# VISOKOGORSKA JEZERA V VZHODNEM DELU JULIJSKIH ALP

# HIGH-MOUNTAIN LAKES IN THE EASTERN PART OF THE JULIAN ALPS

**Uredil / Edited by ANTON BRANCELJ**

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# *Visokogorska jezera v vzhodnem delu Julijskih Alp*

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# PREDGOVOR FOREWORD

Julijske Alpe so del največjega evropskega gorstva, Alp. Ime je latinskega izvora po rimskem naselju Forum Julii, današnjem Čedadu (Cividale, Italija). Raztezajo se od doline Soče med Tolminom in Kobaridom z dolgim hrbtom Stolovega pogorja med Kobaridom in Guminom (Gemona, Italija) do Kanalske doline (Val Canale, Italija) na severu oziroma vzhodu do Zgornje Savske doline. Po obliki so nekako ovalno zaokroženo gorovje z zračno razdaljo med Klužami (Chiusaforte, Italija) ob reki Beli (Fella) na zahodu in Kranjem oziroma Ljubljansko kotlino na vzhodu približno 80 km. V smeri sever–jug, med Kranjsko Goro in Tolminom, pa je zračna razdalja približno pol manjša (40 km). Julijske Alpe so tudi obmejno gorovje med Italijo in Slovenijo. V osnovi jih delimo na Vzhodne in Zahodne Julijske Alpe. Vanje se najbolj globoko zajeda slikovita dolina Soče. Zahodne Julijske Alpe v Italiji so po površini manjše in segajo do Predela (Paso di Predil, 1156 m). Večji vzhodni del, približno tri četrtine Julijskih Alp, predstavljajo tako imenovane Vzhodne Julijske Alpe (1542 km$^2$), včasih jih imenujejo tudi Osrednje Julijske Alpe. V Sloveniji je to največja in najvišja alpska visokogorska skupina. Najvišji vrh Triglav (2864 m) se vidi iz večjega dela Slovenije, zato ni naključje, da je ta gora postala nacionalni simbol Slovenije in Slovencev. Ime gore je sestavljenka, ki govori o treh glavah, torej skupku treh vršacev, ki skupaj sestavljajo goro.

Slovenija je večinoma gorata ali hribovita dežela, ker ima le slaba šestina njenega ozemlja povprečni naklon od 0 do 2$^o$. Visokogorje Julijskih Alp v Sloveniji obsega približno 3000 km$^2$, ima povprečni naklon 24,6$^o$ in predstavlja dobrih 15 % površine Republike Slovenije. Alpski svet, ki ga sicer delimo v visokogorje, hribovje (23 %) in alpske ravnine (4 %), v celoti obsega dobrih 42 % ozemlja Slovenije. Še vedno precej razgiban dinarski svet s povprečnim naklonom 11,4$^o$ obsega 28,1 %, panonski svet 21,2 % in sredozemski svet 8,6 % površja Slovenije. Slovenija je dežela na stičišču teh štirih velikih evropskih naravnogeografskih območij. Alpski svet obsega manj kot polovico njenega ozem-

The Julian Alps which are part of the largest European mountain range, the Alps, got their name of Latin origin after the settlement of Forum Julii, a Roman predecessor of the present Cividale. They extend from the valley of the Soča between Tolmin and Kobarid, with a long ridge of Mt. Stol range between Kobarid and Gemona to Val Canale (Italy) in the north and the Zgornje-Savska Dolina (the Upper Sava valley) in the east. They form a slightly oval–rounded mounatin range, with a longitudinal distance of about 80 kilometers between the westernmost point at Chiusaforte by the river Fella and the easternmost point at Kranj in the Ljubljanska kotlina basin. The distance in the nort–south direction, between Kranjska Gora and Tolmin, is about a half shorter (40 km). The Julian Alps are also a border area across which runs the borderline between Italy and Slovenia. Generally, they are divided into the Eastern and the Western Julian Alps. They are most deeply indented by the picturesque valley of the Soča river. The Western Julian Alps in Italy are smaller in size and they stretch to the Passo di Predil (1156 m). The larger, eastern part, embracing three quarters of the Julian Alps, is named Vzhodne Julijske Alpe (the Eastern Julian Alps) and covers 1542 sq km; it is sometimes also called Osrednje Julijske Alpe (the Central Julian Alps). They are the largest and the highest alpine high-mountain group in Slovenia, with the highest peak of Mt. Triglav (2864 m) which can be seen from a major part of Slovenia. So, it was not by mere chance that Mt. Triglav became a national symbol of Slovenia and the Slovenians. Its name is a combination of the words three (Tri–) and heads (–glav), denoting a body of three summits which together form the mountain.

Slovenia is mainly mountainous and undulated, so that only a mean sixth of its surface has an average inclination from 0 to 2 degrees. The high mountains of the Slovenian part of the Julian Alps, with the average inclination of 24.6 degrees, cover about 3000 sq km and account for a gross 15 % of Slovenia's surface. Together with its other two components, undulated areas (23 %) and Alpine plains (4 %), the Alpine world covers gross 42 % of the territory of Slovenia, and the rest is occupied as follows: the rather agitated Dinaric world of an average inclination of 11.4 degrees covers 28.1 %, the lja, vendar se Slovenci zaradi razgibanosti površja dežele, v kateri živijo, radi štejejo med hribovce in seveda tudi velike ljubitelje gorskega sveta. Tako ni naključje, da je bilo v času njenega osamosvajanja zelo priljubljeno geslo, da je Slovenija »Dežela na sončni strani Alp«.

Nekakšno, lahko bi rekli, prav organsko povezanost Slovencev z gorami lahko primerjamo s podobno navezanostjo prebivalcev obmorskih krajev na morje. Stoletja je bilo visokogorje prostor, ki sicer ni bil stalno poseljen, bil pa je stalno obiskovan in razmeroma zelo obljuden. Spomladi so na planine gnali živino na pašo in jeseni so se z njo vračali v domačo vas. Še pred pol stoletja skorajda ni bilo manjše uravnave v gorskem svetu, na kateri ne bi bila organizirana planina, danes so mnoge opuščene. Na veliko planinah pa še pasejo. Ponekod je zanimanje za pašo v gorah še vedno tako veliko, da primanjkuje prostora za živino. Zaradi svojih posebnosti je bil to vedno nekako poseben prostor, stran, na obrobju vsakdanjih okvirov vaškega življenja, nekako odmaknjen od oblasti, ki je bila stoletja tuja, neslovenska. Tu so se pastirji morali zanašati nase, vladali so in marsikje so še vedno v veljavi številni nenapisani zakoni, pravila obnašanja in delovanja. Tu je bilo nekako več svobode, vsekakor pa manj vsakodnevne utesnjenosti. Morda prav zato ni naključjej, da o tem življenju, številnih mitih in legendah pripoveduje tudi prvi slovenski mladinski igrani film Kekec (Josip Vandot, režija Jože Gale), ki je celo dobil nagrado za najboljši otroški igrani film na festivalu v Benetkah (1951).

Poleg tega se na severovzhodnem robu Julijskih Alp, v Kanalski dolini, stikajo tri velike jezikovne skupine evropskih narodov Germani (Avstrijci), Romani (Furlani, Italijani) in Slovani (Slovenci). Le malo kje po svetu, še manj pa v osrednjem delu Evrope se na tako majhnem ozemlju stika tako veliko in tako različnih naravnogeografskih in kulturnozgodovinskih posebnosti. Ta knjiga na nek posreden način govori tudi o tem. Njen namen je prispevati k poznavanju, razumevanju krajev, ki jim lahko rečemo, da so v »popku« Evrope, torej so del naše skupne preteklosti in prihodnosti.

Globoke doline in stene ter ostri vrhovi so večinoma zgrajeni iz različnih apnencev in dolomitov, ki sestavljajo tipični alpski svet. Ostanki visokogorske terciarne uravnave so redki (Kaninski, Kriški, Krnski, Triglavski podi, Komna), več jih je v bolj gozdnatih Vzhodnih Julijskih Alpah (Pokljuka, Mežaklja, Jelovica). Površje je močno ledeniško preoblikovano. Prevladuje kras z brezni in jamami, z značilnostmi kraške hidrografije. Voda, ki ponika v

Pannonian world 21.2 %, and the Mediterranean world 8.6 %. Slovenia lies at the contact of these four large European natural-geographical units, of which the Alpine world accounts for less than a half of its territory; nevertheless, due to the agitated landforms of their country, the Slovenes like to call themselves mountaineers, and they are, of course great mountain lovers. It was also the main motif that gave rise to a very popular slogan, used during the period of gaining independence, which says that Slovenia is "the Country on the Sunny Side of the Alps".

Such strong, nearly organic attachment of the Slovenes to the mountains can be compared to the attachment of the people from the coast to the sea. For centuries, the high mountains were an area which, though not permanently inhabited, was regularly visited and rather populated. In spring, herders used to drive livestock up to alps for pasturing, and return to their home villages in autumn. No more than half a century ago almost no level plot in the mountains could be found without an organized alp; nowadays, a lot of them have been abandoned, but quite a number of them are still in use and in certain areas interest for pasturing in the mountains is so great that there is not enough room for all livestock. Because of their specific features, alps have always been a world for itself, away from the everyday rural life, and at the margin of its routines, somehow remote from the authorities that were for centuries foreign, non–Slovenian. Herders had to rely on themselves only in these alps, where numerous unwritten laws and codes of behaviour and practice were in force, and in many a place they still are. Greater freedom was felt on the alps and certainly less everyday frustrations were experienced. It may also be the reason why the first Slovene movie for the young, *Kekec* (filmed after a book by Josip Vandot and directed by Jože Gale), depicts this kind of life, including numerous myths and legends; it even won first prize in the category of children's movies at the Venice Festival in 1951.

At the northeast edge of the Julian Alps, in Val Canale, people of three great European language groups meet, the Germanic (the Austrians), the Romance (the Friulians and Italians) and the Slavic (the Slovenes). There are but few places in the world, and even fewer in the central part of Europe, where so many natural-geographical and cultural-historical diversities would meet in such a small area. Indirectly, the present book therefore speaks about these features, too. Its purpose is to contribute to the knowledge about and comprehension of the places which lie, so to say, in the "navel" of Europe and, thus, they are part of our shared past and future.

Deep valleys, slopes and faces and pointed summits are mainly made of various limestones and dolomites as the main bedrocks of a typical Alpine landscape. Remains

Triglav (2864 m) in Triglavska severna stena s Kriških podov (Foto: Anton Brancelj)
*Mt. Triglav (altitude 2864 m) and the Triglav north face from Kriški podi (Photo: Anton Brancelj)*

prevotljeno karbonatno notranjost, prihaja na dan večinoma na obrobju v močnih kraških izvirih, ponekod spremljanih z lepimi slapovi. Na mnogih planinah je problem oskrbe živine z vodo in morali so napraviti umetne zbiralnike, kale. V visokogorju Julijskih Alp so površinski vodni tokovi razmeroma redki, ker se ti pojavijo le na območjih manjših vložkov neprepustnih kamnin. Če bi imele kotanje, ki so jih ustvarili ledeniki, več neprepustne podlage, bi bilo tudi več visokogorskih jezer. Nekaj pa jih je, in to so slikovita »vodna očesa«. Jezera so razmeroma majhna, prav zato pa so nekakšni »biseri« Julijskih Alp. V Dolini Triglavskih jezer si sledi sedem jezer drugo za drugim, kot da bi bila nanizana na ogrlici.

Ta knjiga je posvečena odkrivanju in vsestranskemu opisovanju teh »biserov«. Je prva svoje vrste. Njen cilj je, da poskuša celovito osvetliti visokogorska jezera z različnih zornih kotov. Pota v svetu znanosti nas vedno znova utrjujejo v spoznanju, da imajo resnična in poglobljena raziskovanja veliko obrazov. Prav to poskuša osvetliti ta knjiga in v tem je njena največja vrednost.

doc. dr. Milan Orožen Adamič

Ljubljana, 2. maj 2002

of the high-mountain Tertiary planation process are rare (the plateaus of Kaninski–, Kriški–, Krnski– and Triglavski podi, Komna), but they occur more often in the woody Eastern Julian Alps (Pokljuka, Mežakla, Jelovica). The surface was intensely transformed by glaciers. Karstic surface prevails, with pits and abysses and caves, and with all the characteristics of karst hydrography. Water sinks to the perforated carbonate underground and mainly comes out at margins in abundant karst springs, in some places even as beautiful waterfalls. There is a problem of water supply to the livestock on many alps, so artifical water collectors, *kali*, had to be made. Surface streams are rather rare in the high mountains of the Julian Alps because they only run on the surface where minor inlays of impermeable rocks occur. If the glacier–made basins had larger bases of impermeable rocks, high-mountain lakes would be more numerous, but the existing ones are gorgeously picturesque "water eyelets". They are rather small in size; however, because of their remarkable beauty they are true "pearls" of the Julian Alps. In the valley of Dolina Triglavskih jezer, seven lakes follow one another as if gathered on a necklace string.

The present book, intended to present and describe these "pearls" omnisidedly, is the first of its kind. Its aim is to cast light from different angles on the whole complexity of high-mountain lakes. The scientific world with its different ways of research proves again and again that proper and thorough investigations have many different faces. It is exactly what this book is trying to highlight and that is its greatest value.

Doc. Milan Orožen Adamič, Ph.D.

Ljubljana, May 2, 2002

Jeseni leta 1945 sva se s prijateljem Jožetom po štiriletni okupaciji prvič podala v visokogorje Julijskih Alp. Pot naju je vodila v triglavsko pogorje. Bilo je lepo septembrsko popoldne, ko sva se vzpenjala prek melišč na Hribarice na poti proti Triglavskim sedmerim jezerom. Srečanje z jezerci, položenimi med venec vršacev, je bilo za naju čudovito planinsko, stik z njimi pa biološko doživetje. Spomin mi uhaja na množico drobnih rdečih rakcev samookcev, ki so "švigali" sem in tja po vodi. Za njihovo ime nisem vedel, pa bi jih rad poznal. Le malokdo se je tedaj zanimal za te "nepomembne" jezerske prebivalce.

Prva obsežnejša botanična raziskovanja Doline Triglavskih jezer je začel in vodil prof. dr. Fran Jesenko (1875–1932) leta 1924. S skupino študentov biologije je, nekaj let zapored, tod botaniziral. Šele po 2. svetovni vojni je bolj sistematična raziskovanja žive narave te zanimive doline pognala v tek botaničarka in znana naravovarstvenica prof. dr. Angela Piskernik (1886–1967) v okviru Zavoda za zaščito in znanstveno proučevanje kulturnih spomenikov in prirodnih znamenitosti Slovenije. Redki članki o živi naravi te doline in jezer so izhajali v različnih poljudnoznanstvenih in strokovnih revijah. Prava podoba celote ni bila zbrana še nikjer.

Potem pa se je skupina biologov, raziskovalcev pri Nacionalnem inštitutu za biologijo, pod vodstvom dr. Antona Branclja lotila raziskav vseh visokogorskih jezer v Julijskih Alpah. Povezali so se še z Biološkim inštitutom Jovana Hadžija pri Znanstvenoraziskovalnem centru SAZU, Institutom Jožef Stefan, Inštitutom za geografijo, Oddelkom za geografijo pri Filozofski fakulteti in z Geološkim zavodom Slovenije. Raziskave so povezali še z mednarodnimi projekti proučevanja alpskih jezer in jezer na drugih evropskih območjih. V sorazmerno kratkem obdobju, od začetkov raziskovanj je minilo le dobrih deset let, je bilo opravljeno obsežno in zahtevno terensko in laboratorijsko delo. Raven spoznanj o naravi visokogorskih jezer pa je toliko dozorela, da so se raziskovalci in pisci odločili vsebino dognanj predstaviti širši javnosti. Ta monografija je pravo darilo bralstvu doma in v tujini za *Evropsko*

In the autumn of 1945, after four years of occupation of our country, my friend Jože and I set off for the high mountains of the Julian Alps for the first time. We made for the Triglav mountain range. It was a nice September afternoon when we crossed the screes up to the Hribarice saddle on our way towards the seven Triglav lakes. Seeing these little lakes surrounded by a wreath of mountain peaks was a wonderful mountaineering experience, and coming into touch with them was a marvelous biological experience. My memory still recollects a multitude of tiny red crustaceans, *copepoda,* darting in the water in all directions. I did not know their name then but I would have liked to. Hardly anyone was interested in these "insignificant" lake dwellers at that time.

The first botanical investigations of the valley of Dolina Triglavskih jezer on a more extensive level were initiated and conducted by Professor Dr. Fran Jesenko (1875–1932) in 1924. With a group of biology students he botanized in this area for several years running. It was only after the 2nd World War that more systematic investigations of the living nature in the highly interesting Dolina Triglavskih jezer were initiated, this time by a botanist and renown nature–conservationist, Professor Dr. Angela Piskernik (1886–1967); they were carried out within the scope of the Institution for the Conservation and Scientific Research of Cultural and Natural Monuments of Slovenia. Sporadic papers about the living nature of the Dolina and the lakes were published in various popular–science publications and scientific periodicals. A complex picture of the whole was not compiled or presented anywhere.

