matter. Figure 4 shows the results of counting the remains of valves of the six most frequently appearing species of diatoms in the sediment.

TABLE 1: A LIST OF DIATOMS IN THE SEDIMENT OF THE LARGEST OF THE LOVRENŠKA JEZERA (LAKES) ON POHORJE, 1998.
PREGLEDNICA 1: SEZNAM KREMENASTIH ALG V SEDIMENTU VELIKEGA LOVRENŠKEGA JEZERCA NA POHORJU, 1998.

Achnanthes helvetica alpina	*Eunotia praerupta*
Achnanthes minutissima	*Eunotia tenella*
Amphora libyca	*Fragilaria arcus arcus*
Amphora pediculus	*Fragilaria pinata*
Aulacoseira sp	*Fragilaria sp*
Cocconeis placentula	*Frustulia romboides crassineuria*
Cyclotella ocellata	*Navicula cryptotenella*
Cyclotella steligera	*Navicula subtilissima*
Cymbella microcephala	*Nitzschia sp*
Cymbella minuta	*Nitzschia sp.*
Denticula tenuis	*Pinnularia borealis*
Diatoma vulgaris	*Pinnularia microstauron*
Diploneis elliptica	*Pinnularia viridis*
Epithemia adnata	*Stephanodiscus minutulus*
Eunotia exigua	

Typical of the entire association of diatom remains is that their number measured per unit of sediment dry matter falls very rapidly with depth (Figure 5): from about 500 remains/µg of dry matter in the upper layer to only a few remains at the depth of about 15 cm and even less in the lower layers.

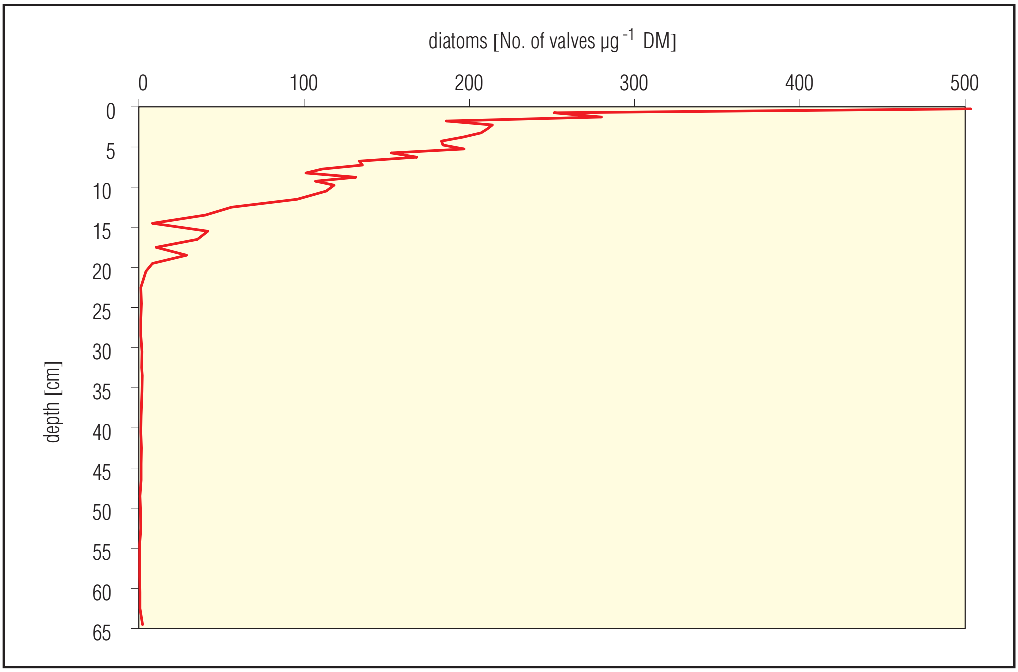

Figure 5. All remains of diatoms in the sediment profile of the Lovrenška jezera (lake) (number of valves/µg DW).
Slika 5: Skupno število ostankov kremenastih alg v profilu sedimenta iz Lovrenškega jezerca na Pohorju (število ostankov/µg DM).

Of the six most frequent diatom species, four are typical of acidic waters of high moors. Typical of the majority of species is also that they require somewhat higher contents of electrolytes, which is also a consequence of airborne pollution with nitrogen and sulphur oxides.

3.6. Water flea remains

The remains of six water flea species were established in the sediment: *Chydorus sphaericus, Alona* sp., *Acantholeberis curvirostris, Daphnia rosea, Ceriodaphnia quadrangula,* and *Bosmina* sp. The first three are benthic species living at the bottom, while the last three are plankton species living in free water. Water flea remains were present in all layers down to the depth of 65 cm; however, their numbers change (Figure 6). In the lower oldest layers, the remains are quite rare, and the total number of all is less than 10,000 remains/g DW. At the depth of about 45 cm, their number increases to about 50,000/g DW, and then their number decreases slightly up to the depth of 25 cm where there is a bigger jump (over 60,000 remains/g g DW). From this height toward the top and the recent layers, the total number of remains displays a decreasing trend in which the lowest value found was at the depth of about 14 cm.

With regard to the species present, we determined that the remains of four species were present throughout the whole profile (Figure 7). The remains of *Chydorus sphaericus* are the most frequent. Their presence shows a trend of increasing from the depth of 65 cm to 25 cm, the biggest figure being 25,000 remains/g DW. The number of remains decreases from the depth of 25 cm upwards, although the remains are also most frequent in the young layers close to the surface (about 10,000 remains/g DW). *Alona* sp. and *Daphnia rosea* show a similar curve, but their remains are 3 to 4 times less frequent than those of *Chydorus*. In the