Finally, a group of biologists, researchers at the National Institute of Biology at, conducted by Anton Brancelj, Ph.D., launched an investigation of all the high-mountain lakes in the Julian Alps. They joined forces with the Jovan Hadži Institute of Biology at the Scientific Research Center at the Slovenian Acadamy of Sciences and Arts, the Jožef Stefan Institute, the Institute of Geography, the Department of geography at the Faculty of Art and the Geological survey of Slovenia. The researches were further coordinated with international projects for the studies of Alpine lakes and lakes in other European regions. In a relatively short time – only a little more than ten years passed since the beginning of the investigation – extensive and demanding fieldwork and laboratory works were done. So much knowledge was accumulated about the nature of high-mountain lakes that the research-

*leto gora* (2002). Čeprav bodo raziskovanja nadaljevali, je nadvse hvalevredno, da so o neživi in živi naravi jezer spregovorili vsem planinskim popotnikom in strokovnjakom, ki smo na planinskih pohodih uživali njihovo lepoto in se hkrati spraševali o njihovem rojstvu, življenju in usodi. Mnogim gornikom bo odslej obisk in postanek ob njih še večje doživetje. Poleg estetskih doživetij si bodo lahko odgovorili mnoga vprašanja o naravi teh gorskih očesc. Iz strokovno neoporečnih zapisov in grafično zelo nazornih predstavitev, bralci lahko spoznavajo geološko zgodovino in limnološko dogajanje v jezercih. Čeprav so na pogled podobna, se jezerca razlikujejo drugo od drugega po sestavi življenjskih združb, po zgradbi usedlin in mineralizacijskih procesih, ki potekajo v njihovih vodah. Vsako od jezerc je svojevrstno *živo telo*, kjer se neživi in živi svet povezujeta v nenehnem kroženju snovi. Njihova ekološka raznolikost in biotska raznovrstnost segata od ultraoligotrofnega, npr. Kriška jezera, do oligotrofnega (večina jezerc) in celo do evtrofnega jezera, kot je Krnsko. Za proučevanja ekologije jezer, kroženja snovi in pretoka energije ponujajo odličen laboratorij pod modrim nebom. Prepričan sem, da bo prav ta monografija spodbudila nov zagon raziskovanj. Udejanila je željo, ki sem jo kot spomin na prvo srečanje s temi jezeri gojil že dolga desetletja. Sedaj vem, kje bom našel ime za drobne rdeče rakce in kje bom lahko prebral več o življenju teh jezerc. Dolgo sem čakal, a vendar dočakal.

Monografija odseva uspešnost skupinskega raziskovanja. Njen pomen ni vezan le na okolje Julijskih Alp, ampak seže še v druge predele Alp in do jezer v severni Evropi. Posebnost tega dela je tudi v geografskem položaju in geološki (karbonatni) osnovi jezer, saj so mnoga druga alpska jezera v kotanjah silikatnih kamnin.

Monografija je izvirna in celovita predstavitev narave naših visokogorskih jezerc, je nov prispevek k splošni limnologiji in osnova za učinkovito naravovarstvo gorskega sveta. Besedilo dopolnjujejo številni estetsko dovršeni fotografski motivi iz gorske pokrajine. Z monografijo se Slovenci predstavljamo znanstvenemu svetu in širši strokovni javnosti tudi kot alpski narod, ki ljubi, ceni in varuje naravo svojih gora.

prof. dr. Kazimir Tarman

Ljubljana – Šiška, 9. maj 2002

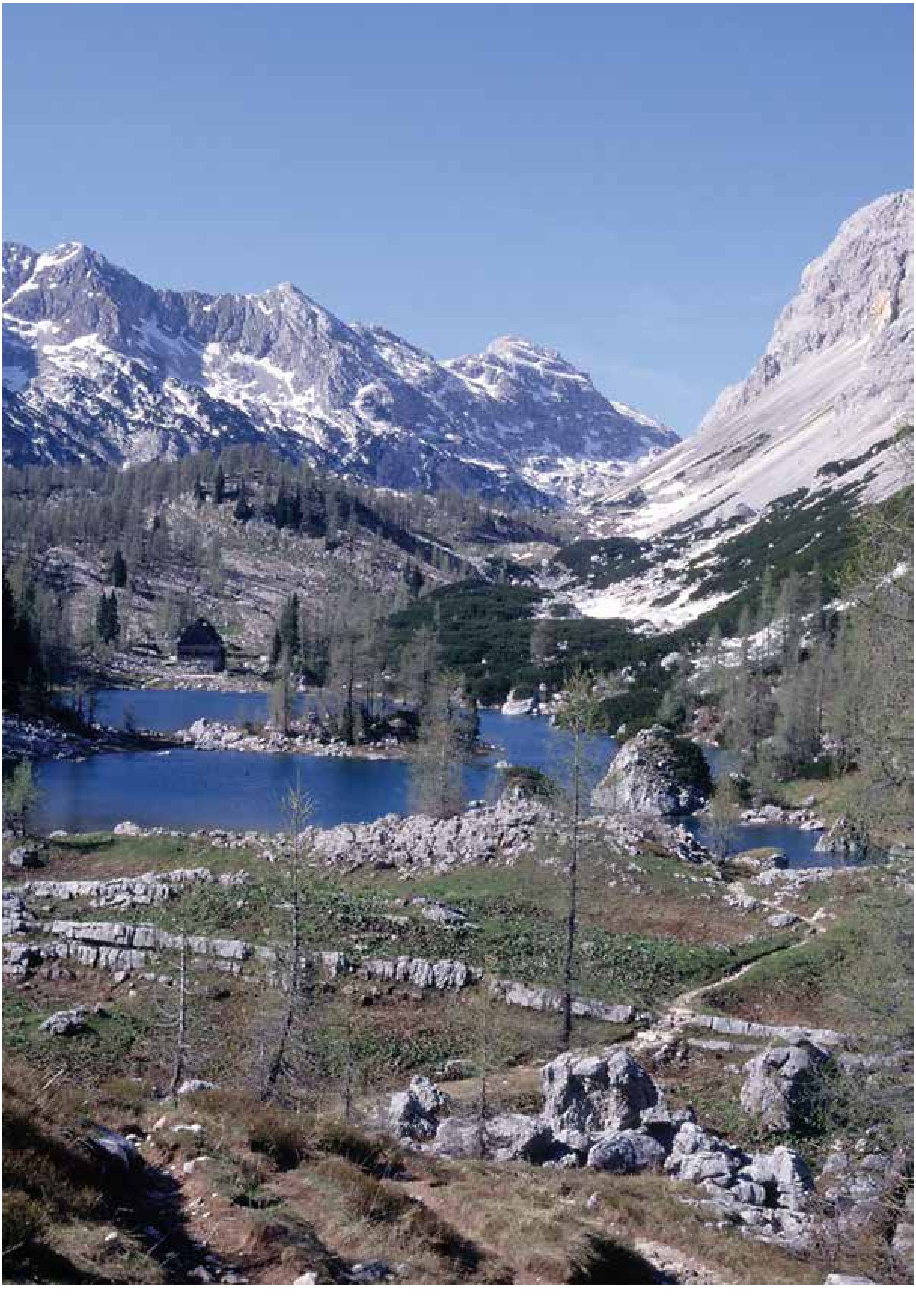
ers and authors decided to present the results of their work to a wider public. The monograph in front of us is a true present to the reading public at home and abroad for the *European Year of Mountains* (2002). Although the researches will be carried on, it is particularly meritorious that the current information about the non-living and living nature of the lakes has been offered to all of us, mountain–goers and experts, who enjoyed their beauty during our visits to the mountains and were also curious about their origin, life and prospects. To many mountaineers a visit to the lakes and staying by them will, henceforth, be an even deeper experience. In addition to aesthetic pleasure, they will be able to find answers to numerous questions about the nature of these mountain eylets. Through these highly expert writings and very illustrative graphic presentations the readers can learn about the geological history of and the limnological processes in these lakes. Though similar by appearance, the lakes differ one from another by the structure of life associations, composition of sediments and mineralization processes going on in their waters. Each of these lakes is a specific *living body*, where the non-living and the living worlds interlace in an eternal cycle of substance circulation. Their ecological and biotic diversities range them from ultra-oligotrophic lakes, e.g. Kriška jezera, to oligotrophic ones (most of the lakes), and even to euthrophic lakes, such as Krnsko jezero. They make a pefect open air laboratory for the studies of the ecology of lakes, circulation of substance and energy flow. I firmly believe that the present monograph will give a fresh impetus to research. It has fulfilled my wish that occurred to me many decades ago at my first visit to the lakes. Now I know where to find the name of the tiny red crustaceans, or where to get more information about the life in the lakes. I have been waiting for a long time, and finally here it is.

The monograph reflects the success of team research. Its importance is not only limited to the area of the Julian Alps, but reaches also to other regions of the Alps, and even as far as the lakes in North Europe. Two features typical of the discussed area are the geographical position of the lakes and their geological bases which are made of carbonate rocks; namely, many other alpine lakes lie in the basins made of silicate rocks.

The monograph is an original and comprehensive presentation of the nature of our high-mountain lakes; it is a fresh contribution to general limnology and makes a basis for efficient nature conservation of the mountainous world. The text is complemented with numerous, aesthetically perfect photos of the mountainscape. With this monograph, the Slovenes are presented to the scientific world and to a wider expert public as an Alpine people who loves, appreciates and protects the nature of its mountains.

Professor Dr. Kazimir Tarman

Ljubljana – Šiška, May 9, 2002



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Anton BRANCELJ,
Nacionalni inštitut za biologijo, Ljubljana

Ljubljana, 30. maj 2002

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Anton BRANCELJ,
National Institute of Biology, Ljubljana

Ljubljana, May 30, 2002

Panorama ob bregu Jezera v Ledvicah (Foto: Anton Brancelj)
*Panorama of the shore of Jezero v Ledvicah (Photo: Anton Brancelj)*

# *Poglavje* 1 *Chapter*

## *Uvod in pregled dosedanjih raziskav*

## *Introduction and Historical Overview*

Anton BRANCELJ*

Slovenija je majhna in pokrajinsko raznovrstna dežela v jugovzhodni Evropi. Na majhnem prostoru, velikem komaj 20.273 $km^2$ se srečujejo štiri pokrajine, vsaka s svojim značilnim zunanjim videzom. Severni in severozahodni del Slovenije označujejo visoke gore, ki so del gorske verige, imenovane Alpe. Veriga je dolga preko 2000 km in se na zahodu začne v Franciji, na vzhodu se konča v Avstriji, na jugu pa sega tudi v Slovenijo. V smeri od vzhoda proti zahodu, pa tudi v smeri sever–jug so Alpe precej manj raznolike kot v navpični smeri, to je od nižin do najvišjih vrhov. Vznožja Alp so pokrita z listopadnimi ali mešanimi gozdovi, ki so zaradi človekove dejavnosti že marsikje močno spremenjeni. Tem gozdovom sledi pas iglastih gozdov, nad njimi pa se začnejo alpske trate, kjer so, zlasti v preteklosti, pasli ovce in govedo. Nad alpskimi tratami je kraljestvo golih skal, snega in ledu. To območje, pa tudi celotno območje Alp, je sedaj v glavnem oblegano s planinci in turisti. Pravzaprav so Alpe v vsej zgodovini človeške kulture igrale vlogo zahtevnega, ne pa tudi sovražnega okolja. Človek je iz njihovih nedrij pridobival les in rude ali pa je lovil divjad. V poletnem času so ljudje celo živeli v visokogorju, kjer so pasli živino.

Najvišji vrhovi v Alpah segajo preko 4000 m in so večji del leta pokriti s snegom in ledeniki. Voda iz staljenega snega in deževnica napajata brezštevilne potočke in jezera, ki so pomemben vir kakovostne pitne vode za ljudi, ki živijo na vznožju Alp, pa tudi v njihovi širši okolici. Ohranjanje kakovosti vode je zato ena od prednostnih nalog, ki zahteva in bo zahtevala tudi v prihodnje zelo veliko časa in

Slovenia is a small and very diverse country in south–eastern Europe, where four different regions with specific landscapes meet in a small area of 20,273 $km^2$. Its north and north-western part is characterised by high mountains, which are part of the mountain chain known as the Alps. The chain runs for more than 2000 km from France in the west to Austria in the east and to Slovenia in the south. From the east to the west and from the south to the north, the Alps are much less diverse than in the vertical direction, from the lowlands to the highest peaks. In the vertical profile, the foothills are covered mainly by deciduous or mixed forest, which has mostly been intensively modified by human activities. This is followed by coniferous forest and then by alpine pastures, which, in the past, were used for pasturing cows and sheep. Above the pastures there is a region of bare rocks, snow and glaciers. Mountaineers and tourists now frequent that area, as well as the rest of the Alps. The Alps have acted in human history as a harsh but not uniquely hostile environment. They have provided humans with wood, ore and game animals for food. During the summer people have lived there and bred their livestock.

The highest peaks in the Alps rise above 4000 m and, for most of the year, are covered by snow and glaciers. Water from melted snow, ice and rain feeds countless streams and lakes, which are an important source for high quality drinking water for people living in the foothills. Water quality assurance is thus a crucial activity that needs a lot of time and energy, now and in the future. To meet

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energije. Za njeno zagotavljanje je nedvomno potrebno v prvi vrsti pridobiti podatke o količini in kakovosti ter podatke o obstoječih ali potencialnih virih onesnaženja. Edina zanesljiva vira teh informacij sta sistematična in interdisciplinarna raziskovalna dejavnost in monitoring.

Čeprav večina Slovencev ve, da imamo v naših Julijskih Alpah jezera, jih le malo zna našteti, koliko jih je v resnici. Tudi seznam strokovne literature, ki tematsko pokriva slovenska alpska jezera, je presenetljivo kratek. Prvi strokovni članki, ki obravnavajo visokogorska jezera, bodisi z geografskega, geološkega ali biološkega stališča, so bili napisani že konec 19. stoletja. Vendar so v vseh primerih jezera obravnavana le obrobno oz. nepopolno. Kot prvi sistematični prikaz visokogorskih jezer v Sloveniji lahko štejemo geografski opis, ki ga je objavil Ivan Gams (1962). Nekaj let kasneje se je skupina potapljačev odpravila v Jezero v Ledvicah, kjer je opravila nekaj dodatnih meritev. Ugotovili so, da je jezero nekoliko plitvejše, kot ga je izmeril Gams (Orožen Adamič, 1970). Temu je sledilo dolgo ob-

Pozimi smo morali pred začetkom jemanja vzorcev v led izkopati luknjo. (Foto: Gregor Muri)
*In winter we have to make a hole in ice before sampling. (Photo: Gregor Muri)*

the demand for a continuing supply of high quality water the first step is, beyond any doubt, to collect information on the quality and quantity of available water, on the environment and on existing or potential sources of pollution. There can be only one source of such information, and that is a systematic and interdisciplinary, long-term research and monitoring activity.

One of the most impressive areas of the Alps in Slovenia is that of the Julian Alps with its several small lakes. The latter are very popular among Slovenian people but very few really know how many lakes are there. The literature covering the Slovene alpine lakes is very sparse. The first competent articles, dealing with high-mountain lakes in Slovenia from geographical, geological or biological points of view, date from the end of the 19th century but the authors did not pay special attention to the lakes themselves. The geographer Ivan Gams (1962) made the first systematic survey of high-mountain lakes in Slovenia. A few years later a group of scuba divers made some additional measurements in the lake Jezero v Ledvicah – (the word "jezero" is Slovene for lake). They found it somewhat shallower than reported by Gams (Orožen Adamič, 1970). Again, there was a quite a long period with no published papers, but the lakes became more and more popular, attracting a large number of mountaineers and tourists.

A significant change took place in 1989. A group of biologists from the Department of Biology of Edvard Kardelj University and from the Institute of Biology, on the initiative of Prof. Dr. Danijel Vrhovšek, made the first survey of macrophytes and zooplankton in some of the high-mountain lakes (Blaženčić *et al.*, 1989). Next year, as part of a surface water monitoring programme in Slovenia, conducted by the Hydrometeorological Survey – of the Ministry of Civil Engineering and Environment, the first measurements and analyses of water were made in Jezero na Planini pri Jezeru, Triglav Lakes valley and Krnsko jezero. Similar analyses have since been running for several years on Blejsko jezero and Bohinjsko jezero (Bricelj *et al.*, 1991, 1992, 1993, 1994). The aim was to determine the status of high-mountain lakes and consequently to take measures for their protection. After 1993, the budget was cut, but we continued the activities at our own expense. Unexpectedly we very soon got an opportunity to direct our research into a completely different context.

Colleagues from the Institute of Biology and some external co-workers applied in 1992 for a national project "Catalogue of limnoflora and limnodobje, ko o jezerih v strokovnih krogih ni bilo skoraj nič objavljenega, čeprav so jih obiskovale množice gornikov in turistov.

Prvi premik je bil storjen leta 1989. Takrat je ekipa biologov z Oddelka za biologijo Univerze Edvarda Kardelja in Inštituta za biologijo na pobudo dr. Danijela Vrhovška naredila prvi sistematični pregled rastlin (makrofiti) in živali (zooplankton), ki naseljujejo visokogorska jezera (Blaženčić in sod., 1989). Leta 1990 so v okviru monitoringa površinskih stoječih voda v Sloveniji (izvajali so ga v okviru sedanjega MOP-ARSO) naredili prve fizikalne, kemijske in biološke analize nekaterih jezer (Jezero na Planini pri Jezeru, Sedmera jezera, Krnsko jezero). Tovrstne analize so že nekaj časa potekale na Blejskem in Bohinjskem jezeru (Bricelj in sod., 1991, 1992, 1993, 1994). Cilj tovrstnih raziskav je bil, da se ugotovi, v kakšnem stanju so visokogorska jezera, in da se predlagajo morebitni ukrepi za njihovo varovanje. Denarja za nadaljevanje monitoringa visokogorskih jezer po letu 1993 ni bilo več. Sodelavci Inštituta za biologijo so se zato odločili, da bodo na lastne stroške nadaljevali z rednimi letnimi pregledi jezer. To se jim je kmalu obrestovalo in raziskave jezer so nepričakovano dobile povsem drugačno osnovo.