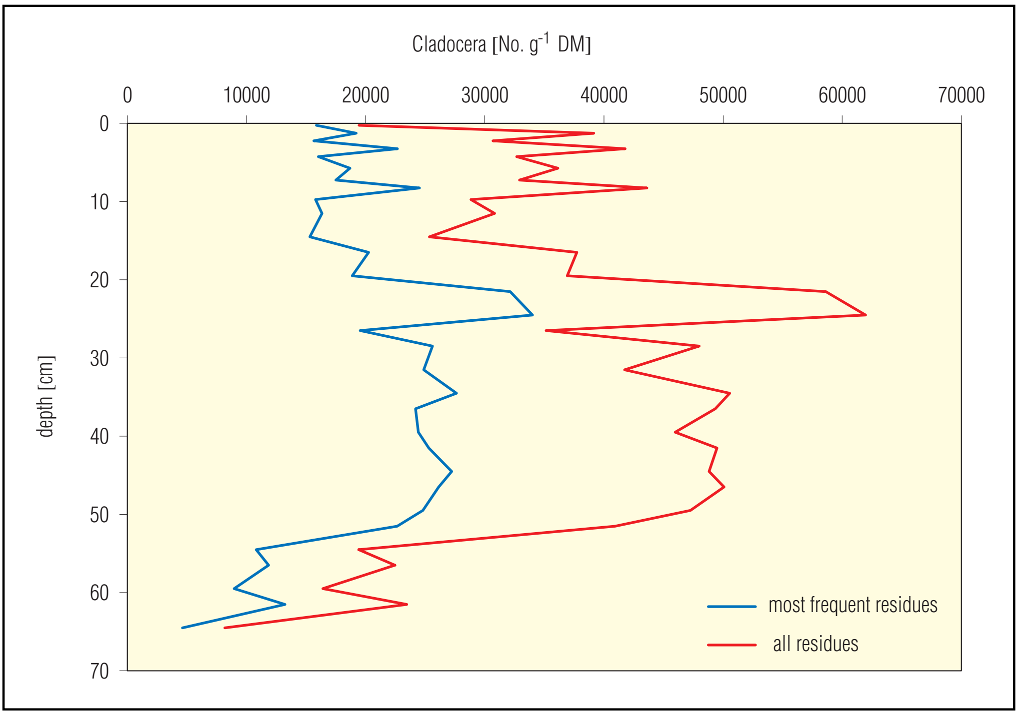

Figure 6. Distribution of all remains of Cladocera in the sediment profile of the Lovrenška jezera (lake) (right curve – all remains, left curve –most frequent remains of each species, number of remains/g DW).
Slika 6: Razporeditev ostankov vseh vrst vodnih bolh v vzdolžnem profilu sedimenta iz Lovrenškega barja na Pohorju (desna krivulja – upoštevani so vsi ostanki vodnih bolh; leva krivulja – upoštevani so le najpogostejši ostanki pri posamezni vrsti) (ostanki/g DM).

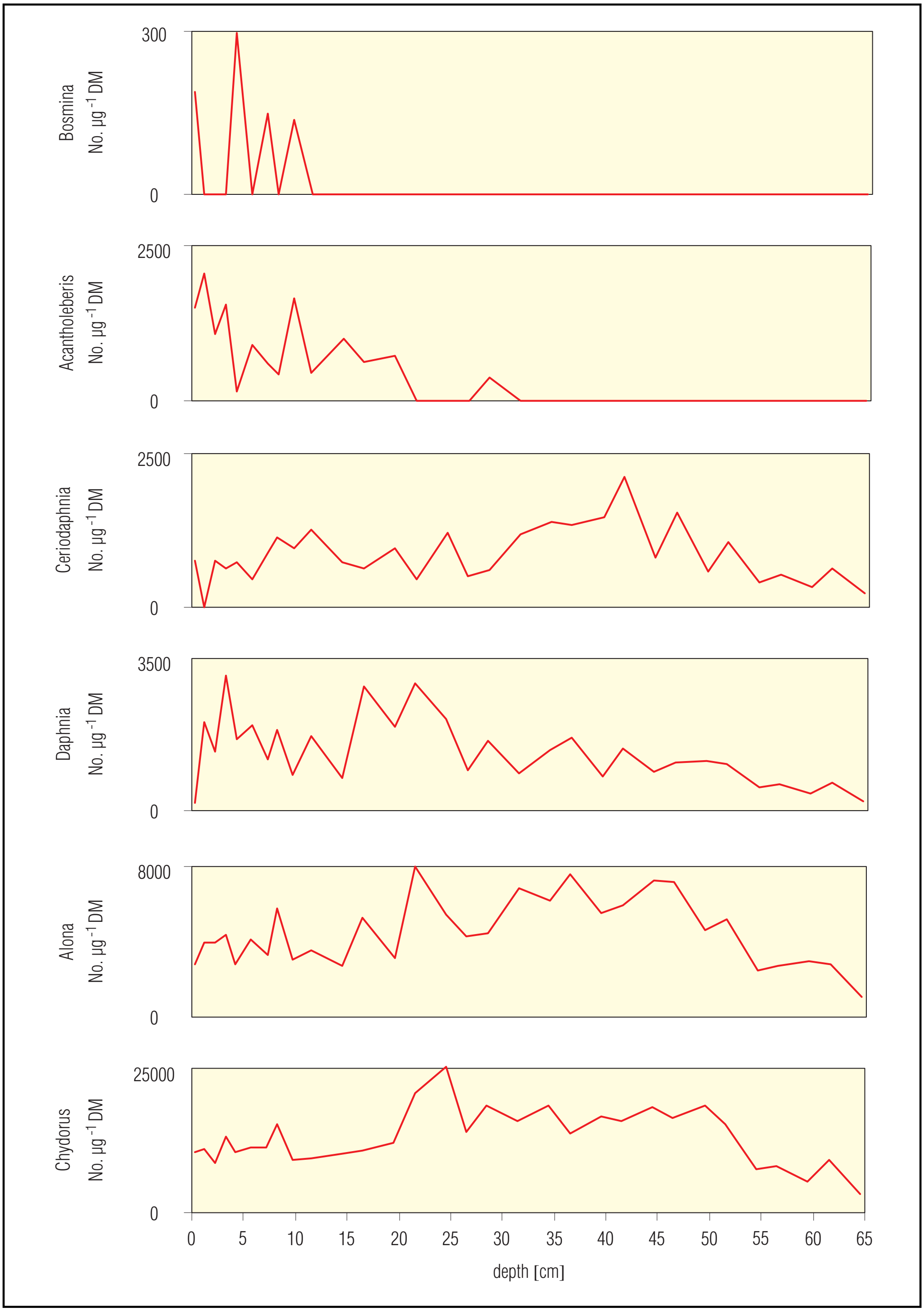

Figure 7: Remains of six species of Cladocera in the sediment profile of the Lovrenška jezera (lake) on Pohorje (number of remains/g DW).
Slika 7: Pogostost ostankov šestih vrst vodnih bolh v vzdolžnem profilu sedimenta iz Lovrenškega jezerca na Pohorju (ostanki/g DM).