Leta 1992 je bil na takratnem Ministrstvu za znanost in tehnologijo prijavljen nacionalni projekt Katalog limnoflore in limnofavne Slovenije, ki smo ga izvajali sodelavci Inštituta za biologijo ob sodelovanju zunanjih sodelavcev. Eden od rezultatov projekta je bila knjižica Življenje v vodah Triglavskega narodnega parka, ki jo je izdal Triglavski narodni park leta 1995. V njej smo zbrali vse do tedaj objavljene podatke o rastlinstvu in živalstvu v vodah parka.

Resničen preobrat pri raziskavah visokogorskih jezer se je zgodil konec leta 1993, ko je bil v Delu objavljen razpis za sodelovanje na mednarodnem projektu AL:PE 2 (Acidification of Mountain Lakes: Palaeolimnology and Ecology) v 4. okvirnem raziskovalnem programu evropske skupnosti – ta je projekt tudi financirala. Koordinator projekta Environmental Change Research Center s sedežem na University Collegeu v Londonu nas je po obisku in ogledu laboratorijev ter dotedanjih rezultatov raziskav povabil k sodelovanju. V okviru enoletnega sodelovanja smo v letu 1994 opravili vrsto analiz vode, rastlinstva in živalstva ter sedimenta na Zgornjem Kriškem jezeru, kjer smo ugotovljali vplive kislega dežja na visokogorska jezera. Zanimivi rezultati analiz in zgledno sodelovanje skupine so nam omogočili, da smo se lahko vključili v naslednji projekt – v 5. okvirnem programu ES. V njem smo lah-

fauna Sloveniae" financed by the former Ministry of Science and Technology. As a result of the project a book was published in 1995 entitled "Life in the waters in the Triglav National Park". The book was actually a collection of data on plants and animals recorded in the waters within the park.

An event which shed a completely new light on our work on high-mountain lakes, happened at the end of 1993, when we read in the newspaper "Delo" a call for co-operation in an international project AL:PE 2 (Acidification of Mountain Lakes: Palaeolimnology and Ecology) within the 4th framework of research activity financed by the European Community.

The co-ordinator of the project (from University College London – Environmental Change Research Centre) visited Ljubljana and after inspecting the laboratories and reviewing the results and papers, decided to invite us to join the group. The invitation was for one year only (1994), because we joined the project in its last year. The main aim of the whole project was to study the effects of acid rain on high-mountain lakes and we made a complex of analyses of water, fauna, flora and sediments in Zgornje Kriško jezero. Some interesting results and good co-operation resulted in participation in the next European project, in the 5th framework, from the very beginning. The MOLAR (Measuring and modelling the dynamic response of remote mountain lake ecosystems to environmental changes) project ran from spring 1996 to spring 1999. As the object of our interest in each region, we selected one pristine lake. The criteria were that it should be above the tree line and have been exposed to the minimum of human impact. We put forward the hypothesis that high-mountain lakes are the most sensitive to environmental change and that their reactions to such changes are relatively fast, because they are small and sensitive.

Eighteen laboratories and 60 researchers from Norway, Finland, England, Italy, Austria, Switzerland, France, Spain, Czech Republic, Slovakia, Poland and Slovenia participated in the project. For our part of the project, we selected Jezero v Ledvicah in the Julian Alps, which fulfils all the requirements of the project. There were several aims of the MOLAR project. We had to determine how lakes from selected mountain regions all over Europe differ in the physical and chemical properties of their water, what are the qualitative and quantitative differences in biota, and what environmental changes there have been in and around the lakes over the last few centuries. We were to give special ko sodelovali že od priprave naprej. Projekt MOLAR (Measuring and modelling the dynamic response of remote mountain lake ecosystems to environmental changes) se je začel spomladi leta 1996 in se je zaključil spomladi leta 1999. Za objekt raziskovanj so bila izbrana visokogorska jezera, ki ležijo nad gozdno mejo in kjer je vpliv človekove dejavnosti kar najmanjši. Pričakovali smo, da so ta jezera najbolj občutljiva za spremembe v okolju. Ker pa so razmeroma majhna, naj bi nanje tudi hitreje reagirala.

V projektu je sodelovalo 18 laboratorijev iz Norveške, Finske, Anglije, Italije, Avstrije, Švice, Francije, Španije, Češke, Slovaške, Poljske in Slovenije z okoli 60 raziskovalci. Slovenci smo v okviru tega projekta kot objekt raziskav predlagali Jezero v Ledvicah, ki je izpolnjevalo vse pogoje za vključitev v mrežo evropskih visokogorskih jezer. Cilj projekta MOLAR je bil ugotoviti, kako se izbrana jezera v različnih gorstvih v Evropi med seboj razlikujejo po kemijskih in fizikalnih lastnostih vode, kakšne so razlike v rastlinstvu in živalstvu in kako sta se jezero in njegova okolica spreminjala v zadnjih stoletjih. Pri tem sta bila v ospredju problem onesnaževanja okolja in problem klimatskih sprememb. Z izborom jezer od severa (Norveška) proti jugu (Italija, Slovenija) ter od zahoda (Španija) proti vzhodu (Češka, Poljska) naj bi dobili prvo celovito podobo o sedanjem stanju visokogorskih jezer, o velikosti in smeri sprememb, ki so jih doživela v zadnjih stoletjih. Rezultati raziskav naj bi omogočili tudi izdelavo modelov, s katerimi bi lahko ocenili intenzivnost onesnaževanja, zlasti preko zraka, in njegove posledice na širšem območju, ne samo na izbranih jezerih.

V letu 1996 smo začeli tudi v okviru nacionalnega projekta z intenzivnimi raziskavami treh visokogorskih jezer, Jezera v Ledvicah, Krnskega jezera ter Jezera na Planini pri Jezeru. Projekt je potekal pod naslovom SLO-Alpe (Slovenska alpska jezera: ekologija in paleolimnologija), ki ga je Ministrstvo za znanost in tehnologijo najprej podprlo za tri leta, nato pa podaljšalo financiranje še do sredine leta 2001. V okviru tega projekta so sodelavci Nacionalnega inštituta za biologijo izvajali vrsto raziskav v sodelovanju s sodelavci Odseka za znanosti o okolju na Institutu Jožef Stefan, z Oddelka za geografijo Filozofske fakultete, z Biološkega inštituta Jovana Hadžija pri ZRC SAZU; z Inštituta za geografijo ter z Geološkega zavoda Slovenije – Podzemne vode. Obravnavana jezera se med seboj razlikujejo po intenzivnosti neposrednega človekovega vpliva, s tem pa tudi po njihovem stanju. Jezero na Planini pri

attention to the problems of pollution and climate change. Lakes were selected along two main directions: from the north (Norway) to the south (Italy) and from the west (Spain) to the east (Czech Republic, Poland). Such a geographical distribution would provide us with global information on the present day situation in remote lakes all over Europe. In addition, we collected information on the quality and quantity of changes over the last few centuries, with special emphasis on the intensity of pollution, particularly that transported over long distances. The results from the project should enable us to produce models for the intensity of pollution and its consequences, not only for certain selected lakes or regions but also on European scale.

In 1996 we started a national project SLO-Alpe (Slovenian alpine lakes: ecology and paleolimnology) on three high-mountain lakes, Jezero v Ledvicah, Krnsko jezero and Jezero na Planini pri Jezeru. The project was financed by the Ministry of Science and Technology over five years (1996–

Pred merjenjem nekaterih fizikalnih in kemijskih lastnosti vode (Foto: Davorin Tome)
*Before measuring some physical and chemical properties of water (Photo: Davorin Tome)*

Vzorce sedimenta smo iz najgloblje točke jezera dobili s pomočjo težnostnega vzorčevalnika (korerja). (Foto: Anton Brancelj)
*Sediment cores were collected with a gravity corer from the deepest point of the lake. (Photo: Anton Brancelj)*

Jezeru spada med jezera, kjer je bil vpliv človeka v preteklosti (in tudi še v sedanjosti) (Brancelj in sod., 2000) največji, medtem ko je bil tovrstni vpliv na Jezero v Ledvicah najmanjši. Jezero na Planini pri Jezeru je danes še vedno med najbolj obremenjenimi jezeri v Sloveniji, medtem ko je Jezero v Ledvicah eno redkih oligotrofnih jezer, kjer je vpliv človeka (še vedno) zanemarljiv. Poleg številnih fizikalnih, kemijskih in bioloških analiz nas je zanimala tudi zgodovina in intenzivnost človekovih posegov v pojezerju – t. i. socio-ekonomski odnosi. In prav to je bila tudi ena od pomembnih tem, ki smo jih vključili v projekt EMERGE (European Mountain lake Ecosystems: Regionalisation, diaGnostics & socio-economic Evaluation), ki poteka v 5. okvirnem programu Evropske skupnosti (začetek spomladi leta 2000, zaključek spomladi leta 2003). V njem

2001). Researchers from the National Institute of Biology co-operate intensively with colleagues from the Department of Environmental Sciences of the Jožef Stefan Institute, from the Department of geography of the Faculty of Art, from the Jovan Hadzi Biological Institute of the Scientific Research Centre of the Slovenian Academy of Sciences and Arts, from the Institute of Geography and from the Geological Survey of Slovenia.

The lakes differ in the intensity of human impact, both in the past and today, which is reflected in their trophic status (i.e. concentration of nutrients). Jezero na Planini pri Jezeru was in the past, and still is (Brancelj *et al.*, 2000), the most intensively affected by human activities, while Jezero v Ledvicah was the least influenced. Jezero na Planini pri Jezeru is now one of the most eutrophic (rich in nutrients) lakes in Slovenia while Jezero v Ledvicah is one of the few pristine and oligotrophic (poor in nutrients) lakes, with negligible human impact. Apart from numerous analyses made on the selected lakes, we were interested also in the socio-economic aspect – the history and intensity of human impact in and around the lake in the past. This topic formed an important segment of the next European project EMERGE (European Mountain lake Ecosystems: Regionalisation, diaGnostics & socio-economic Evaluation), run within the 5th framework from spring 2000 to spring 2003. Within this project, there are 28 participating laboratories, with more than 90 researchers. Apart from the participants already mentioned under the MOLAR project, three additional countries were included – Denmark, Romania and Bulgaria. From the geographical point of view the project extended considerably into eastern Europe with the Rila Mountains and to the northwest with Greenland. This geographical extension should lead to a better understanding of processes in climate change and global pollution.

In a decade of research undertaken by researchers from the National Institute of Biology and colleagues from other Slovenian institutions, as well as from abroad, a considerable amount of data, knowledge and experience has been accumulated. A lot of important and interesting data originate from physical measurements, chemical analyses and biological surveys from high-mountain lakes and their surroundings. From the bottom of most of the lakes, we collected sediment samples, which were analysed in detail. Their physical and chemical properties, their age, quality and quantity of organic pollutants, concentration of heavy metals, intensodeluje 28 laboratorijev z več kot 90 raziskovalci. Poleg že prej naštetih držav so se v projekt vključile tudi Danska, Romunija in Bolgarija. S tem se je ta geografsko pomaknil daleč v vzhodno Evropo (pogorje Rila) in proti severozahodu (Grenlandija), kar bo veliko prispevalo k boljšemu razumevanju procesov pri spremembah klime in onesnaževanju.

V desetletju raziskav, ki smo jih opravili raziskovalci Nacionalnega inštituta za biologijo s številnimi sodelavci doma in v tujini, se je nabralo veliko podatkov ter novih spoznanj. Analizirali smo fizikalne in kemijske značilnosti vode, opravili biološke analize v visokogorskih jezerih, zlasti njihove flore in favne, vključno s sezonskimi spremembami v vrstni sestavi in količini. Z dna večine jezer smo odvzeli vzorce sedimenta, na katerih so bile opravljene zelo natančne analize. Le-te so obsegale njihove fizikalne in kemijske lastnosti, starost, vrsto in količino organskih onesnaževalcev, vsebnost težkih kovin, procese mineralizacije in količino ter vrstno sestavo rastlinskih in živalskih ostankov. Večina analiz sedimenta je bila narejena na globinskih profilih, tako da smo lahko sledili spremembam v jezerih in ob njih skozi obdobje nekaj sto let. Tako danes lažje razumemo njihovo trenutno stanje. Poleg tega smo leta 1996 v bližini doma pri Sedmerih jezerih postavili avtomatsko vremensko postajo, ki je ves ta čas nepretrgoma merila meteorološke podatke. Z njihovo pomočjo danes lažje razumemo pojave v jezerih in ob njih. Meteorološka postaja je merila smer in hitrost vetra, količino dežja, temperaturo, zračno vlago, energijo vpadle in odbite svetlobe, v zadnjih dveh letih pa tudi intenzivnost ultravijoličnega sevanja, katerega vrednosti so v zadnjih desetletjih narasle zaradi onesnaževanja ozračja. Te raziskave smo sredi leta 2000 dopolnili še z neprekinjenimi meritvami temperature vode v površinski plasti vode v petih jezerih. Jezera ležijo na različnih nadmorskih višinah ter so različno izpostavljena sončnemu obsevanju in vetrovom. Cilj je bil ugotoviti, kako se temperatura vode v jezerih spreminja preko leta, kakšne so razlike med temperaturami glede na nadmorsko višino in lego. Pridobili smo tudi podatke o dolžini trajanja ledu na posameznih jezerih. Ena od nalog je bila ugotavljanje podzemnih povezav med nekaterimi izbranimi jezeri. Rezultati vseh teh analiz in meritev, podprti tudi s slikovnim gradivom, bodo predstavljeni v naslednjih poglavjih knjige. Nekateri od predstavljenih rezultatov so plod sodelovanja s tujimi laboratoriji, ki so specializirani za posamezne analize.

Terensko delo je bilo pomemben del našega programa, kjer smo doživeli veliko prijetnih in sonč-

sity of mineralisation and quality and quantity of remains of biota were all studied. Because sediments build up over long periods of time and are usually undisturbed, most of our analyses were done in vertical profiles, covering periods of several centuries. This enables us to follow changes within the lakes for longer periods and to understand better their present situation. In 1996 we erected an automatic weather station near the hut in the Valley of Seven lakes. The station recorded meteorological data for five years without serious problems and data on wind speed and direction, amount of rain precipitation, temperature, humidity and solar radiation are available for the whole period. For the last two years, we have also collected data on UV-b radiation, which increased in the last decades as a result of air pollution. In June 2000, we put probes into five selected lakes to measure water temperature continuously at a depth of one metre. The lakes are situated on different elevations and they have different exposure to solar radiation and wind. The aim of such measurements is to detect the duration of ice cover and to establish the temperature regime of the lakes over the whole year. In some lakes, we have identified underground connections between lakes or between lakes and springs.

Field work is an important part of our work and a lot of days are spent in the mountains, many of them in fine weather, often interrupted with rainy or very cold days with a lot of snow. In our fieldwork diary for the whole period, there are notes of more than 137 visits. Between 1991 and 1995 we visited the lakes 17 times, between two and six times a year. We focussed mainly on the autumn period when biota is well developed and water chemistry should be a good indicator of human impact. Between 1996 and 1999, the number of visits increased to 103 (between 20 and 33 per year), dropping again to 17 in the last two years. Some of the sampling was done with temperatures dropping below –15 °C, and we were faced with problems of failures of electronic probes due to low temperatures and ice formation on sampling devices.

The results of analyses and measurements, supported by figures, tables and photos, will be presented in several chapters. Some results originate from the collaboration with laboratories from abroad, specialised in specific analytical methods. In addition, while we have a lot of data from the lakes, there are still some topics about which we have insufficient knowledge and need to study more intensively in the future. Some measurements and analyses have already ceased because, in our opin-

Pobiranje sedimentacijskih pasti na Jezeru v Ledvicah pozimi ni bilo prijetno opravilo. (Foto: Anton Brancelj)
*Collecting sediment traps in Jezero v Ledvicah in winter was not a pleasant job. (Photo: Anton Brancelj)*

nih dni, ki pa so jih prekinjali deževni pa tudi zelo mrzli dnevi z obilico snega. V dnevniku terenskega dela se je zapis ustavil pri 137 dneh. Med letoma 1991 in 1995 smo jezera obiskali 17-krat, in sicer dva- do šestkrat na leto. V večini primerov so bili obiski v jesenkem času, ko sta bili flora in favna v jezerih dobro razviti, kemizem vode pa naj bi najbolj odražal vpliv človeka. V obdobju od 1996 do 1999 je število terenskih dni naraslo na 103 (med 20 in 33 dni na leto), ki pa je v zadnjih dveh letih upadlo na skupno 17 terenskih dni. Nekaj terenov smo opravili v težkih razmerah, ko so bile temperature celo pod –15 °C, ko niso delovale elektronske naprave in se je na vzorčevalnikih sproti delal led.

Nekatere raziskave smo na tej stopnji že bolj ali manj zaključili, saj menimo, da imamo za splošni pregled stanja na razpolago dovolj podatkov. Druge smo komaj začeli, vendar jih nameravamo izvajati tudi v prihodnje. Čeprav so podatki in rezultati v teh primerih skopi, smo jih vključili v delo, ker želimo s tem prikazati vse naše dosedanje raznovrstno vedenje o jezerih. Obenem želimo tako opozoriti na še ne pokrita področja raziskav, ki jih bomo v prihodnje opravljali mi ali naši nasledniki.

ion, we have collected enough data to reach some general conclusions. Some analyses and measurements have just commenced and these we shall continue in the future. Such types of data, however, are not sufficient to allow us to draw more fundamental conclusions. We include them to make a better overview on our activities and to throw light on some specific problems. In the end, we would like to draw attention to topics that need more intensive research. We shall carry out some of them while others will remain as a challenge for future generations.

The aim of this book is not a detail presentation of existing data but a general overview on the situation in the lakes and their surroundings. We try to avoid tables as much as possible and we include only the most illustrative figures. The detailed results of our 10-years work will be presented in specialised articles in scientific journals, most of them international. The aim of this book is to outline the complexity of processes in and around the lakes, which are physically small but which, from a scientific point of view, are very interesting, very important and, in some cases, even unique.

## NACIONALNI IN EVROPSKI PROJEKTI O VISOKOGORSKIH JEZERIH V SLOVENIJI: NATIONAL AND EUROPEAN PROJECTS ON HIGH-MOUNTAIN LAKES IN SLOVENIA:

*Nacionalni / National:*

SLO-Alpe: Slovenska alpska jezera: ekologija in paleolimnologija (obdobje: 1996–2001)
SLO-Alpe: Slovenian mountain lake: ecology and palaeolimnology (period: 1996–2001)

*Evropski / European:*

AL:PE 2 – Acidification of Mountain Lakes: Palaeolimnology and Ecology 2 (obdobje / period: 1994)
MOLAR – Measuring and modelling the dynamic response of remote mountain lake ecosystems to environmental changes (obdobje / period: 1996–1999)
EMERGE – European Mountain lake Ecosystems: Regionalisation, diaGnostics & socio-economic Evaluation (obdobje / period: 2000–2003)

V PROJEKTU SLO-Alpe SODELUJOČE INSTITUCIJE IZ SLOVENIJE:
PARTICIPATING INSTITUTIONS FROM SLOVENIA IN THE PROJECT SLO-Alpe:

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*Poglavje* 2 *Chapter*

# *Klimatske in dendroklimatske značilnosti vzhodnega dela Julijskih Alp*

# *Climatic and Dendroclimatic Features of the Eastern Part of the Julian Alps*

Darko OGRIN* & Anton BRANCELJ**

## UVOD

Glede na klimatsko členitev Slovenije imajo Julijske Alpe, tako kot Karavanke, Kamniško-Savinjske Alpe in najvišja območja Pohorja ter Trnovskega gozda in Snežnika, gorsko podnebje. Razen gorskih območij nad 1500 m imajo ta tip podnebja tudi alpske doline in nekatere predalpske kotline in doline, ki jim dajejo gorski značaj predvsem zimske temperature. Zaradi različne geografske lege in geomorfološke strukture obstajajo pomembne klimatske razlike med zahodnimi in vzhodnimi območji gorskega sveta v Sloveniji. Zahodna so zaradi prevladujoče zahodne in jugozahodne zračne cirkulacije bolj namočena in imajo zaradi večje masivnosti ter višin izrazitejšo vertikalno klimatsko pasovitost.

V prispevku so prikazane klimatske razmere Julijskih Alp s pomočjo podatkov obstoječe mreže meteoroloških postaj (Kredarica, Rateče-Planica, Dom na Komni, Vogel, Stara Fužina idr.). Klimo Julijskih Alp smo analizirali po posameznih klimatskih elementih za standardno klimatološko obdobje 1961–1990. Podatke smo črpali iz publikacij nekdanjega Hidrometeorološkega zavoda RS, sedanje ARSO (serija Klimatografija Slovenije, Meteorološki letopisi Slovenije), del pa neposredno iz arhiva HMZ RS (ARSO). Poseben poudarek smo dali tudi analizi podatkov avtomatske meteorološke postaje (model: AWS, ÄT Device), ki je za potrebe evropskih projektov EMERGE IN MOLAR in tudi nacionalnega projekta Slovenska alpska jezera: ekologija in paleoekologija delovala v obdobju oktober 1996–

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## INTRODUCTION

According to the climatic division of Slovenia, the Julian Alps, just like the Karavanke, the Kamnik-Savinja Alps, and the highest parts of the Pohorje, the Trnovski gozd plateau and Mt. Snežnik, fall within the mountain climate zone. In addition to the mountainous areas above 1500 m, this type of climate also prevails in the alpine valleys and in some sub-alpine basins and valleys, having a mountain character mainly because of winter temperatures. Due to different geographical positions and geomorphologic features, considerable climatic differences exist between the western and eastern parts of the mountainous areas in Slovenia. Thanks to the prevailing west- and southwest air circulation the western areas receive more abundant precipitation, and because of their massive character and higher altitudes their vertical climatic zoning is more explicit.

The climatic conditions in the Julian Alps by individual climatic parameters for the standard climatological period from 1961 to 1990 are presented by means of the data collected at the weather stations located in the study area (Kredarica, Rateče-Planica, Dom na Komni, Vogel, Stara Fužina). The data were taken from the publications of the former Hydrometeorological Institute of the Republic of Slovenia, or the present ARSO [Agency of the Republic of Slovenia for Environment] (two series: Klimatografija Slovenije / Climatography of Slovenia/ and Meteorološki letopis Slovenije / Meteor-

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avgust 2001 pri Dvojnem jezeru v Dolini Triglavskih jezer na nadmorski višini okoli 1700 m. Za čas do septembra 1998 je del zbranih podatkov predstavil že Brancelj s sodelavci (2000). Za potrebe nacionalnega projekta so bile v okolici Krnskega jezera, Jezera v Ledvicah in Jezera na Planini pri Jezeru narejene tudi nekatere dendrokronološke in dendroklimatološke raziskave. Rezultati le-teh so predstavljeni v drugem delu prispevka.

Klimatska problematika slovenskega gorskega sveta in v okviru njega Julijskih Alp je pritegnila pozornost številnih raziskovalcev. Pri zgodnejših delih (Melik, 1954; Furlan, 1954; Pristov, 1959; Manohin, 1965) so opazne težave, ki so bile povezane s kratkimi nizi opazovanj in redko mrežo meteoroloških postaj. Malo je celovitih pregledov podnebja Julijskih Alp (Melik, 1954; Pučnik, 1971). Tri dela obravnavajo podnebje posameznih pokrajin, ki segajo v Julijce: Zgornje Posočje (Bernot, 1978), Gorenjsko (Bernot, 1981), Trontelj (1995) pa na poljuden način opisuje podnebje od Bohinja do

Avtomatska meteorološka postaja (AWS ΔT Device) pri Dvojnem jezeru zbira podatke o sedmih meteoroloških parametrih od leta 1996. (Foto: Anton Brancelj)
*The Automatic Weather Station (ΔT Device) near Dvojno jezero has collected data on seven meteorological parameters since 1996. (Photo: Anton Brancelj)*

ological Annals of Slovenia) and partly directly from the archives of the Hydrometeorological Institute of the Republic of Slovenia or the ARSO. A special emphasis is also laid on the analysis of the data from the automatic weather station (model: AWS, ÄT Device), which operated from October 1996 through August 2001 near the lake Dvojno jezero in the valley of Dolina Triglavskih jezer (the Triglav Lakes Valley) at the altitude of about 1700 m for the requirements of two European projects, EMERGE and MOLAR, and one national project, "Slovenian Alpine Lakes: Ecology and Paleoecology". A. Brancelj *et al.*, (2000) already presented a part of the collected data for the period before September 1998. Within the context of the national project some dendrochronological and dendroclimatological research was also undertaken in the surroundings of the lakes Krnsko jezero, Jezero v Ledvicah and Jezero na Planini pri Jezeru. The results obtained are presented in the second part of this paper.

Climate-related problems in the Slovenian mountainous area, and within it in the Julian Alps have attracted attention of numerous researchers. Difficulties can be traced in older research (Melik, 1954; Furlan, 1954; Pristov, 1959; Manohin, 1965) which were due to short spans of observations and a sparse network of weather stations. There are only a few comprehensive surveys of the climate in the Julian Alps (Melik, 1954; Pučnik, 1971). Three works discuss the climate of individual regions which reach into the Julian Alps: Zgornje Posočje (= Upper Soča region) (Bernot, 1978), Gorenjsko (Bernot, 1981), and the area between Bohinj and Bled, the climate of which is described in a popular manner (Trontelj, 1995). Even greater attention was paid to the weather and climate on Mt. Kredarica, the highest lying weather station in Slovenia (Pristov, 1959; Manohin, 1965; Bernot, 1969; Hočevar, 1979; Trontelj, 1994), also in connection with the decline of the Triglav glacier

Bleda. Še več pozornosti sta pritegnila vreme in podnebje na Kredarici, naši najvišji meteorološki postaji (Pristov, 1959; Manohin, 1965; Bernot, 1969; Hočevar, 1979; Trontelj, 1994), tudi v povezavi s krčenjem Triglavskega ledenika (Gams, 1994; Nadbath, 1999). S problematiko posameznih klimatskih elementov so se ukvarjali Furlan (1954, 1968), Pristov in Trontelj (1975) in Bernot (1979). O zgornji gozdni meji, tudi v povezavi s klimatskimi razmerami, je pisal Lovrenčak (1987), o odnosu med priraščanjem dreves in klimo pa Ogrin (1991, 1998, 1999) ter Ogrin in Krevs (1995).

(Gams, 1994; Nadbath, 1999). Furlan (1954, 1968), Pristov and Trontelj (1957) and Bernot (1979) discussed certain problems of individual climatic parameters. Lovrenčak (1987) wrote about the upper forest line, also in relation to climatic conditions, while Ogrin (1991, 1998, 1999) and Ogrin and Krevs (1995) wrote about the relation between tree growth increments and the climate.

## PODNEBJE JULIJSKIH ALP S POUDARKOM NA RAZMERAH DOLINE TRIGLAVSKIH JEZER

*Sončno obsevanje*

V Julijskih Alpah so vrednosti trajanja sončnega obsevanja med najnižjimi v Sloveniji. Izstopajo alpske doline, ki imajo slabo osončenost tako poleti kot pozimi. V zimski polovici leta je po dolinah zelo pogosta inverzijska megla, v topli polovici leta pa imajo doline manj sonca zaradi konvektivne oblačnosti, ki nastane nad gorami. Stara Fužina ob Bohinjskem jezeru je s 1582 sončnimi urami letno (preglednica 1) naša najslabše obsijana meteorološka postaja, saj sije sonce v povprečju okoli 600 ur manj kot v Primorju. Visokogorje je na boljšem, še posebej v zimskem času, ko je lahko sonca celo več kot v Primorju. Na Kredarici sije sonce povprečno 1787 ur letno, pozimi 368 ur, kar je 50 ur več kot v Portorožu. V zimskem času je v visokogorju od vseh letnih časov najmanj oblačnih dni, na Kredarici

## THE CLIMATE OF THE JULIAN ALPS WITH SPECIAL REFERENCE TO THE CONDITIONS IN THE VALLEY OF DOLINA TRIGLAVSKIH JEZER

*Insolation*

The duration of insolation in the Julian Alps ranks among the lowest values in Slovenia. The Alpine valleys stand out in particular with their very poor insolation both in summer and in winter. In the winter, inversion fog occurs very often in the valleys, while in the summer, the valleys receive less sunshine because of the convective cloudiness which appears above the mountains. With 1582 hours of sunshine per year Stara Fužina on the shore of the lake Bohinjsko jezero is the least insolated weather station in Slovenia; on average the insolation it receives is for about 600 hours lesser than in Primorsko (the Littoral) region (Table 1). The conditions in the high mountains are better, especially in wintertime when there is even more sunshine than in Primorsko. The average duration of sun-

| | | Zima Winter | Pomlad Spring | Poletje Summer | Jesen Autumn | Leto Year |
|---|---|---|---|---|---|---|
| Kredarica (2514 m) | Obsevanje [h] Insolation [hrs] | 368 | 430 | 541 | 448 | 1787 |
| | Št. jasnih dni No. of clear days | 19 | 8 | 6 | 19 | 52 |
| | Št. oblačnih dni No. of cloudy days | 24 | 37 | 29 | 27 | 118 |
| Stara Fužina (547 m) | Obsevanje [h] Insolation [hrs] | 183 | 450 | 619 | 328 | 1582 |
| | Št. jasnih dni No. of clear days | 10 | 10 | 7 | 6 | 34 |
| | Št. oblačnih dni No. of cloudy days | 42 | 37 | 27 | 37 | 143 |

Vir podatkov: Klimatografija Slovenije, tretji zvezek, 1991
Source: Klimatografija Slovenije, Vol. 3, 1991

Preglednica 1: Povprečno trajanje sončnega obsevanja (v urah) ter število jasnih in oblačnih dni na Kredarici in v Stari Fužini v obdobju 1961–1990 (Triglavski narodni park, Slovenija)

*Table 1: Average duration of insolation (in hours) and number of clear and cloudy days on Kredarica and at Stara Fužina in the 1961–1990 period (Triglav National Park; Slovenia)*

okoli 24. Slabo so osončena poletja, saj je v polovici poletnih dni trajanje sončnega obsevanja manjše od 6 ur. Povprečna letna variabilnost sončnega obsevanja je okoli 7 %, letnih časov pa 13 %. Izjemoma lahko vrednosti za letne čase presežejo dolgoletno povprečje za 30 %, pozimi celo 50 %, ali pa je sonca za 15 do 30 % manj kot običajno.

Izračuni kažejo, da prejmejo območja z gorskim podnebjem v Sloveniji okoli 3713 MJ $m^{-2}$ sončne energije letno, največ v tretji dekadi junija (16,1 MJ $m^{-2}$), najmanj pa v tretji dekadi decembra (3,3 MJ $m^{-2}$) (Gabrovec, 1996). Letna energija kvaziglobalnega obsevanja je v Alpah za skoraj 700 MJ $m^{-2}$ manjša kot v submediteranski Sloveniji. V razgibanem gorskem svetu so velike razlike zaradi ekspozicije in osenčenosti. Severne alpske stene prejmejo letno le okoli 800 MJ $m^{-2}$, najbolj sončna prisojna pobočja pa kar šestkrat več.

Primerjava rezultatov o energiji globalnega sončnega sevanja (vsota direktnega in difuznega sevanja) kakor tudi ostalih klimatskih elementov med meteorološko postajo na Kredarici in avtomatsko postajo, ki je delovala pri Dvojnem jezeru, je delno vprašljiva zaradi različnega inštrumentarija in metodologije meritev, čeprav so tudi senzorji pri avtomatski postaji narejeni v skladu s standardi Svetovne meteorološke organizacije (WMO).

V triletju 1997–1999 je Kredarica dobila povprečno 1180 kW $m^{-2}$ (4300 MJ $m^{-2}$) sončne energije letno, poletne vrednosti so se gibale okoli 430 kW $m^{-2}$, zimske pa okoli 170 kW $m^{-2}$. Največ energije je bila deležna maja (168 kW $m^{-2}$), najmanj pa decembra (41 kW $m^{-2}$). Območje Dvojnega jezera je dobilo letno skoraj dvakrat več energije kot Kredarica (2294 kW $m^{-2}$), kar je glede na slovenske razmere občutno preveč. Vzrok lahko tiči v večjem deležu difuznega sevanja, saj je bila meteorološka postaja nameščena na pločevinasti strehi. Razporeditev po letnih časih je podobna kot na Kredarici, z razliko, da so bile na Kredarici jeseni in zime približno izenačene, pri Dvojnem jezeru pa so jeseni dobile bistveno več energije sončnega sevanja (preglednica 2).

*Temperatura zraka*

V gorskem svetu je temperatura zraka odvisna predvsem od nadmorske višine. Pomembno vlogo ima mikroreliefni položaj, zelo pomembne so zlasti depresijske oblike reliefa, v katerih se ob radiacijskem tipu vremena razvije temperaturna inverzija. V dolinah Julijskih Alp je povprečna letna temperatura v savskem delu med 5 in 8 °C, v soškem delu, ki je toplejši zaradi vpliva morja, pa do 9,5 °C. Doli-

shine per year on Kredarica is 1787 hours, or 368 hours in winter, which is 50 hours more than at Portorož (i.e. Primorsko). The fewest cloudy days throughout the seasons are registered in the high mountains in wintertime, on Kredarica there are about 24. Summers are poorly insolated; the daily insolation of 50 % of summer days is shorter than 6 hours. The average yearly insolation variability accounts for about 7 %, and the seasonal variability accounts for 13 %. Exceptionally seasonal values can exceed the multi-year averages by 30 %, in winter by as much as 50 %, in other words there is by 15 to 30 % less sunshine than on average.

Calculations have shown that the areas with mountainous climate in Slovenia receive about 3713 MJ $m^{-2}$ of solar energy per year, of which the largest portion (16.1 MJ $m^{-2}$) is received in the third decade of June, and the smallest (3.3 MJ $m^{-2}$) in the third decade of December (Gabrovec, 1996). The yearly energy of quasiglobal solar radiation in the Alps is almost by 700 MJ $m^{-2}$ less than it is in submediterranean Slovenia. Great differences occur in the mountainous area as a result of different exposure and shadiness of individual locations. The north alpine faces receive only about 800 MJ $m^{-2}$ per year, while the most insolated, sunny slopes receive up to six times more.

Comparison of the results from the energy of global solar radiation (the sum of direct and diffuse radiation) and other climatic elements, obtained from the weather station on Kredarica and from an automatic weather station, which operated near the lake Dvojno jezero, is partly questionable because different instruments and measurement methodologies were applied, even though the sensors at the automatic station, are made in compliance with the standards of the World Meteorological Organisation (WMO).