Figure 8: Collecting a sample of the sediment with modified Kajak sediment sampler on frozen Lovrenška jezera (lakes, October 1998, photography Anton Brancelj).
Slika 8: Zbiranje vzorcev sedimenta s pomočjo modificiranega Kajak vzorčevalnika na zamrznjenem Lovrenškem jezeru (oktobra 1998, fotografija Anton Brancelj).

Figure 9: Modified Kajak sediment sampler with a sediment core (Lake Krnsko jezero, Slovenia; September 1998).
Slika 9: Modificiran Kajakov vzorčevalnik s sedimentnim jedrom (Krnsko jezero, septembra 1998, fotografija Anton Brancelj).

Daphnia, the number of remains between the depth of 15 cm and the surface is quite constant; the only exception is the surface layer of the sediment where the remains are very rare. *Ceriodaphnia quadrangula* also has a similar curve as the preceding three species; however, the number of its remains begins to decrease in the upward direction from the depth of 40 cm.

In contrast to the preceding species, remains of *Acantholeberis curvirostris* appear for the first time only in the upper half of the sediment core, and the number of these remains grows constantly toward the surface of the sediment. The remains of the species *Bosmina* sp. appear for the first time only at the depth of about 10 cm. The number of remains is relatively small, up to 300 per gram of dry sediment, and oscillates considerably.

4. Discussion

Because of their specific location, sediment from the Lovrenška jezera (lakes) is particularly interesting for the study of environmental changes and for paleolimnology. As the moor is situated at the top of a hill, precipitation is the only source of water supplying its small lakes, and we cannot therefore speak of a classic hinterland. Accordingly, influences from the surroundings are minimal since there is no filling by inflowing streams or surface runoff. On the other hand, these characteristics make it more difficult to interpret the data gathered for the purpose of establishing the age of the sediment and to compare the results with the outcome of other similar research (Leavitt et al. 1994; Brancelj et al. 1997). Considering that already at the depth of about 57 cm we encountered siliceous sand, we can conclude that this depth represents the beginning of the moor's creation and that the depth of around 65–70 cm probably represents the beginning of the small lake that was created when the ice began retreating after the period of glaciation; taking the altitude into account, some 6000 to 8000 years ago. From this we can conclude that 65 cm of sediment represents a time span of at least about 6000 years, and that the last 14–16 cm correspond to the last hundred years. This indicates a distinctly non-linear development of the sediment, which contradicts the finding that the physical characteristics of the sediment (the share of the dry mass and the ignition remains) indicate uniform sedimentation. Other analyses have shown that the dynamics of change were greatest in the upper 14–20 cm. In attributing time periods to the events, we can use as a basis the results of the ^{210}Pb and ^{137}Cs activity and the SCP particle analysis. The latter analysis showed that the highest concentration of 40,000 particles/g DW is in the layer of 2–2.5 cm. This number is high: in a study involving 32 lowland lakes in the Czech Republic, concentrations of 1000 to 34,000 particles were determined in the surface layers of these lakes, with a prevailing value of about 6000 SCP/g DW (Fott *et al.* 1998). As our small lake lies at an altitude of 1515 m above sea level, it is perhaps more appropriate to compare our findings with the results of research done on mountain lakes in Europe and elsewhere in Slovenia. Comparing these results, we can say that the Lovrenška jezera (lakes) rank among the moderately polluted lakes (Wik & Renberg 1991; Wathne *et al.* 1997; Urbanc-Berčič *et al.* 1997). Regardless of the type of comparison, we can say that the high SCP content in the sediment of the Lovrenška jezera (lakes) is most certainly influenced by its exposed location. Airborne pollutants that accompany the emission of carbon particles such as nitrogen oxides, sulphur oxides, carbon oxides, and other particles that for the most part cannot be determined directly, have a greater influence on the changing of processes in the lakes than the SCP. This can be deduced from the oscillations observed in water flea and diatom remains that begin at the depth of about 20 cm and coincide with the beginning of airborne pollution due to the use of fossil fuels. Diatoms are very rare in layers deeper than 20 cm, indicating conditions unfavourable for their existence (unfavourable chemical composition of water). Furthermore, many remains were also damaged, which additionally reduces their number in the samples. Starting at the depth of 15 cm and proceeding toward the surface, the number of remains in the sediment steadily increases. A small change of the dynamics occurs at the depth of about 8 cm, which corresponds, according to its lead dating, with the end World War II. It is very probable that the decreased industrial production and heating in the neighboring towns, both of which are strong sources of airborne pollutants and of nutrients, is reflected indirectly in the lakes. This is also shown by the simultaneous occurrence of the species *Bosmina sp.* in the sediment. This species is closely connected with eutrophication processes and an increased quantity of algae. However, that the species is evidently only in the colonization phase can be deduced from its low numbers and the conspicuous oscillations in the number of remains. At the same time, the relatively sharp and sudden fall in the number of remains of four species (*Chydorus*, *Alona*, *Daphnia*, and *Ceriodaphnia*) at the depth of between 15 and 20 cm, as well as the continuing trend of decreasing until the present, indicates that these changes began in the early years of this century or even in the middle of the last century.

5. Conclusion

Analyses of sediment from one of the Lovrenška jezera (lakes) shows that qualitative and quantitative changes in the composition of the lake's flora and fauna have occurred in the past. The biggest changes occurred at the depth of 20 cm, which on the time scale corresponds with the period following 1850. Since then, the quantity of the diatoms in the lake has grown, among which acidophilic types dominate. In the same period, there is a discernible decreasing trend for some generally spread species of water fleas, and at the same time, taxons appear that are typical of eutrophic environments rich in nutrients (the *Bosmina* genus) or of very specific environments such as acidic and dystrophic peat moors (the *Acantholeberis* genus). The presence of SCP at the depth of 20 cm and the growth of its concentration toward the surface also reflect the accelerated changes in the environment since the middle of the 19th century. Based on the analyses done, we can conclude that the established changes are the consequence of airborne pollution.

6. Summary

Environmental changes are becoming global and are quite seriously affecting life on earth. Environmental pollution with various substances is reflected in the soil, in the water, and in the air. The reasons for it are becoming quite clear and originate in the intensive and unevenly distributed processes spurred by man and the modern way of life. In order to change this pattern, it is urgently necessary to recognize the interdependence of these processes, as well as to evaluate them. Because eventually all changes in the immediate or more distant surroundings are registered in the water environment, waters and especially lakes are a suitable subject for research. With modern analytical methods, along with qualitative and quantitative assessments of environment pollution, we can discern also time sequence of events. Paleolimnological methods make possible the reconstruction of events in a lake and its surroundings based on the remains of several lake plants and animals found in the sediment. The best preserved are the tiny shells of diatoms (Bacillariophyceae) and water fleas (Cladocera), on the basis of which a detailed analysis of changes in the lake is possible. By measuring the activity of certain radionuclides, in particular ^{137}Cs and ^{210}Pb, and by determining the concentration of spherical carbon particles (SCP), the age of sediments can be precisely established for the last 150 years.

The subject of research was the largest of the eleven small Lovrenška jezera – moor lakes on Pohorje. By analyzing a 65 cm long sediment core, we find that the lakes have experienced the greatest changes since 1850, which is recorded at the depth of about 20 cm. The sedimentation in the lake has occurred quite unevenly. In the upper third of the sediment core we determined 27 different taxons of diatoms. Of the six more frequently found species, four are typical of acidified moor waters. Their numbers decrease with depth. We found three moor species of water fleas in the water and the remains of six species in the sediment whose presence changed quite considerably. From the changes in the composition of species, we discerned the beginnings of the eutrophication processes. Regarding the concentrations of SCP released into the air during the burning of fossil fuels, especially diesel oil and heating oil, we observed that their concentration decreases with depth and that the first particles appear at the depth of about 20 cm. This layer is therefore about 150 years old since it coincides with the beginnings of the use of fossil fuels.

Based on all the analyses, we can conclude that airborne pollution is the main source of foreign, allochthonous substances that in recent decades have had a strong influence on the changing of these small lakes, particularly since they lie at the top of a ridge where there is practically no runoff of material from the hinterland, normally the cause of the additional deterioration of lakes.

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8. Summary in Slovene – Povzetek

Analiza sedimenta iz Lovrenškega jezera na Pohorju

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1. Uvod

V zadnjih nekaj desetletjih smo priča vse bolj pospešenemu spreminjanju naravnega okolja. Vzroki za to so povsem jasni in jih lahko pripišemo predvsem človekovemu stremljenju po novih urbanih območjih, širjenju industrije, prometnim povezavam, intenzivnemu kmetovanju, vodnogospodarskim posegom in potrebam po novih turističnih območjih. Nekatere posledice tega delovanja se odražajo bolj na lokalnem območju, druge pa lahko zajamejo veliko večje, celo svetovne razsežnosti. Posledice se kažejo predvsem v dveh oblikah:

a) splošno onesnaževanje okoljskih prvin, zraka, vode in tal, ter v
b) spreminjanju globalne klime, predvsem kot posledica zračnih emisij.

Raziskovalci okolja si že dlje časa prizadevajo ugotoviti, v kolikšni meri so te spremembe že napredovale. Največje spremembe v naravi so se zgodile v zgodovini človeštva dvakrat. Prvič takrat, ko je človek prešel iz lovsko-nabiralniškega sistema na kmetijsko-živinorejski način življenja. Druga, intenzivnejša sprememba, se je zgodila z industrijsko revolucijo v sredini prejšnjega stoletja. Medtem ko so se spremembe, povzročene s prehodom na kmetijsko-živinorejski način življenja, še lahko do neke mere popravljale, saj je šlo predvsem za počasnejše, fizične spremembe v okolju (goloseki, požigalništvo, erozija), ki so bile tudi bolj ali manj lokalizirane. Veliko večje spremembe pa so se zgodile ob industrijski revoluciji po letu 1850, ko že lahko govorimo o spremembah na planetarni ravni in so povezane z uporabo fosilnih goriv, premoga in nafte. Posledice tovrstne aktivnosti se kažejo tudi v spremembah kemijskega okolja v smislu povečevanja uporabe škodljivih in strupenih snovi ter zaradi zakisovanja.

Recentne poškodbe oz. obremenitve okolja se s sodobnimi merilnimi tehnikami in opazovanji dajo dokaj dobro kvantitativno in kvalitativno ovrednotiti. Problem nastane, ko skušamo ugotoviti, kdaj in pod kakšnimi pogoji so se v preteklosti spremembe začele. V tem primeru je potrebno poiskati primerno okolje, kjer se take spremembe zapišejo in tudi ohranijo. Vodno okolje, še zlasti jezera, so eno od takih okolij. V njih potekajo procesi tvorbe sedimenta v relativno mirnih okoliščinah, kar tudi omogoča kronološko zapisovanje dogajanj v jezeru in njegovi neposredni okolici. Jezerski sedimeti zato prestavljajo časovno kapsulo ali letopise, ki se jih da z ustreznimi metodami »prebrati« in tako rekonstruirati pretekla dogajanja. Metodologija izhaja iz predpostavke, da se fizikalni, kemijski in biološki dejavniki jezerskega ekosistema spreminjajo skladno s spremembami v okolju oz. z določenim časovnim zamikom. V jezerskih sedimentih se spreminja njihova fizična sestava (razmerje med organsko in anorgansko snovjo), kemična sestava (sestava kamnin in organske snovi) in vsebnost ostankov rastlin in živali (vrstna sestava in številčnost). Med analizami bioloških parametrov so bile doslej najbolj poznane palinološke analize pelodnega prahu, ki pa so kazale predvsem na spremembe v vegetaciji v ožji in širši okolici jezer.