During the three-year period, from 1997 to 1999, Kredarica received, on average, 1180 kW $m^{-2}$ (4300 MJ $m^{-2}$) of solar energy per year; summer values oscillated around 430 kW $m^{-2}$, and winter values oscillated around 170 kW $m^{-2}$. It received the greatest quantity of energy in May (168 kW $m^{-2}$), and the smallest in December (41 kW $m^{-2}$). According to the AWS ΔT measurements, the area of the lake Dvojno jezero received annually almost twice as much energy as Kredarica (2294 kW $m^{-2}$), which, considering typical Slovenian conditions, appears too high. The cause may lie in an artificially greater percentage of diffuse radiation, since the weather station was installed on a tin roof. The distribution by seasons is similar to that on Kredarica, with the

| | Mesec / Month | | | | | | | | | | | | Leto |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
| Dvojno jezero | 66 | 161 | 241 | 250 | 247 | 240 | 319 | 275 | 235 | 137 | 74 | 49 | 2294 |
| Kredarica | 53 | 54 | 120 | 146 | 168 | 139 | 143 | 121 | 97 | 62 | 41 | 36 | 1180 |

Preglednica 2: Energija globalnega sevanja (v kW $m^{-2}$) pri Dvojnem jezeru (nadmorska višina 1700 m) in na Kredarici (nadmorska višina 2514 m) v obdobju oktober 1996–december 1999 (Triglavski narodni park, Slovenija)
*Table 2: Global radiation energy (in kWm$^{-2}$) near the lake Dvojno jezero (altitude 1700 m) and on Kredarica (altitude 2514 m), in the October 1996–December 1999 period (Triglav National Park; Slovenia)*
Vir podatkov / Sources:
Kredarica: Meteorološki letopisi Slovenije 1996–1999 / Meteolological Annales of Slovenia 1996–1999
Dvojno jezero: meritve avtomatske meteorološke postaje AWS ΔT Device measurements from the Automatic Weather Station ΔT Device

ne na soški strani Julijcev so izrazito toplejše pozimi in pri najnižjih temperaturah. Povprečna januarska temperatura je v zgornji Soški dolini 1 do 2 °C pod ničlo, v Bohinjski dolini okoli –3 °C, v zgornji Savski dolini pa od –4 do –6 °C. Povprečna julijska temperatura se giblje med 16 in 19 °C.

Zaradi pogoste temperaturne inverzije imajo kraji v dolinah nižje minimalne temperature kot območja, ki ležijo nad jezerom hladnega zraka v termalnem pasu. Tako ima vas Krn za desetinko višjo povprečno letno najnižjo temperaturo od skoraj 460 m nižje ležečega Bovca, zimske najnižje temperature pa so v Krnu višje od bovških za okoli 0,5 °C. Še večja je razlika pri povprečnih minimalnih temperaturah med Ratečami (864 m) in Planino pod Golico (970 m) v zgornji Savski dolini, kjer so inverzije še izrazitejše. 100 m višje ležeča Planina je v letnem povprečju toplejša od Rateč skoraj za 1,5 °C, pri zimskih in januarskih pa za okoli 2,5 °C. Ob posameznih inverznih vremenskih razmerah so razlike med kraji, ki ležijo v jezeru hladnega zraka, in tistimi nad njim še večje. Po meritvah v Bohinju v prvi polovici leta 2000 so znašale 5 do 6 °C, lahko pa so še večje.

Po podatkih meteorološke postaje Dom na Komni je povprečna letna temperatura v Julijskih Alpah na 1500 m n. v. okoli 3,7 °C, januarska –4 °C, julijska pa 12,4 °C. Povprečne najnižje in najvišje temperature se od povprečnih razlikujejo za 3,5 do 4,5 °C. 1000 m višje na Kredarici se letni povprečki gibljejo okoli –1,6 °C, januarski okoli –8,2 °C, julijski pa 5,8 °C. Temperaturni gradienti, izračunani s pomočjo postaj na različnih nadmorskih višinah, kažejo, da se povprečna letna temperatura znižuje s stopnjo –0,49 °C/100 m, januarska s stopnjo –0,29 °C/100 m in julijska z –0,59 °C/100 m.

difference that autumns and winters were approximately equal on Kredarica, while the vicinity of the lake Dvojno jezero in autumns was much richer in solar energy (Table 2).

*Air temperature*

Air temperature in the mountainous areas primarily depends on the altitude above sea level. An important role is also played by micro-landforms, depressions in particular, where temperature inversion develops during the radiation weather type. The average annual temperatures in the valleys of the Julian Alps are between 5 and 8 °C in the Sava area, and up to 9.5 °C in the Soča area which is warmer because of the influence of the sea. The valleys in the Soča area of the Julian Alps are explicitly warmer in winter and at minimum temperature. The average January temperature in the upper Soča valley is between –1 and –2 °C, in the valley of Bohinj it is about –3 °C, and in the upper Sava valley between –4 and –6 °C. The average July temperature oscillates between 16 and 19 °C.

Because of frequent temperature inversions there is lower minimum temperature in the valleys than in the areas lying above the layer of cold air in the thermal zone. So, the village of Krn has one tenth of a degree higher average annual minimum temperature than Bovec, lying 460 meters lower, while winter minimum temperature is about 0.5 °C higher at Krn than at Bovec. The difference in the average minimum temperature is even greater between Rateče (864 m above sea level) and Planina pod Golico (970 m), both in the upper Sava valley where inversions are even more frequent. The annual average at Planina pod Golico, 100 m higher, is almost 1.5 °C warmer than the average at Rateče, and winter and January temperature, 2.5 °C. During individual inversion events the differences are even greater between the places that lie in the layer of cold air and those lying above it. Measurements performed in the first half of 2000 in Bohinj showed the difference to be 5 to 6 °C, but they can be even greater.

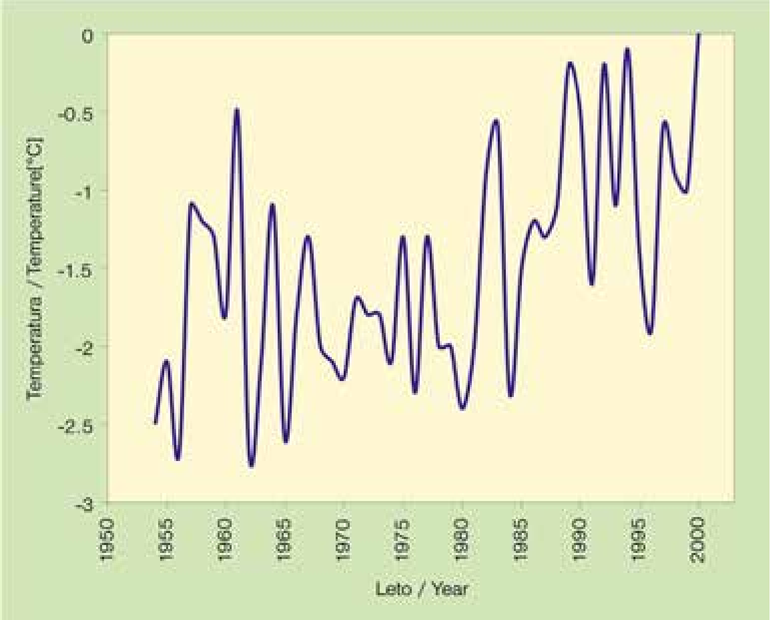
According to the data of the weather station at Dom na Komni the average annual temperature in the Julian Alps at 1500 meters above sea level is about 3.7 °C, in January –4 °C, and in July 12.4 °C. The average minimum and maximum temperatures

Aktualna tema zadnjih let je postopno segrevanje ozračja tako na globalni kot na regionalni in lokalni ravni. Meteorološki postaji Kredarica in Rateče imata meritve od leta 1953 oziroma 1949 naprej. Pogoji meritev se na obeh postajah niso bistveno spreminjali, zato so njuni podatki zelo primerni za raziskavo temperaturne spremenljivosti in trendov. Pri obeh je opazen trend naraščanja temperature zraka, še posebej po letu 1980. V celotnem obdobju je povprečna letna temperatura na Kredarici naraščala s stopnjo 1,1 °C/30 let (slika 1), v Ratečah pa z 0,3 °C/30 let. Na Kredarici so se ogrevale predvsem zime (+1,3 °C/30 let) in poletja (+0,8 °C/30 let), v Ratečah pa poletja (+0,5 °C/30 let). Desetletje 1991–2000, ki velja za eno najtoplejših doslej, je bilo v Ratečah toplejše od povprečja 1961–1990 za 0,9 °C, na Kredarici pa za 0,2 °C. Na Kredarici se je nadaljevalo ogrevanje zim (toplejše od povprečja za 1,4 °C) in poletij (+1,2 °C), v Ratečah pa predvsem poletij (+1,2 °C).

Meritve pri Dvojnem jezeru so nam omogočile primerjavo temperatur na profilu med Staro Fužino v Bohinju (n. v. 547 m), Voglom (1535 m), Dvojnim jezerom (1700 m) in Kredarico (2514 m) (preglednica 3). Ob Bohinjskem jezeru je bila povprečna letna temperatura 8,4 °C, 1000 m višje na Voglu 4,9 °C, pri Dvojnem jezeru 4,0 °C, na Kredarici pa –0,6 °C. Temperatura se je z višino spreminjala s stopnjo –0,39 °C/100m. Zimski gradient je bil nižji, –0,29 °C/100m, poletni pa večji, z upoštevanjem Stare Fužine –0,88 °C/100 m, brez nje pa –0,66 °C/100 m.

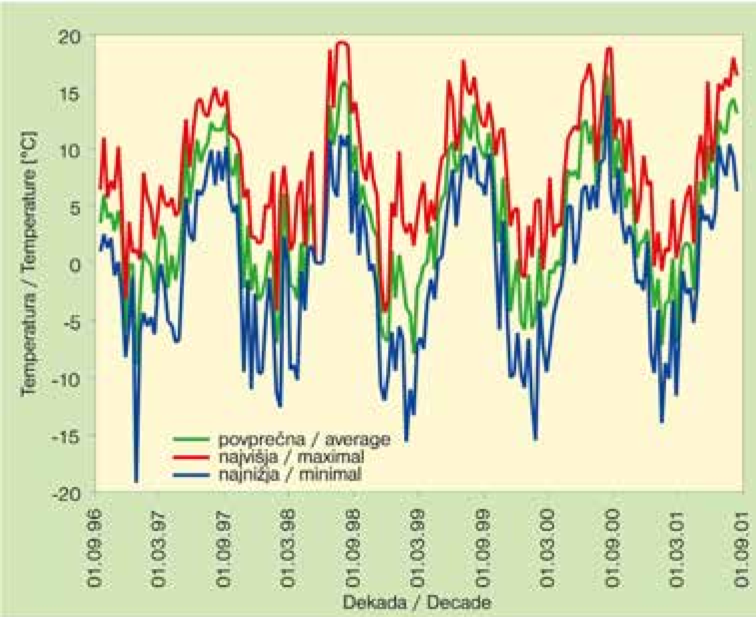
Pri Dvojnem jezeru so bile povprečne zimske deviate from the averages by 3.5 to 4.5 °C. On Mt. Kredarica, lying a thousand meters higher, the annual average oscillates around –1.6 °C, in January around –8.2 °C, and in July around 5.8 °C. Temperature gradients calculated from the data collected at the stations at different altitudes above sea level show that the average annual temperature drops with the increasing altitude at the rate of 0.49 °C/100 m, in January at the rate of 0.29 °C/100 m, and in July at the rate of 0.59 °C/100 m.

Gradual warming of the atmosphere on all levels, global, regional and local, is a topical subject of recent years. Measurements at the weather stations Kredarica and Rateče have been performed since 1953 and 1949 respectively. Measurement conditions at either station have not changed considerably, so their data are very suitable for investigation into the variability and trends in temperature. A trend towards increasing air temperature is noticeable at both stations, especially after 1980. The average annual air temperature has been increasing throughout the period at the rate of 1.1 °C/30 years on Kredarica (Figure 1) and at the rate of 0.3 °C/30 years at Rateče. Both, winters (1.3 °C/30 years) and summers (0.8 °C/30 years) have become warmer on Kredarica, while only summers (0.5 °C/30 years) have become warmer at Rateče. The 1991-2000 decade, which has been established as one of the warmest decades, was 0.9 °C warmer than the average of the 1961-1990 period at Rateče, and 0.2 °C on Kredarica. The warming continues at both, winters (warmer than the average by 1.4 °C) and




Slika 1: Povprečne letne temperature zraka na Kredarici (nadmorska višina 2514 m; Triglavski narodni park, Slovenija) v obdobju 1953–2000

*Figure 1: The average annual air temperature on Kredarica (altitude 2514 m; Triglav National Park, Slovenia) in the 1953–2000 period*




Slika 2: Povprečne, najvišje in najnižje temperature zraka po dekadah pri Dvojnem jezeru (nadmorska višina 1700 m; Triglavski narodni park, Slovenija) v obdobju september 1996–september 2001

*Figure 2: The average, maximal and minimal air temperature per decade near the lake Dvojno jezero (altitude 1700 m; Triglav National Park, Slovenia) in the period from September 1996 to September 2001*

temperature –2,5 °C, poletne pa 11,2 °C, jeseni so bile toplejše od pomladi, kar kaže na določeno maritimnost temperaturnega režima, saj tudi povprečna letna temperaturna amplituda komajda preseže 15 °C . Najvišja temperatura je bila pri Dvojnem jezeru 13. 8. 1998, in sicer 24,5 °C, najnižja pa –20,3 °C 28. 12. 1996.

Dni z minimalno temperaturo pod 0 °C je bilo okoli 110 letno, z razponom od 94 dni (leta 2000) do 119 dni (leta 1999). Nad 10 °C je imelo v povprečju 79 dni letno, največ leta 1997, 85 dni, najmanj pa leta 1998, 68 dni. V povprečju je trajalo obdobje s povprečno dnevno temperaturo nad 10 °C, kar približno sovpada z vegetacijsko dobo za drevje, od 19. junija do 5. septembra, pod lediščem pa so bile povprečne dnevne temperature med 11. novembrom in 20. marcem (129 dni).

summers (1.2 °C) on Kredarica, but mainly during summers (1.2 °C) at Rateče.

Measurements performed near the lake Dvojno jezero enabled the comparison of temperature on an elevation profile between Stara Fužina in Bohinj (547 m), Vogel (1535 m), Dvojno jezero (1700 m) and Kredarica (2514 m) (Table 3). The average annual temperature by the lake Bohinjsko jezero was 8.4 °C, a thousand meters higher on Vogel it was 4.9 °C, near the lake Dvojno jezero 4.0 °C, and on Kredarica –0.6 °C. The temperature dropped with the increasing altitude at the rate of 0.39 °C/ 100 m. The winter gradient was lower (0.29 °C/100 m) and the summer one was higher; it amounted to 0.88 °C/100 m with the data from Stara Fužina included, and 0.66 °C/100 m without the inclusion of these data.

The average winter temperature near the lake Dvojno jezero was –2.5 °C, and the summer one was 11.2 °C; autumns were warmer than springs which points to a certain maritime character of the temperature regime; the average annual temperature amplitude hardly exceeds 15 °C. The highest temperature of 24.5 °C at the lake Dvojno jezero was registered on August 13, 1998, and the lowest, –20.3 °C, on December 28, 1996.

On average, there were 110 days per year with minimum temperature below 0 °C, within the range of 94 days (in 2000) to 119 days (in 1999). Temperature higher than 10 °C was registered on 79 days per year on average, the most numerous were in 1997 (85 days), and the fewest in 1998 (68 days). On average, the period with the average daily temperature above 10 °C lasted from June 19 to September 5, which mainly coincides with the growt period for trees, while the average daily temperature below 0 °C was between November 11 and March 20 (129 days).