V zadnjem času so se razvile paleolimnološke metode, ki omogočajo rekonstrukcijo dogajanj v jezeru in njegovi neposredni okolici tudi na podlagi ostankov rastlin in živali, ki živijo v samem jezeru (Battarbee & Kneen, 1986, Birks, 1998). Med temi skupinami so v jezerskih sedimentih najbolje ohranjene lupinice kremenastih alg ali diatomej (Bacillariophyceae) in vodnih bolh (Cladocera), po katerih je mogoča analiza sprememb. Metoda radioaktivnih sledilcev kot sta ^{210}Pb in ^{137}Cs pa omogoča določitev starosti jezerskih sedimentov za časovno obdobje 100–200 let.

2. Material in metode

Delne raziskave gorskih jezer v Sloveniji je pred več kot 30 leti opravil Gams (1962). Objavljeni podatki so še danes za nekatera, tedaj raziskana jezera, edini pisni vir. Tudi za Lovrenška jezera na Pohorju so bili edini podatki objavljeni v tem članku. Tako je Zavod za spomeniško varstvo Maribor, ki več let pripravlja strokovne podlage za razglasitev območja Pohorja za krajinski park, v letu 1998 naročil študijo analize sedimenta v petem, največjem od skupine 11 barskih jezerc. Z raziskavo naj bi natančno ugotovili, kdaj so ta jezerca nastala in kako se je spreminjalo življenje v njih glede na intenzivne okoljske spremembe v zadnjih 150 letih, v obdobju industrializacije.

Odvzem vzorcev smo opravili 19. 11. 1998. Jezero je bilo pokrito z 8 cm debelim ledom, pod njim je bilo približno 1,2 m vode, na dnu pa sediment, sestavljen pretežno iz temnih plasti šote. Vzorce smo jemali na najglobljі točki jezerca, katerega dolžina je 40 m in širina 20 m.

Vzorčevali smo s prirejenim Kajakovim gravitacijskim vzorčevalnikom (korerjem), na katerem je bila 1 m dolga prozorna cev iz pleksi stekla s premerom 6 cm. Vzeli smo 4 vzorce dolžine 65–70 cm. Cevi smo neprodušno zaprli in jih pripravili za prenos v laboratorij. Istočasno smo odvzeli tudi vzorce zooplanktona za analizo prisotne združbe.

V laboratoriju smo jedro sedimenta prečno razrezali na tanjše rezine. Zgornjih 10 centimetrov smo razrezali na 0,5 cm debele rezine, preostanek vzorca do dolžine 65 cm pa na 1 cm debele rezine. Od vsake plasti smo odvzeli del za določanje starosti sedimenta, del za analizo ostankov vodnih bolh, diatomej in SCP delcev ter vzorec za določanje sestave sedimenta (Lotter *et al.*, 1998).

Vzorcem za sestavo sedimenta smo izmerili volumen ter jih stehtali. Sušili smo jih pri 105° C čez noč in nato stehtali za suho maso (DM) ter izrazili kot odstotek sveže mase (FM). Sledil je sežig vzorcev pri 520° C in tehtanje žarilnega preostanka. Količino organske mase smo izrazili kot odstotek od suhe mase (LOI).

Starost sedimentov smo določali preko dveh radioaktivnih izotopov in sicer ^{210}Pb in ^{137}Cs (Pennington *et al.*, 1976). Vzorce smo zamrznili, jih liofilizirali in suhe homogenizirali. Zatehtali smo jih v polietilenske ampule. Specifično aktivnost ^{210}Pb in ^{137}Cs smo določili z uporabo visokoločljivostne spektrometrije gama (VLG). Posamezne vzorce smo merili 28–41 ur v čistem germanijevem (Ge)-detektorju z izvrtino, ki je povezan z večkanalnim analizatorskim sistemom Maestro. Specifično aktivnost ^{210}Pb smo merili pri energiji 46,5 keV, ^{137}Cs pa pri energiji 661,6 keV. Določili smo tudi ^{241}Am (59,5 keV).

Sveže vzorce za analizo ostankov vodnih bolh smo stehtali, sprali drobnejše delce sedimenta skozi plastično mrežico s 40 μm okenci, preostanek sedimenta z ostanki vodnih bolh pa smo namenili determinaciji vrst. S pomočjo določevalnih ključev smo ostanke določali do vrst, določili pa smo tudi njihovo število. To omogoča kvalitativno in kvantitativno rekonstrukcijo sprememb v jezeru (Brancelj *et al.*, 1997).

Tudi za določitev diatomej smo uporabili sveži sediment, ki smo ga stehtali, nato pa anorganske in organske delce sedimenta razgradili s pomočjo vodikovega peroksida, tako da so ostale v vzorcu samo še silikatne lupinice diatomej. Vzorcu smo dodali še znano količino lateksovih kroglic zaradi kvantitativnega vrednotenja ostankov. Alge smo določali s pomočjo določevalnih ključev (Krammer & Lange-Bertalot, 1991).

Kot pomožno metodo za določanje starosti sedimenta smo uporabili metodo določanja kroglastih ogljikovih delcev (SCP). Ti delci nastajajo pri visoki temperaturi pri sežigu fosilnih goriv (nafta, premog, olje). Delci potujejo po zraku, veter pa jih lahko zanese daleč stran od mesta emisije. Prve SCP lahko pričakujemo v plasteh, ki sovpadajo z začetkom rabe fosilnih goriv in z industrijsko revolucijo po letu 1850, največje koncentracije pa lahko pričakujemo v plasteh iz 70-ih let 20. stoletja. Metodo določanja je dopolnil Rose (1994). Del sedimenta smo zatehtali v polietilenske epruvete in večino organske in anorganske snovi razgradili s pomočjo fluorove, dušikove in solne kisline, tako da so ostali predvsem ogljikovi delci. Kroglaste oblike velikosti do 50 μm smo pod mikroskopom prešteli in izračunali njihovo koncentracijo na enoto suhega sedimenta (število SCP/g DM).

3. Rezultati

3.1. Favna

Zooplankton je bil v jezeru slabo zastopan, saj smo vzorčevali pozimi, ko je bilo jezero že zamrznjeno. Ugotovili smo le prisotnost treh vrst vodnih bolh: planktonske vrste *Daphnia rosea* in dveh bentoških vrst *Chydorus sphaericus* in *Acantholeberis curvirostris.* Vse tri vrste so značilne za barske vode. Še zlasti velja to za vrsto *Acantholeberis curvirostris,* ki je vezana izključno na zakisane barske vode z nizkimi vrednostmi pH.

3.2. Sediment

Sediment je po celotni globini enotne, temno rjave barve z različno vsebnostjo vode. Specifična teža in suha teža se z globino večata in na globini 57 cm močno narasteta (slika 1). Na tej globini se pojavi večja količina kremenčevega peska, kar verjetno kaže, da smo zadeli na preperino matične osnove. Vsebnost vode v sedimentu je med 95 % na površini in okoli 88 % na globini 70 cm. Podobno je tudi z organsko snovjo. V zgornjih 55 cm je v suhi snovi med 80 in 95 % organske snovi, nato pa njen delež naglo upade na račun kremenčevega peska, ki je pomešan med sediment.

3.3. Datacija sedimenta

Izmerjene so bile specifične aktivnosti ^{210}Pb, ^{137}Cs in ^{241}Am v profilu sedimenta, na podlagi določitve ^{210}Pb pa je bila izračunana njegova starost v zgornjih 14 cm. Meritve so pokazale, da so najvišje vsebnosti ^{137}Cs v zgornjih plasteh do 4,5 cm, kar je posledica černobilske nesreče leta 1986. Povišane vsebnosti v globini 6 cm so po vsej verjetnosti posledica nadzemnih poskusov jedrskega orožja v zgodnjih 50. in 60. letih. V sedimentu je opazno nihanje vsebnosti ^{210}Pb, vendar pa je očiten trend padanja tega radionuklida z globino. Iz podatkov o vsebnosti ^{210}Pb v posameznih plasteh globinskega profila smo določili njihovo starost oz. hitrost sedimentacije. Za izračun smo uporabili tri različne modele računalniškega programa (Shukla, 1996): CRS, CIC in ADE model. Razlika med modeli je v tem, da CIC (Constant Initial Concentration) model upošteva konstantno začetno aktivnost ^{210}Pb, CRS (Constant Rate of Supply) model pa konstantno hitrost vnosa ^{210}Pb. ADE model upošteva tudi mešanje in difuzijo ^{210}Pb v sedimentu. Na sliki 2 je prikazana starost posamezne plasti sedimenta, izračunana po vseh treh modelih. Menimo, da daje CIC model boljšo oceno starosti sedimentov, saj leto 1959 (globina 6 cm) izračunano po CIC modelu, sovpada z nekoliko povišano vrednostjo ^{137}Cs in prisotnostjo ^{241}Am ^{137}Cs in prisotnostjo ^{241}Am (jedrski poskusi v 60-letih), poleg tega pa je sedimentacija enakomerna po vsem analiziranem profilu in znaša 1,8 mm na leto. Podobne rezultate daje tudi ADE model. Po teh izračunih je torej sediment na globini 14 cm star okoli 100 let. Po CRS modelu pa so sedimenti v globini 14 cm približno 30 let mlajši, vendar se po tem modelu sedimentacija po profilu zelo spreminja, kar je v nasprotju s fizikalnimi lastnostmi sedimenta (delež suhe mase in žarilni ostanek).

3.4. Kroglasti ogljikovi delci SCP

V šestih vzorcih od površine (0–0,5 cm) do globine 19–20 cm smo določili koncentracijo SCP. Prisotnost SCP kaže na stopnjo onesnaženosti izbrane lokacije z zračnimi polutanti, obenem pa smo z dobljenimi podatki dodatno ugotavljali starost sedimenta. Metoda je učinkovita za obdobje zadnjih 150 let, saj so se ti delci začeli pojavljati z uporabo fosilnih goriv. Analiza je pokazala, da je največja koncentracije 40.000 SCP/g DM v globini 2,5 cm, najnižja še preiskana plast v globini 20 cm pa je imela koncentracijo 6000 SCP/g DM (slika 3). Ovrednotili smo tudi velikost delcev in jih razporedili v tri razrede, do 5 µm, od 5 do 20 µm in od 20 do 50 µm. Prevladujejo delci srednjega razreda, precej pa je tudi velikih delcev, kar kaže na bližnji vir onesnaževanja.

3.5. Ostanki kremenastih alg

V sedimentu smo določili ostanke 27 različnih taksonov kremenastih alg (preglednica 1). Najpogostejša je bila vrsta *Eunotia tenella*, ki je imela v vrhnji plasti sedimenta okoli 300 ostankov/µg suhe snovi. Pogostost ostalih vrst je bila mnogo manjša, le nekaj valv/µg suhe snovi. Na sliki 4 so prikazani rezultati štetja ostankov valv šestih najpogostejših vrst kremenastih alg v sedimentu.

Za celotno združbo ostankov kremenastih alg je značilno, da njihovo število na enoto suhe mase sedimenta z globino zelo hitro upada (slika 5) – z okoli 500 ostankov/µg suhe mase v vrhnji plasti na komaj nekaj ostankov na globini okoli 15 cm; nižje plasti pa so še siromašnejše.