*Padavine*

Julijske Alpe, še posebej njihov zahodni in južni del, spadajo med najbolj namočena območja Slovenije in Evrope. V zahodnem in južnem delu gorovja pade zaradi prisilnega dvigovanja zraka ob gorskih pregradah v 130 do 150 padavinskih dne-

*Precipitation*

The Julian Alps, their western and southern parts in particular, belong to the wettest regions in Slovenia and also in Europe. Because of the forced rise of the air up the mountain barriers, more than 3000 mm of precipitation per year falls in the west-

| | Mesec / Month | | | | | | | | | | | | Leto |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
| Kredarica | -6.1 | -6.5 | -5.5 | -3.9 | 1.9 | 4.6 | 6.0 | 8.7 | 3.0 | 1.1 | -4.5 | -6.2 | -0.6 |
| Dvojno jezero | -3.1 | -1.8 | -0.4 | 1.6 | 7.6 | 9.8 | 11.4 | 12.5 | 8.8 | 4.5 | -0.5 | -2.5 | 4.0 |
| Vogel | -1.8 | -1.3 | 0.1 | 2.6 | 8.8 | 11.5 | 13.1 | 14.2 | 8.7 | 6.0 | 0.3 | -2.2 | 4.9 |
| Stara Fužina | -1.2 | 0.8 | 4.8 | 8.1 | 10.8 | 16.5 | 17.5 | 18.2 | 13.3 | 9.4 | 3.8 | -0.8 | 8.4 |

Preglednica 3: Povprečne mesečne in letne temperature zraka (°C) na Kredarici (nadmorska višina 2514 m), pri Dvojnem jezeru (nadmorska višina 1700 m), na Voglu (nadmorska višina 1535 m) in Stari Fužini (nadmorska višina 547 m) v obdobju oktober 1996–avgust 2001 (Triglavski narodni park, Slovenija)

*Table 3: Average monthly and annual air temperatures (°C) on Kredarica (altitude 2514 m), by the lake Dvojno jezero (altitude 1700 m), on Vogel (altitude 1535 m), and at Stara Fužina (altitude 547 m) in the October 1996–August 2001 period (Triglav National Park; Slovenia)*

Vir podatkov / Sources:
Meteorološki letopisi Slovenije 1996-1999 / Meteorological Annales of Slovenia 1996-1999
Arhiv HMZ RS (ARSO) / Archives HMZ RS (ARSO)
Dvojno jezero: meritve avtomatske meteorološke postaje AWS ΔT Device / measurements from the Automatic Weather Station ΔT Device

vih več kot 3000 mm padavin letno, v vzhodnem in severnem delu, ki leži v blagi padavinski senci, pa v 115 do 130 dnevih od 1800 do 2500 mm. Maksimum namočenosti je med Krnom in Komno. Orografske padavine so najizdatnejše v jesenskih mesecih, ko je vlaga v dotekajočem zraku neprimerno večja kot pozimi ali spomladi, ko se morje že nekoliko ohladi. V 30-letnem obdobju 1961–1990 je padlo v Lepeni povprečno 3018 mm padavin, na Voglu pa 3077 mm. V Stari Fužini znaša povprečje 2333 mm, na Kredarici 1994 mm in v Ratečah 1563 mm. Dejansko pa v gorskem svetu pade še več padavin, saj ombrometri ob vetrovnem vremenu prestrežejo premalo padavin. Po korigiranih podatkih (Kolbezen in Pristov, 1998) pade npr. na dobro prevetreni Kredarici 3228 mm padavin letno, kar je 60 % več od izmerjene količine, na Voglu pa 10 % več. V manj vetrovnih alpskih dolinah je padavin po korigiranih podatkih za 2 do 5 % več od izmerjenih količin.

Ne glede na veliko povprečno namočenost Julijskih Alp se količina padavin od leta do leta zelo spreminja. V grobem je po 2. svetovni vojni opazen rahel trend zniževanja letne količine padavin, zlasti v jesenskih mesecih. Variabilnost padavin je velika. Povprečna letna relativna variabilnost znaša okoli 15 %. Pri letnih časih je največja pozimi, med 40 in 65 %, spomladi in jeseni je med 30 in 40 %, najbolj konstantne pa so padavine poleti (povprečna relativna variabilnost 20 do 30 %), ki so zelo pogosto lokalnega konvekcijskega nastanka. V posameznih mesecih je lahko dolgoletno povprečje preseženo za več kot 100 %, v ekstremnih primerih tudi več, ali pa padavin praktično ni. Izjema so poletni meseci, ko zanesljivo pade vsaj nekaj 10 % običajne vsote.

ern and southern parts of the mountains in 130 to 150 days, while in the eastern and northern parts, which are slightly sheltered from precipitation, 1800 to 2500 mm falls in 115 to 130 days. The area between Mt. Krn and the Komna plateau receives the maximum precipitation. Orographic precipitation is most abundant in the autumn months, when the inflowing air is much more humid than in winter or spring when the sea has already cooled a little. Between 1961–1990, 3018 mm of precipitation fell on average at Lepena, and 3077 mm on Vogel. The average at Stara Fužina was 2333 mm, on Kredarica 1994 mm, and at Rateče 1563 mm. In fact, precipitation in the mountains is even more abundant because the rain gauges do not capture all the precipitation in windy weather. According to corrected data (Kolbezen & Pristov, 1998), on Kredarica, for example, where it is very windy, 3228 mm of precipitation falls each year, which is 60 % more than the measured amount, and on Vogel it is 10 % more. Less windy alpine valleys receive, according to the corrected data, from 2 to 5 % more precipitation than the measured amounts appear to indicate.

In spite of the high average precipitation in the Julian Alps its quantity changes considerably from year to year. After the World War II a general trend towards a moderate decrease has been noticed in the annual precipitation particularly in autumn months. The variability of precipitation quantity is considerable. The average annual relative variability is about 15 %. Seasonally the variability is at its greatest in winter, between 40 and 65 %, in spring and autumn it is between 30 and 40 %, while the most constant precipitation occurs in summer (the average relative variability being 20 to 30 %) and it is very often of local convective origin. In particular months the multi-year average can be exceeded by more than 100 % or even more in ex-

Z vidika poplavne ogroženosti je pomembna največja količina padavin, ki lahko pade v enem dnevu. Zgornje Posočje je glede tega rekorder v Sloveniji, saj jih lahko pade tudi več kot 400 mm, to je toliko, kolikor znaša povprečje za november na Komni, ki je običajno najbolj namočen mesec v letu.

Razporeditev padavin preko leta je relativno enakomerna, z dvema manjšima viškoma in nižkoma. Podobno kakor vsa zahodna Slovenija imajo tudi Julijske Alpe submediteranski padavinski režim, s primarnim viškom v jeseni, običajno novembra, in sekundarnim viškom na prehodu pomladi v poletje, maja ali junija. Najmanj padavin pade pozimi (februarja) ter julija in avgusta.

Po podatkih avtomatske meteorološke postaje pri Dvojnem jezeru je padlo v obdobju 1997–2000 povprečno nekaj nad 2000 mm padavin letno, največ leta 2000, 2409 mm, od tega polovico novembra, najmanj pa leta 1999, 1458 mm. Največ padavin v enem dnevu je padlo 10. 10. 1999, 177 mm.

V skladu z dolgoletnimi povprečji za ta konec Slovenije so bile najbolj namočene jeseni (oktober in november), ko je padla skoraj polovica letne vsote, sledijo poletja (julij), najmanj padavin pa je postaja namerila pozimi. Rezultati v hladnem delu leta so delno nepopolni, saj naprava nima talilca snega. Primerjava (tudi grafična) s sosednjimi uradnimi padavinskimi postajami pa je pokazala, da so podatki primerljivi in da ni nobenih odstopanj ne v razporeditvi in ne v količini padavin, kar je posledica kompenzacije napak pri obeh načinih merjenja (preglednica 4).

V hladni polovici leta pade v visokogorju Julijskih Alp večina padavin v obliki snega. V visokogorju težko ločimo zadnje spomladansko sneženje od prvega jesenskega, saj lahko v višinah nad 1500 m sneži celo leto. Na Kredarici (n. v. 2514 m) sneg običajno neprekinjeno obleži od začetka novembra

treme cases, or, on the other hand, there is practically a total lack of precipitation, except for summer months when at least some tens of percent of the usual quantity fall.

Of decisive importance as regards the possibility of floods is the maximum precipitation that can fall in a single day. In this respect, the upper Soča region is a record holder in Slovenia; over 400 mm of precipitation can fall there in a single day, which is equal to the average precipitation at Komna in the whole of November, usually the wettest month in the year.

Precipitation is rather evenly distributed throughout the year, with two minor maximums and minimums. Like all of west Slovenia, the Julian Alps have a sub-mediterranean precipitation regime with the primary maximum in autumn, usually in November, and the secondary maximum at the turn of spring into summer, in May or June. The least precipitation falls in winter (February) and in July and August.

The data from the automatic weather station near the lake Dvojno jezero show that in the 1997-2000 period the average precipitation per year was roughly 2000 mm. The largest amount, 2409 mm, fell in the year 2000, and the smallest quantity, 1458 mm fell in 1999. The largest daily amount of 177 mm was registered on October 10, 1999.

According to the multi year averages in this part of Slovenia, autumn is the wettest season (October and November) when almost a half of the total annual precipitation falls, then follows summer (July), and the smallest precipitation amounts were registered in winter. The results for the cold part of the year are somewhat incomplete, because the rain gauge was without a snow melter. A comparison (graphical comparison as well) with the neighboring official stations for precipitation measuring

| | Mesec / Month | | | | | | | | | | | | Leto |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
| Kredarica | 118 | 51 | 170 | 189 | 140 | 208 | 246 | 171 | 173 | 313 | 310 | 140 | 2229 |
| Dvojno jezero | 146 | 23 | 111 | 155 | 82 | 161 | 232 | 144 | 193 | 318 | 422 | 62 | 2049 |
| Vogel | 164 | 44 | 111 | 251 | 167 | 201 | 297 | 156 | 237 | 453 | 416 | 175 | 2672 |
| Stara Fužina | 129 | 32 | 179 | 183 | 127 | 181 | 226 | 133 | 172 | 324 | 483 | 163 | 2332 |

Preglednica 4: Povprečne mesečne in letne vsote padavin (v mm) za Kredarico (nadmorska višina 2514 m), Dvojno jezero (nadmorska višina 1700 m), Vogel (nadmorska višina 1535 m) in Staro Fužino (nadmorska višina 547 m) v obdobju oktober 1996–avgust 2001 (Triglavski narodni park, Slovenija)
*Table 4: Average monthly and annual precipitation (mm) on Kredarica (altitude 2514 m), near the lake Dvojno jezero (altitude 1700 m), on Vogel (altitude 1535 m), and at Stara Fužina (altitude 547 m) in the October 1996–August 2001 period (Triglav National Park; Slovenia)*

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Meteorološki letopisi Slovenije 1996–1999 / Meteorological Annales of Slovenia 1996–1999
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Dvojno jezero: meritve avtomatske meteorološke postaje AWS ΔT Device / measurements from the Automatic Weather Station ΔT Device

do začetka junija. Na Komni (n. v. 1520 m) in na Voglu (n. v. 1535 m) se snežna odeja pojavi v oktobru in traja do maja. Od decembra do vključno aprila je praktično neprekinjena, kakšen dan s snežno odejo imamo lahko tudi septembra in junija. V alpskih dolinah se snežna odeja pojavlja med novembrom in aprilom, pri čemer lahko tudi v osrednjih zimskih mesecih za nekaj časa skopni. Več kopnih dni in manjše število dni s snegom imajo nekoliko toplejše doline na soški strani Julijcev. V povprečju se snežna odeja tu pojavlja v 80 do 100 dneh letno, v dolinah povirja Save pa v 90 do 130 dnevih letno. V višinah med 1000 in 1500 m se sneg obdrži med 150 in 200 dnevi na leto, na Kredarici pa znaša dolgoletno povprečje 262 dni.

O višini snežne odeje v gorah težko govorimo, ker je ta zelo odvisna od lokalnih reliefnih razmer (uravnjenost površja, strmina pobočij, ekspozicija) in mikro klime, še posebej izpostavljenosti vetru. V visokogorju Julijskih Alp lahko računamo v povprečno namočenih zimah z debelino snega 3 do 5 m, v izjemno namočeni zimi in pomladi 2000/2001 so npr. na Kredarici namerili celo 7 m snega. V alpskih dolinah pa lahko zapade največ 2 do 3 m snega.

*Veter*

O splošni sliki vetrov v Julijskih Alpah je težko govoriti, ker na vetrovne razmere zelo vpliva mikro lega. Nasplošno so naše Alpe zaradi lege na jugovzhodnem robu centralnih Alp v relativnem zatišju pred močnimi severozahodnimi in severnimi vetrovi in odprte toplim in vlažnim jugozahodnim vetrovom. Jugozahodni vetrovi pihajo ponavadi pred prihodom ciklonov, za hladno fronto in odhajajočimi cikloni pa se pojavljajo vetrovi iz severnega kvadranta, ki so razmeroma hladni in suhi. Za mirno vreme, brez močnejših splošnih vetrov, je značilna lokalna zračna cirkulacija, do katere pride zaradi krajevnih razlik v ogretosti. Izmenjujejo se šibki pobočni vetrovi čez dan s podolinskimi ponoči.

V alpskih dolinah je vetrovnost nasplošno šibka. Delež tišin je npr. v Ratečah skoraj 68 %, v Bovcu 40 % in v Stari Fužini 27 %. Če veter piha, je zanj značilno, da se kanalizira v smeri dolin. Tako v Ratečah in Stari Fužini prevladujejo vetrovi iz vzhoda in zahoda, v Bovcu pa iz severovzhoda in jugozahoda. Delež teh vetrov se giblje med 7 in 15 %, njihove povprečne hitrosti pa ne presegajo 3 m $s^{-1}$.

V visokogorju so vetrovi pogostejši in dosegajo višje hitrosti. Na Komni in Kredarici je po podatkih za obdobje 1961–1990 znašal delež brezvetrja od 13 do 19 %. S 26 % oziroma 17 % so na Komni

showed that the data are comparable, and that no deviations occur in the distribution or in the quantities of precipitation (Table 4).

Precipitation in the high mountains of the Julian Alps mainly falls in the form of snow in the cold part of the year. But it is difficult to distinguish the last spring snow from the first autumn snow in high mountains, because at the altitudes above 1500 meters snow can be the only precipitation throughout the year. On Kredarica (2514 m) snow cover lies continually from the beginning of November to the beginning of June. On Komna (1520 m) and Vogel (1535 m), snow cover occurs in October and lasts until May. From December to April it is practically uninterrupted, and a day with snow cover can also occur in September and June. Snow in alpine valleys usually lies from November to April, but it can melt away for some time even in the central winter months. There are more days without snow cover and a smaller number of days with it in the slightly warmer valleys on the Soča side of the Julian Alps. On average, snow in this area lies 80 to 100 days per year, and 90 to 130 days in the valleys of the Sava headwaters. At altitudes between 1000 and 1500 m, snow lies from 150 to 200 days per year, and on Kredarica the multi-year average is 262 days.

It is difficult to discuss the thickness of snow cover in the mountains because it strongly depends on local landforms (surface and slope morphometry, and exposure), microclimate, and exposure to wind in particular. In the high mountains of the Julian Alps, snow cover of 3 to 5 m can be expected in winters with the average precipitation, while during the 2000–2001 season, when above average precipitation fell in winter and spring, as much as 7 m of snow was registered on Kredarica. In alpine valleys, a maximum of 2 to 3 m of snow can fall.

*Wind*

It is not possible to talk about a general system of winds in the Julian Alps, because micro-location has a strong impact on wind conditions. Due to their position at the south-east edge of the higher central Alps, the Alps in Slovenia in general lie in a relative lee from strong NW and N winds and they are open to warm and humid south-west winds. The latter usually blow before the arrival of cyclones. Winds from the north quadrant develop after the cold front and cyclones have gone, and they are rather cold and dry. During calm weather, without stronger general winds, a typical local air circulation develops because of the local warmth differ-

Radiacijska megla nad Soško dolino v Trenti (Triglavski narodni park, Sovenija). Višina meglene plasti kaže na višino jezera hladnega zraka. (Foto: Anton Brancelj)
*Radiation fog above the valley of Soča river in Trenta (Triglav National Park; Slovenia). The height of the fog layer shows the height of the lake of cold air. (Photo: Anton Brancelj)*

najpogostejši zahodni in severozahodni vetrovi, na Kredarici pa s 36 % prevladujejo severozahodni vetrovi pred jugovzhodnimi (22 %). Ostali vetrovi se pojavljajo z do 10-odstotnim deležem. Podatkov za Kredarico ne smemo jemati kot razmere v prosti atmosferi, ker vrh Triglava odklanja zahodne in jugozahodne vetrove. Na Komni dosegajo v povprečju največje hitrosti južni vetrovi (4,7 m $s^{-1}$), na Kredarici pa severni (7,8 m $s^{-1}$). Najmočnejši sunki lahko na Kredarici presežejo 50 m $s^{-1}$.

Meritve pri Dvojnem jezeru so potrdile odvisnost prevladujočih smeri vetrov od reliefnih danosti. Dolina Triglavskih jezer poteka v smeri sever–jug, iz teh smeri je pihalo tudi največ vetrov. Z 20-odstotnim deležem so prevladovali severni vetrovi, sledili so jim severozahodni in severovzhodni ter južni in jugozahodni (preglednica 5). Brezvetrja (hitrosti vetra, manjše od 0,2 m $s^{-1}$) je bilo 8 %. Povprečne polurne hitrosti vetrov so bile majhne, nekaj nad 1 m $s^{-1}$, na Kredarici npr. nad 5 m $s^{-1}$, največje pa med 6,4 in 9,6 m $s^{-1}$. Močnejši vetrovi so praviloma pihali iz severnega kvadranta. V zimskem in spomladanskem času so bili še bolj kot sicer dominantni severni vetrovi, poleti in jeseni pa je bilo nekaj več južnih

ences. Weak slope winds by day alternate with valley winds at night.

Windiness in the alpine valleys is generally weak. For example, calm conditions at Rateče account for 68 %, at Bovec 40 %, and at Stara Fužina 27 % of recorded data. When the wind blows, it is channeled in the direction of valleys. So at Rateče and Stara Fužina east and west winds prevail, and at Bovec, north–east and south–west winds. The percentage of these winds oscillates between 7 and 15 % and their average velocities do not exceed 3 m $s^{-1}$.

Winds are more frequent in the high mountains where they also reach higher velocities. According to the data of the 1961–1990 period, calm conditions on Komna and Kredarica accounted for 13 to 19 % of data recorded. West (26 %) and north-west (17 %) winds are most frequent at Komna, while on Kredarica, north-west (36 %) winds prevail over the south-east (22 %) ones. Other wind directions account for about 10 % of recorded data. The data for Kredarica must not be considered as conditions in atmosphere, because the peak of Mt. Triglav deflects the west and south-west winds. On Komna the south-west winds are the ones that reach the highest velocities (4.7 m $s^{-1}$) on average, and on Kredarica, it is the north winds (7.8 m $s^{-1}$) whose strongest gusts may exceed 50 m $s^{-1}$.

The measurements near the lake Dvojno jezero confirmed the dependence of prevailing wind directions on landforms. The valley of Dolina Triglavskih jezer runs in the north-south direction and from these two directions most of the winds blow. North winds prevail (20 %), followed by north-west and south-east winds, and then finally south and south-west winds (Table 5). Calm conditions (wind velocity less than 0.2 m $s^{-1}$) accounted for 8 % of recorded tada. The average 30-minute wind velocities are small, slightly more than 1 m $s^{-1}$ (on Kredarica, for example, more than 5 m $s^{-1}$), and the maximum velocities, between 6.4 and 9.6 m $s^{-1}$. Stronger winds blow mainly from the north quadrant. In winter and spring, north winds are even more dominant, while in summer and autumn, south winds are slightly more frequent. In summer-

| | S<br>N | SV<br>NE | V<br>E | JV<br>SE | J<br>S | JZ<br>SW | Z<br>W | SZ<br>NW | Tišine<br>Calms |
|---|---|---|---|---|---|---|---|---|---|
| 1 [%] | 20.0 | 12.7 | 4.7 | 7.4 | 11.9 | 11.4 | 8.1 | 15.2 | 8.0 |
| 2 [m s] | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | |
| 3 [m s] | 9.1 | 8.4 | 7.5 | 7.8 | 8.1 | 6.4 | 6.9 | 9.6 | |

Preglednica 5: Pogostost vetra po smereh (%) [1], povprečne polurne hitrosti [2] in največje polurne hitrosti vetra po smereh [3] pri Dvojnem jezeru (nadmorska višina 1700 m) v obdobju oktober 1996–avgust 2001, izmerjene s pomočjo avtomatske meteorološke postaje ΔT Device (Triglavski narodni park, Slovenija)

*Table 5: Wind frequency (%) [1], average 30-minute velocity [2], and maximum 30-minute velocity [3] by directions as measured by AWS ΔT Device near the lake Dvojno jezero (altitude 1700 m) in the period October 1996 – August 2001 (Triglav National Park; Slovenia)*

vetrov. V poletnem času je bilo tudi manj brezvetrja. Zaradi primrznitve anemometra in vetrnice je bilo v zimskem času okoli 2 % izpada podatkov.

time, calm conditionss were also less frequent. Because of a frozen anemometer and wind vane, about 2 % of winter data were not registered.

## DENDROKLIMATSKE ZNAČILNOSTI JULIJSKIH ALP

Za potrebe projekta Slovenska alpska jezera: ekologija in paleoekologija smo za območje Krnskega jezera, Jezera v Ledvicah in Jezera na Planini pri Jezeru naredili tudi nekatere dendrokronološke in dendroklimatološke raziskave, s katerimi smo ugotavljali osnovne zveze med debelinskim priraščanjem dreves in klimatskimi razmerami. Rezultati teh raziskav so bili že objavljeni (Ogrin, 1998, 1999), v prispevku povzemamo le glavne ugotovitve, združene tudi z ugotovitvami raziskav na Komni in Vršiču.

Debla smrek (*Picea abies* (L.) Karsten) in macesnov (*Larix decidua* Mill.), ki smo jih vzorčili za raziskavo, so rasla na nadmorski višini od 1400 do 1750 m, na 3 do 20$^0$ strmih apnenčastih in dolomitnih pobočjih z različno ekspozicijo in zelo skromnimi talnimi razmerami. Pri vzorčenju in analizi smo upoštevali standardne dendrokronološke in dendroklimatološke postopke. V končni fazi smo za območje Julijskih Alp izdelali 8 lokalnih kronologij drevesnih letnic, po 4 smrekove in 4 macesnove. Kronologije so različno dolge, od 38 do 135 let (1861–1996), kolikor je dolga macesnova kronologija za območje Jezera v Ledvicah. Iz lokalnih kronologij smo izdelali dve regionalni kronologiji, smrekovo in macesnovo.

## DENDROCLIMATIC CHARACTERISTICS OF THE JULIAN ALPS

For the requirements of the project “Slovenian Alpine Lakes: Ecology and Paleoecology” some dendrochronological and dendroclimatological research was also undertaken in the areas of the lakes Krnsko jezero, Jezero v Ledvicah, and Jezero na Planini pri Jezeru, to establish basic relationships between tree increments and climatic conditions. Ogrin (1998, 1999) published the results of these investigations, so the present paper just summarises the principal conclusions, in combination with the results of investigations carried out on the Komna plateau and Mt. Vršič.

The spruce (*Picea abies* (L.) Karsten) and larch (*Larix decidua* Mill.). that were sampled for the investigation grew at altitudes between 1400 and 1750 m above sea level, on 3–20 degree steep limestone or dolomite slopes of different exposure and very modest soil conditions. The sampling and the analysis followed standard dendrochronological and dendroclimatological procedures. The final stage included the elaboration of eight local chronologies of annual rings for the area of the Julian Alps, four for spruce and four for larch. The chronologies vary in length, from 38 to 135 years (from 1861 to 1996); the latter referring to the larch chronology for the area of the lake Jezero v Ledvicah. Two regional chronologies were derived from local chronologies, one for spruce and another for larch.

### *Odvisnost debelinskega prirastka od klimatskih razmer*

Odnose med širino letnic in temperaturami ter padavinami smo raziskovali s pomočjo korelacijske analize in odzivnih funkcij za lokalne in za regio-

### *Dependence of tree increments on climatic conditions*

Relationships between the annual rings and temperature and precipitation were studied by nalni kronologiji. Pri tem smo upoštevali 13-mesečno obdobje, od septembra preteklega leta, ko se formira zasnova bodočega prirastka, pa do septembra tekoče rastne sezone.

V gorskem svetu Julijskih Alp vplivajo temperature na debelinski prirast smrek (*Picea abies*) predvsem v dveh obdobjih: v obdobju rasti in pozimi. V vegetacijski dobi izstopa vpliv nadpovprečnih temperatur v mesecih v začetku rasti (maj, r = 0,31; junij, r = 0,31; julij, r = 0,31) (slika 3), ko je kambij najbolj aktiven. Pozitivno in statistično pomembno korelacijo smo dobili tudi za celotno poletje (r = 0,32). V vseh teh mesecih in v celotnem poletju je povprečna temperatura v slovenskih gorah na nadmorski višini okoli 1500 m, od koder je večina vzorcev, okoli oziroma pod 12 °C, kar je v povprečju pod spodnjo optimalno mejo za fotosintezo.

V nasprotju s poletnimi delujejo višje zimske temperature zaviralno na debelinski prirast smrek v rastni sezoni (december, r = –0,34; zima, r = –0,32). Višje zimske zračne temperature povzročijo, še posebej v kombinaciji z vetrom, v času, ko so korenine hladne ali celo zamrznjene, povečano transpiracijo, ki privede do fiziološke sušnosti in poškodb iglic ter tkiv. Hladne korenine pa, tudi če zemljišče ni zamrznjeno, ne morejo zagotoviti zadostne količine vlage za nadomestitev izgube, ki nastane zaradi povečanega izhlapevanja. Ta proces prizadene predvsem tiste drevesne vrste, ki obdržijo čez zimo iglice, med njimi tudi smreko.

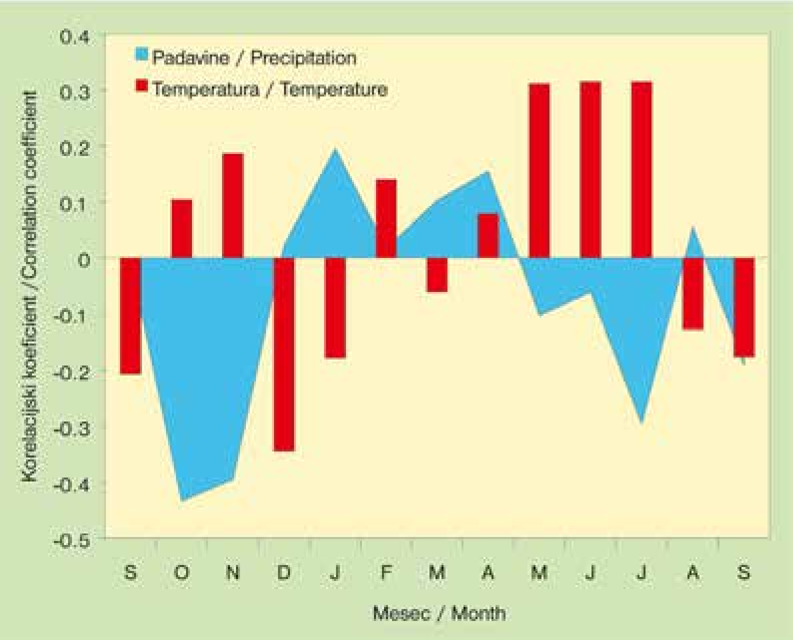
Zaradi velike namočenosti Julijskih Alp so padavine v vegetacijski dobi v obratnem sorazmerju s širi-

means of correlation analysis and response functions for local chronologies and both regional chronologies. 13-month periods were considered, from September of the previous year, when the base of the future increment forms, to September of the current vegetation season.

In the mountainous area of the Julian Alps, temperature influences the formation of radial increments in fir (*Picea abies*) particularly in two periods, i.e. the vegetation period and winter. In the vegetation period the influences of above-average temperature during the initial months of this period stands out (May: r = 0.31; June: r = 0.31; July: r = 0.31) (Figure 3), when the cambium is most active. A statistically relevant positive correlation was also obtained for the entire summer (r = 0.32). During all these months and throughout the summer, the average temperature in Slovenian mountains at the altitude of about 1500 m, where most of the samples were taken, is about 12 °C or lower which on average, is less than the lower optimum limit for photosynthesis.

In contrast to summer, higher winter temperature impedes the formation of radial increments during the vegetation season (December: r = –0.34; winter: r = –0.32). Higher air temperature in winter, especially in combination with wind, causes increased transpiration in the period when roots are cool or even frozen, which leads to physiological drought and damage to needles and tissues. Even if the ground is not frozen, cool roots cannot provide sufficient moisture to make up for the loss of moisture which results from the increased evaporation. This process particularly affects the tree species, which retain needles in winter, such as spruce.

Because of the considerable wetness of the Julian Alps an inverse ratio exists between the pre-




Slika 3: Dolgoletna odzivna funkcija za smreke (*Picea abies* (L.) Karsten) iz Julijskih Alp (nadmorska višina 1400–1750 m; Triglavski narodni park, Slovenija) na količino padavin in temperaturo po posameznih mesecih

*Figure 3: A long-term response function of spruce (Picea abies (L.) Karsten) in the Julian Alps (altitude between 1400 and 1750 m; Triglav National Park; Slovenia) for amount of precipitation and temperature per individual month*

no letnic (junij, r = –0,31; julij, r = –0,29; poletje, r = –0,24; vegetacijska doba, r = –0,29). Višja količina padavin pomeni ožje letnice in obratno. Vpliv padavin na širino letnic v vegetacijski dobi razlagamo posredno preko vpliva na temperaturo zraka. Padavinske dneve spremlja oblačnost, ki v gorah znižuje temperature.

Na podoben način si lahko razlagamo tudi negativni korelaciji za padavine v jeseni preteklega leta (oktober, r = –0,43; november, r = –0,39), to je v času, ko potekajo v drevesih procesi priprav na zimsko mirovanje. Iz višine korelacijskih koeficientov lahko sklepamo, da je dobra priprava na zimo, ki jo omogoča predvsem bolj suha jesen, celo pomembnejši dejavnik debelinskega prirastka smrek v naslednji sezoni kot pa manj padavin v času rasti.

Odziv macesnov na klimatske razmere je podoben odzivu smrek, zlasti v vegetacijski sezoni. Nadpovprečne temperature v tem času pomenijo širše letnice (april, r = 0,41; maj, r = 0,45; julij, r = 0,43; avgust, r = 0,45; september, r = 0,45; poletje, r = 0,77). Debelinski prirastek je odvisen tudi od razmer v jeseni preteklega leta oziroma od pogojev za pripravo na zimsko mirovanje (oktober, r = 0,54).

Čeprav macesni odvržejo iglice, se višje temperature pozimi, predvsem januarja in februarja, negativno odražajo na debelinskem prirastku (januar, r = –0,49; februar, r = –0,53; zima, r = –0,42). Statistično pomemben je tudi korelacijski koeficient za povprečne letne temperature (r = 0,43), kar pomeni, da macesni tvorijo v nadpovprečno toplih letih tudi nadpovprečno širše letnice.

Reakcija na padavinske razmere je šibkejša. Razviden je zaviralen vpliv nadpovprečne količine padavin v juniju in juliju (junij, r = –0,26; julij, r = –0,28), kakor tudi v oktobru preteklega leta (r = –0,27).

### *Prirastne razmere po letu 1861 glede na regionalno macesnovo kronologijo*

V Julijskih Alpah in na splošno v slovenskih gorah je trdnost povezav med klimo in debelinskim prirastkom v primerjavi z višjimi gorstvi po svetu relativno nizka, saj korelacijski koeficienti redko presežejo ± 0,4. Izstopajo le macesni, kjer je močno v ospredju pomen nadpovprečno toplih in podpovprečno namočenih poletij. Korelacijski koeficienti dosegajo vrednosti do ±0,60, s klimo pa lahko pojasnimo okoli 40 % variance debelinskega prirastka. Ker je splošni trend priraščanja pri vseh analiziranih macesnih podoben, smo imeli dobro osnovo za izdelavo povprečne regionalne kronologije za macesne in s pomočjo nje za rekonstrukcijo paleo-

cipitation in the vegetation period and the width of annual rings (June: r = –0.31; July: r = –0.29; summer: r = –0.24; vegetation period: r = –0.29). More abundant precipitation results in narrower annual rings, and vice versa. It is reasonable to explain the impact of precipitation in the vegetation period on the width of annual rings indirectly through the influence on air temperature. Precipitation days are cloudy, which lowers temperatures in the mountains.

It is possible to explain in a similar way also the negative correlation with precipitation in the autumn of the previous year (October: r = –0.43; November: r = –0.39), that is in the period when processes are going on in trees to prepare them for winter dormancy. It can be concluded from the correlation coefficients that a good preparation for winter, which is mainly made possible by a rather dry autumn, is even more important for the formation of radial increments of spruce in the following season than a smaller precipitation amount during the vegetation period.

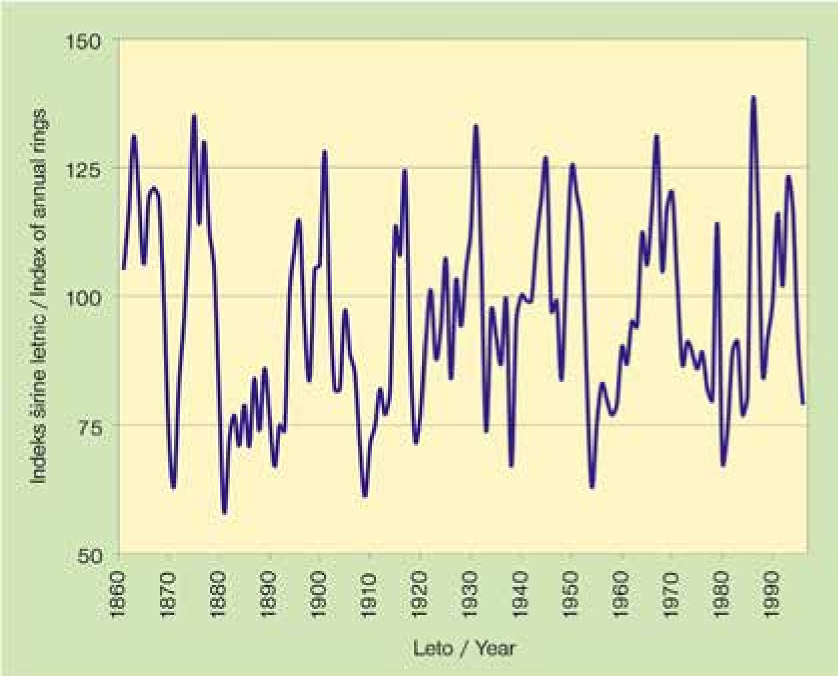
Response of larch to climate conditions is similar to that of spruce, especially in the vegetation period. Above-average temperature in this period results in wider annual rings (April: r = 0.41; May: r = 0.45; July: r = 0.43; August: r = 0.45; September: r = 0.45; summer: r = 0.77). Radial increments also depend on conditions in the autumn of the previous year, or conditions during the preparation for winter dormancy (October: r = 0.54).

Although larch drops its needles, above-average temperature in winter, particularly in January and February, exerts a negative influence on radial increments (January: r = –0.49; February: r = –0.53; winter: r = –0.42). Statistically relevant is also the correlation coefficient for average annual temperature (r = 0.43), which means that in warmer years, larch forms wider annual rings.

Response to precipitation conditions is weaker. An impeding influence is evident from the above-average precipitation in June and July (June: r = –0.26; July: r = –0.28), as well as October of the previous year (r = –0.27).