Od šestih najpogostejših vrst kremenastih alg so štiri značilne za zakisane vode visokih barij. Za večino vrst je tudi značilno, da potrebujejo nekoliko višje vsebnosti elektrolitov, kar je tudi posledica onesnaževanjem preko zraka z dušikovimi in žveplovimi oksidi.

3.6. Ostanki vodnih bolh

V sedimentu so bili ugotovljeni ostanki šestih vrst vodnih bolh: *Chydorus sphaericus*, *Alona* sp., *Acantholeberis curvirostris, Daphnia rosea*, *Ceriodaphnia quadrangula* in *Bosmina* sp. Prve tri so bentoške vrste, ki žive ob dnu, medtem ko so zadnje tri v prosti vodi živeče planktonske vrste. Ostanki vodnih bolh so bili prisotni v vseh plasteh do globine 65 cm, vendar se je njihova številčnost spreminjala (slika 6). V spodnji, najstarejši plasti, so ostanki dokaj redki. Vsota vseh najdenih ostankov je pod 10.000 ostankov/g suhe snovi. Na globini okoli 45 cm se njihovo število poveča na okoli 50.000/g suhe snovi, nakar število rahlo upada do globine okoli 25 cm, kjer pride do večjega skoka (prek 60.000 ostankov/g suhe snovi). Od te globine pa proti vrhu do recentnih plasti kaže število skupnih ostankov trend upadanja, pri čemer je najnižja ugotovljena vrenost na globini okoli 14 cm.

Glede na vrstno prisotnost smo ugotovili, da so ostanki štirih vrst prisotni vzdolž celotnega profila (slika 7). *Chydorus sphaericus* je vrsta, katerega ostanki so najpogostejši. Kaže trend naraščanja od globine 65 do 25 cm z največ 25.000 ostanki/g suhega sedimenta. Število ostankov upada od 25 cm navzgor, čeprav so ostanki tudi v mladih plasteh proti površini najbolj pogosti (okoli 10.000 ostankov/g suhega sedimenta). Podobno krivuljo imata tudi vrsti *Alona* sp. in *Daphnia rosea*, le da so njuni ostanki v primerjavi s *Chydorus*om za 3 do 4-krat manj pogosti. Pri rodu *Daphnia* je število ostankov od globine 15 cm do površine dokaj stalno, izjema je le površinska plast sedimenta, kjer so ostanki zelo redki. Tudi *Ceriodaphnia quadrangula* ima podobno krivuljo kot prejšnje tri vrste, vendar se začne število njenih ostankov zmanjševati že od globine 40 cm navzgor.

V nasprotju s prejšnjimi vrstami, se ostanki vrste *Acantholeberis curvirostris* prvič pojavijo šele v zgornji polovici sedimenta in število teh ostankov konstantno narašča proti površini sedimenta. Ostanki vrste *Bosmina sp.* se prvič pojavijo šele na globini okoli 10 cm. Število ostankov je razmeroma nizko, do 300 na gram suhega sedimenta in močno niha.

4. Diskusija

Zaradi svoje specifične lege je sediment iz Lovrenških jezerc še posebej zanimiv za študij okoljskih sprememb in paleolimnologije. Ker leži barje na vrhu hriba, so padavine edini vir vode, ki napaja jezerca, zato o klasičnem zaledju ne moremo govoriti. Skladno s tem dejstvom so vplivi iz okolja minimalni, saj ni nikakršnega zasipavanja iz pritokov ali površinskega spiranja. Po drugi strani pa je zaradi teh značilnosti težko interpretirati podatke, zbrane za določanje starosti sedimenta in rezultate primerjati z izsledki drugih, podobnih raziskav (Leavitt *et al.*, 1994, Brancelj *et al.*, 1997). Glede na to, da smo na globini okoli 57 cm že naleteli na kremenčev pesek, lahko sklepamo, da predstavlja ta globina začetek najstajanja barja, in da je globina okoli 65–70 cm verjetno začetek jezerca, ki je nastalo, ko se je led po poledenitvi začel umikati; glede na nadmorsko višino lahko sklepamo, da je bilo to pred 6000–8000 leti. Iz tega lahko zaključimo, da predstavlja 65 cm sedimenta časovni razpon najmanj okoli 6000 let, od tega odpade zgornjih 14–16 cm na zadnjih sto let. To kaže na izrazito nelinearno nastajanje sedimenta, kar pa je v nasprotju z ugotovitvijo, da fizikalne lastnosti sedimenta (delež suhe mase in žarilnega ostanka) kažejo na enakomerno sedimentacijo. Ostale analize so pokazale, da je bila največja dinamika sprememb v zgornjih 14–20 cm. Pri časovnem umeščanju dogodkov se lahko opremo na rezultate aktivnosti ^{210}Pb in ^{137}Cs ter na analizo SCP delcev. Ta zadnja analiza je pokazala, da je največja koncentracija 40.000 delcev/g suhe mase v plasti od 2–2,5 cm. Številka je visoka, saj so v študiji, ki je zajela 32 nižinskih jezer na Češkem, določili v površinskih plasteh teh jezer koncentracije od 1000 do 34.000 delcev, s prevlado vrednosti okrog 6000 SCP/g suhe mase (Fott *et al.*, 1998). Ker leži jezerce na višini 1515 m n. v., je morda boljša primerjava z izsledki raziskav v gorskih jezerih v Evropi in doma. S primerjavo teh rezultatov lahko rečemo, da so Lovrenška jezerca med zmerno onesnaženimi (Wik & Renberg, 1991, Wathne *et al.*, 1997, Urbanc-Berčič *et al.*, 1997). Ne glede na vrsto primerjave pa lahko rečemo, da na visoko vsebnost SCP v sedimentu Lovrenškega jezerca prav gotovo vpliva njegova izpostavljena lega. Zračni polutanti, ki spremljajo emisijo ogljikovih delcev, kot so oksidi dušika, žvepla in ogljika ter drugi delci, ki jih večinoma neposredno ne moremo določiti, imajo v primerjavi z SCP večji vpliv na spreminjanje procesov v jezerih. To je mogoče razbrati iz opaznih nihanj ostankov vodnih bolh in diatomej, ki se začnejo od globine približno 20 cm navzgor, kar sovpada z začetki zračne polucije zaradi uporabe fosilnih goriv. Kremenaste alge so v plasteh, globjih od 20 cm, zelo redke, kar kaže na neugodne razmere za njihov obstoj (neugodna kemijska sestava vode). Poleg tega je veliko ostankov tudi poškodovanih, kar še dodatno zmanjšuje njihovo število v vzorcih. Od globine 15 cm proti površju število njihovih ostankov v sedimentu ves čas narašča. Manjša sprememba dinamike je na globini okoli 8 cm, kar po dataciji s svincem odgovarja koncu druge svetovne vojne. Zelo verjetno je, da se zmanjšana industrijska proizvodnja in kurjenje v okoliških mestih, kar je oboje močan vir zračne polucije in tudi hranil, odraža indirektno tudi na jezerih. To nakazuje tudi sočasno pojavljanje vrste *Bosmina sp.* v sedimentu. Ta vrsta je močno vezana na evtrofizacijske procese in povečano količino alg. Vendar je vrsta očitno šele v fazi kolonizacije, kar kaže njeno nizko število in opazna nihanja števila ostankov. Obenem pa razmeroma močan in nenaden padec števila ostankov treh ali celo štirih vrst vodnih bolh (*Chydorus, Alona* in *Daphnia* ter *Ceriodaphnia*) na globini med 15 in 20 cm, kot tudi nadaljnji trend upadanja vse do danes kaže, da segajo začetki teh sprememb v zgodnja leta tega stoletja oz. celo v sredino preteklega stoletja.

5. Sklep

Analize sedimenta iz Lovrenškega barja kažejo, da je v preteklosti prišlo v jezeru do kvalitativnih in kvantitativnih sprememb v sestavi jezerske flore in favne. Največje spremembe so se zgodile na globini okoli 20 cm, kar na časovni skali odgovarja obdobju po letu 1850. Od tedaj je v jezercu naraščala količina kremenastih alg, med katerimi prevladujejo kisloljubne vrste. Pri vodnih bolhah je v istem obdobju opazen trend upadanja nekaterih splošno razširjenih vrst, obenem pa se pojavijo taksoni, ki so značilni za evtrofizirana, s hranili bogata okolja (rod *Bosmina*) ali za zelo specifična okolja, kot so kisla in distrofna šotna barja (rod *Acantholeberis*). Pojavljanje SCP na globini 20 cm in porast koncentracije proti površini prav tako kaže na pospešene spremembe v okolju od srede 19. stoletja. Na podlagi opravljenih analiz lahko sklepamo, da so ugotovljene spremembe posledica onesnaževanja iz zraka.

6. Kratek povzetek

Spremembe v okolju postajajo globalne in povsem resno omejuje življenje na Zemlji. Obremenjevanje okolja z različnimi snovmi se odraža tako v tleh kot tudi v vodi in zraku. Vzroki postajajo povsem jasni in izhajajo iz intenzivnih in neenakomerno razporejenih procesov, katerih gonilo je človek in sodoben način življenja. Za spremembo tega vzorca je nujno prepoznavanje soodvisnosti procesov in njihovo ovrednotenje. Ker se v vodnem okolju prej ali slej zapišejo vse spremembe iz bližnje in daljne okolice, so vode, predvsem jezera, primeren objekt raziskav. S sodobnimi analitskimi metodami lahko poleg kvalitativnega in kvalitativnega obremenjevanja okolja razberemo tudi časovno zaporedje dogodkov. Paleolimnološke metode omogočajo rekonstrukcijo dogajanj v jezeru in njegovi okolici na podlagi ostankov nekaterih jezerskih rastlin in živali v sedimentu. Najbolje se ohranijo lupinice kremenastih alg (Bacillariophyceae) in vodnih bolh (Cladocera), po katerih je mogoča natančna analiza sprememb v jezeru. Z merjenjem aktivnosti nekaterih radionuklidov, predvsem ^{137}Cs in ^{210}Pb ter z določanjem koncentracije kroglastih ogljikovih delcev SCP pa se ugotavlja starost sedimentov, še posebno natančno za obdobje zadnjih 150 let.

Cilj raziskave je bilo največje od 11 Lovrenških barskih jezerc na Pohorju. Z analizo 65 cm dolgega jedra sedimenta smo ugotovili, da so jezerca nastajala pred 6000–8000 leti ter da so se največje spremembe dogajale od leta 1850 dalje, kar je zapisano na globini okoli 20 cm. Sedimentacija je v jezercu potekala precej neenakomerno. Tako smo v zgornji tretjini določili 27 različnih taksonov kremenastih alg. Od šestih pogostejših vrst so štiri značilne za zakisane barske vode. Njihovo število z globino upada. Med vodnimi bolhami smo v vodi našli tri barjanske vrste, v sedimentu pa ostanke šestih vrst, katerih zastopanost se je precej spreminjala. Iz teh sprememb v vrstni sestavi smo razbrali začetke evtrofizacijskih procesov. Tudi iz koncentracije SCP, ki se v zrak sproščajo ob sežigu fosilnih goriv, predvsem olja in nafte, smo razbrali, da koncentracija pada z globino ter da so se prvi delci pojavili v plasti na globini okoli 20 cm. Ta plast je torej stara 150 let, saj sovpada z začetki uporabe fosilnih goriv. Datacija se nekoliko razlikuje od rezultatov analize radionukleidov, ki je bila narejena samo do globine 14 cm.

Iz vseh analiz lahko sklepamo, da je zračna polucija glavni vir tujih, alohtonih snovi, ki so imele v zadnjih desetletjih močan vpliv na spreminjanje jezerc, saj le-ta ležе na vrhu grebena in zato spiranja snovi iz zaledja, kar je običajni vzrok za slabšanje jezer, praktično ni.