### *Increment conditions since 1861 in view of the regional larch chronology*

In the Julian Alps, and in Slovenian mountains in general, the reliability of correlation between the climate and increment width is rather low in comparison to that in the higher mountains of the world, since the correlation coefficients rarely surpass ± 0.4. Larch alone stands out with the empha-




Slika 4: Indeks širine letnic za regionalno macesnovo (*Larix decidua* Mill.) kronologijo Julijskih Alp (nadmorska višina 1400–1750 m; Triglavski narodni park, Slovenija)

*Figure 4: Index of annual rings' width in the regional larch (Larix decidua Mill.) chronology of the Julian Alps (altitude between 1400 and 1750 m; Triglav National Park; Slovenia)*

ekoloških, predvsem klimatskih pogojev priraščanja za obdobje po letu 1861. Za obdobje od leta 1861 do leta 1880 je kronologija sestavljena iz 7 vzorcev, od 1881 do 1910 iz 16, od 1911 do 1930 iz 32, po letu 1931 pa iz 54 vzorcev.

Iz slike 4, ki ponazarja potek priraščanja macesnov brez vpliva biološkega trenda rasti, so razvidna daljša obdobja z manjšim debelinskim prirastkom (npr. 1880–1893, 1907–1914, 1953–1959, 1974–1985) in več krajših obdobij z nadpovprečno rastjo. Obdobij s podpovprečnim prirastkom ni možno vedno enačiti s hladnejšo in vlažnejšo vegetacijsko sezono, ker je lahko manjši prirastek rezultat posameznih, za drevesa stresnih klimatskih dogodkov (npr. nenadnih ohladitev), ki jih klimatska statistika prikrije, ali drugih neklimatskih dejavnikov, npr. zelo plodnih let.

Za obdobje po 2. svetovni vojni, ko imamo na razpolago tudi klimatske meritve, lahko zanesljivo trdimo, da obdobji z manjšim debelinskim prirastkom 1972–1981 in 1955–1960 sovpadata s hladnejšimi in bolj namočenimi poletji, obdobje z nadpovprečnim prirastkom 1991–1995 pa s toplejšimi in nekoliko manj namočenimi poletji. Obdobja z nadpovprečnim priraščanjem 1964–1971 pa s temperaturnimi in padavinskimi razmerami v rastni sezoni ne moremo zadovoljivo pojasniti.

sised importance of the above average warm and below-average wet summers. Correlation coefficients reach the values of up to ±0.60, and the climate can account for about 40 % of the variance in increment width. Since the general trend of increment development is nearly the same in all the analysed larch, this was a good basis for constructing the average regional chronology for larch, by means of which the palaeoecological and especially climatic conditions of increment development were reconstructed for the period after 1861. The chronology for the 1861–1880 period was made of 7 samples, for the 1881–1910 period of 16, for the 1911–1930 period of 32, and for the period after 1931 of 54 samples.

Figure 4, which illustrates the course of larch increment growth without the influence of the biological trend of development, clearly shows longer periods of thinner increments (e.g.1880–1893, 1907–1914, 1953–1959, 1974–1985) and several shorter periods of above-average increments. The periods of thinner increments can not always be attributed to cooler and wetter vegetation seasons because they can also result from individual climatic changes stressful to trees (e.g. sudden cooling), which are not evident from climate statistics, or from other non-climatic factors, e.g. very productive years.

It can be safely concluded that in the period after the World War II for which climatic measurements are also available, two periods, 1972–1981 and 1955–1960, of thinner increments coincide with cooler and wetter summers, while the 1991–1995 period of the above average increments agrees with warmer and somewhat drier summers. However, the temperature and precipitation conditions in the vegetation seasons of the 1964–1971 period can not satisfactorily account for the above-average increments of that time.

## ZAKLJUČKI

Na podnebne razmere Julijskih Alp vpliva velika reliefna razčlenjenost površja z velikimi relativnimi višinskimi razlikami in lega na zahodu Slovenije, v območju alpsko-dinarske pregrade. Izrazita je vertikalna klimatska pasovitost, kjer imajo alpske doline, še posebno v topli polovici leta, podobne temperaturne razmere kot ostali kraji v notranjosti Slovenije. V najvišjih območjih pa so letni temperaturni povprečki pod 0 °C. Južni del Julijskih Alp, ki je po dolini Soče odprt proti morju, ima nekoliko višje temperature od severnega in vzhodnega dela in je zaradi prisilnega dvigovanja zraka ob pobočjih tudi bolj namočen. Julijske Alpe kot celota spadajo med najbolj namočena območja Slovenije in tudi Evrope, kjer lahko pozimi zapade tudi več kot 5 m snega, vendar so padavine zelo variabilne. Alpskim dolinam dajejo poseben klimatski pečat tudi jezera hladnega zraka s temperaturno inverzijo in meglo ter slaba prevetrenost. Zaradi zimskih megel in konvektivne oblačnosti poleti so alpske doline med najmanj osončenimi območji Slovenije. Velika namočenost in relativno nizke temperature v območjih okoli zgornje gozdne meje (termična zgornja gozdna meja je v osrednjih Julijcih med 1700 in 1900 m) pomembno vplivajo na vsakoletni debelinski prirast dreves. Če zanemarimo lokalna odstopanja kot posledico specifičnih rastnih razmer, so za prirast na splošno ugodnejša leta, ko so temperature v vegetacijski dobi nadpovprečne, količina padavin pa podpovprečna. To še posebej velja za macesne, zato so v primerjavi s smrekami primernejši za paleoekološke rekonstrukcije.

## CONCLUSIONS

Climatic conditions in the Julian Alps are influenced by the intense dissection of landforms with high vertical drops, and by the location of the Julian Alps in the west part of Slovenia, in the area of the Alpine-Dinaric barrier. Particularly explicit is a vertical climatic zoning, so that temperature conditions in the alpine valleys, especially during the warm part of the year, are similar to other places of inland Slovenia, and the annual temperature averages in the highest parts are below 0 °C. Temperature in the southern part of the Julian Alps, which is open towards the sea through the valley of the Soča, is slightly higher than those in the northern and eastern parts, and the area is also wetter because of the forced rising of air masses upward the slopes. The Julian Alps as a whole belong to the wettest regions in Slovenia and also in Europe; even more than 5 m of snow can fall there in winter, but the precipitation can vary considerably. A specific climatic characteristic is given to the alpine valleys by the basins of cold air with the accompanying temperature inversion and fog, and by poor windiness. Due to winter fogs and convective cloudiness in summer the alpine valleys belong to the areas with the poorest insolation in Slovenia. Abundant wetness and rather low temperature in the zones along the upper forest line (thermic upper forest line in the Central Julian Alps runs between 1700 and 1900 m) exert important impact on the annual increments of trees. If local deviations, as a consequence of specific growing conditions, are disregarded, more favorable for the development of tree increments are the years with above-average temperature and below-average precipitation in the vegetation season. This particularly applies to larch which, if compared to spruce, is more suitable for palaeoecological reconstructions.

## *Poglavje* 3 *Chapter*

# *Triglavski ledenik* *The Triglav Glacier*

Matej GABROVEC*

### UVOD

V Alpah je bila skupna površina vseh ledenikov v sedemdesetih letih 20. stoletja 2842 $km^2$, od tega 542 $km^2$ v Avstriji, 1342 $km^2$ v Švici, 350 $km^2$ v Franciji in 608 $km^2$ v Italiji (Rott in sod., 1993). V primerjavi s temi ledeniškimi površinami je Triglavski ledenik prav neznaten, saj je v sedemdesetih letih meril okoli 12 ha (Šifrer, 1976), do konca 20. stoletja pa se je njegova površina skrčila na borih 1,375 ha (Peršolja, 2000). Oba slovenska ledenika, poleg Triglavskega ledenika v Julijskih Alpah leži v Sloveniji še Ledenik pod Skuto v Kamniško-Savinjskih Alpah, predstavljata le 0,05 ‰ alpskih ledeniških površin. Kljub temu pa ne gre podcenjevati njunega pomena, saj ležita na jugovzhodnem robu Alp na razmeroma nizki nadmorski višini. Kot taka sta

### INTRODUCTION

In the 1970s, the total area of the glaciers in the Alps amounted to 2842 square kilometers of which 542 were in Austria, 1342 in Switzerland, 350 in France and 608 in Italy (Rott *et al.*, 1993). In comparison with the foregoing sizes, the Triglav glacier is just a minor one, since in the 1970s it extended only over an area of 12 hectares (Šifrer, 1976), and it diminished to as little as 1.375 hectares by the end of the 20th century (Peršolja, 2000). The two Slovenian glaciers taken together – besides the Triglav glacier in the Julian Alps there is another glacier in Slovenia, the Ledenik pod Skuto (the Glacier under Mt. Skuta), which lies in the Kamnik and Savinja Alps – account for only 0.05 ‰ of the total Alpine glacier area. Nevertheless, their significance should not be underestimated, because they both lie on the south-east edge of the Alps at rather low altitudes above sea level and are thus particularly sensitive to climatic changes and, therefore, an interesting object of scientific investigations.

Benescheva upodobitev Triglava iz druge polovice 19. stoletja. Sliko hrani Narodni muzej v Ljubljani. (Foto: Marko Zaplatil)
*Benesch's painting of the Triglav from between 1875 and 1880 (National Museum library) (Photo: Marko Zaplatil)*

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še posebej občutljiva za podnebne spremembe in zato tudi zanimiv predmet znanstvenih proučevanj.

Za vse alpske ledenike so značilna podobna kolebanja v zadnjih 400 letih. Po višku v začetku 17. stoletja so naslednjih 250 let ohranili podoben obseg z razmeroma skromnimi spremembami. Večina vzhodnoalpskih ledenikov je dosegla še en višek med leti 1770 in 1780 ter naslednjega sredi 19. stoletja (Rott in sod., 1993).

## TRIGLAVSKI LEDENIK OD ZAČETKA 17. DO SREDINE 20. STOLETJA

Do podobnih ugotovitev so s proučevanjem starih morenskih nasipov, starih slik in fotografij ter posameznih omemb, zlasti v planinski literaturi, prišli raziskovalci Triglavskega ledenika. Ta leži na severni strani Triglava (2864 m) v Julijskih Alpah na višini med 2400 in 2500 m.

Na obseg ledenika od začetka 17. do konca 19. stoletja kažejo morenski nasipi med Glavo (2426 m) ter koto 2368 m nad zgornjim robom Triglavske severne stene. Tu so morenski nasipi iz dveh različnih obdobij. Na njihovo različno starost kaže poraščenost z modrozelenimi algami *Chroococcus lithophilus* Erceg. Najstarejše morene so skoraj v celoti prekrite z algami, drobir pa je zato temno siv, pogosto prav črn. Raziskava alg, ki jo je opravil Jože Lazar (Šifrer, 1963), je ob prevladi enoceličnih odkrila tudi dvo- in tricelične oblike, nekaj pa tudi štiriceličnih. Na drobirju iz druge morene, ki je samo delno poraščen z algami, štiriceličnih oblik ne najdemo, obstajajo samo enocelične in dvocelične oblike. Skale so tu precej svetlejše od tistih na prvih morenah. Na nekaj višje ležeči tretji skupini moren pa alg po podrobnem pregledu ni bilo moč najti. Milan Šifrer (1963) po legi moren, poraščenosti z algami in razmerah drugod v Alpah sklepa, da so najstarejše morene iz 17. ali 18. stoletja, naslednje iz sredine 19. stoletja, tretji morenski nasip pa naj bi nastal okoli leta 1920, ko je zaradi močno sneženih predhodnih zim prišlo do prekinitve umikanja ledenikov.

Rezultate, pridobljene s terenskimi raziskavami, pa potrjuje tudi ohranjeno slikovno gradivo. Leta 1849 se je na Triglav povzpel slikar Marko Pernhart. Na zelo natančno izrisani Triglavski panorami, ki si jo lahko ogledamo v knjižnici Narodnega muzeja v Ljubljani, lepo vidimo Triglavski ledenik, ki sega do roba Triglavske severne stene. Boljšo primerjavo z novejšimi fotografijami nam daje slika Ladislava Benescha iz let 1875–1880, ki nam prika-

Typical of all the Alpine glaciers are similar oscillations in the last 400 years. After they had reached their greatest size at the beginning of the 17th century, they mainly retained it during the following 250 years, with minor changes only. The majority of eastern Alpine glaciers reached a new climax between 1770 and 1780, and another one in the mid-19th century (Rott *et al.*, 1993).

## THE TRIGLAV GLACIER FROM THE EARLY 17TH TO THE MID-20TH CENTURY

A similar conclusion has been reached by the researchers of the Triglav glacier after investigations into old moraine accumulations and studies of old paintings and photos and of individual notes on the glacier that had mainly been published in mountaineering literature. The glacier lies in the Julian Alps on the north side of Mt. Triglav (2864 meters) at an altitude between 2400 and 2500 m.

The size of the glacier between the early 17th century and the end of the 19th century, can be determined according to moraine accumulations between Mt. Glava (2426 m) and the 2368 m point above the upper ridge of the Triglavska severna stena or Stena (the Triglav north face). These moraine accumulations originated in two different periods. The time of their origin is indicated by a cover of blue-green algae, *Chroococcus lithophilus* Erceg. The oldest moraines are nearly completely covered with algae, therefore the rubble is dark grey or often proper black. The study of algae, made by Jože Lazar (Šifrer, 1963), has confirmed, besides the prevailing monocellular forms, also the existence of two- and three-cell forms, and sporadically even some four-cell forms. On the rubble of the second moraine, which is only partly covered with algae, no four-cell forms occur, but only monocellular and two-cell forms. Rocks of the second moraine are much brighter than those of the first one. After a thorough investigation of the third moraine material which lies slightly higher, algae were not discovered. Following analysis of the location of moraine material, the cover of algae, and the conditions in other Alpine areas, Milan Šifrer drew a conclusion that the oldest moraines originated in the 17th, or the 18th century, the next in the mid-19th century, and the third moraine accumulation supposedly originated around the year 1920 when, due to abundant snows of the preceding winters, the retreat of the glacier temporarily stopped (Šifrer, 1963).

The results obtained through field work have zuje Triglav s severne strani. Iz kopne površine v sprednjem delu slike je očitno, da je bila slika narejena v poletnem času, že bežen pogled pa nam pokaže mnogo večji obseg ledenika od današnjega (Meze, 1955).

O upadanju Triglavskega ledenika, ki ga je v teku petdesetih let sam doživel, nam v Planinskem vestniku poroča Pavel Kunaver (1949). Avtor se še spominja časa, ko je ledenik segal prav v bližino Triglavske severne stene in je čeznjo padal slap. V tem članku je objavljenih tudi več starejših fotografij. Najstarejša Lergetporerjeva fotografija je iz leta 1890, kaže pa zgornji vzhodni del ledenika pod Malim Triglavom. Fotografija Josipa Kunaverja iz leta 1924 kaže večjo debelino ledu v času med obema vojnama. Zanimiva pa je tudi fotografija, ki nam

also been corroborated by some preserved pictorial materials. In 1849 the painter Marko Pernhart climbed Mt. Triglav and painted a carefully detailed panoramic view of the Triglav area. Clearly visible in this painting, kept in the National Museum library (*Narodni muzej*) in Ljubljana, is the Triglav glacier that extends to the edge of the Triglavska severna stena. Better comparable to more recent photographs is a painting by Ladislav Benesch from between 1875 and 1880, depicting the northern view of Mt. Triglav. The snow-free area in the front part of the picture shows clearly that it was painted in summertime, and even a cursory comparison reveals that the size of the glacier was much larger than today (Meze, 1955).

Reports on the decline of the Triglav glacier over a period of 50 years were published in *Planinski vestnik* in 1949 by Pavel Kunaver, who witnessed the process himself. The author still remembered the time when the glacier had extended to the very proximity of the Stena over which a waterfall was falling. The article is also illustrated by several older photos the earliest of which was taken by Lergetporer in 1890, and shows the upper eastern part of the glacier under Mt. Mali Triglav. A photo by Josip Kunaver of 1924 shows thicker ice in the time between the two World Wars; another photo of that time which still shows numerous and deep fissures

Triglavski ledenik 25. septembra 1975 (Foto: Milan Orožen Adamič)
*The Triglav glacier on September 25, 1975 (Photo: Milan Orožen Adamič)*

kaže takrat še številne in globoke ledeniške razpoke. Po avtorjevi oceni se je debelina ledenika v naslednjih 25 letih stanjšala za dve tretjini (Kunaver, 1949). V naslednjem letniku Planinskega vestnika je isti avtor zapisal v članku z alarmantnim naslovom Triglavski ledenik v agoniji?: “In v avgustu se je pokazal ledenik do skrajnosti gol, skromen in stisnjen tja med golo Glavo nad Steno in med masiv Triglava. Pokazalo se je, da je od njegove nekdanje velikosti ostala le še ena četrtina kotline med Kredarico, Steno in Triglavom, pokrita z ledom.” (Kunaver, 1950).

## RAZISKOVANJE LEDENIKA PO DRUGI SVETOVNI VOJNI

Redna letna opazovanja Triglavskega ledenika so se začela leta 1946. Še pred formalno ustanovitvijo Inštituta za geografijo (sedanjega Geografskega inštituta Antona Melika) jih je finančno omogočila Slovenska akademija znanosti in umetnosti. Prvi sodelavci so bili takratni najboljši študenti geografije (Melik, 1955). Odtlej so sodelavci Geografskega inštituta opravljali redne letne meritve in svoje izsledke objavljali v Geografskem zborniku (Meze, 1955; Šifrer, 1963, 1976, 1987; Gabrovec, 1998). V nadaljevanju so na kratko povzeti glavni rezultati teh razprav.

Leta 1946 sta ledenik prvič izmerila in postavila na njegovo obrobje prve merilne točke Milan Šinkovec in Stanko Fon (Meze, 1955). S pomočjo kompasa in vrvi sta izmerila razdalje od točke do točke in na tej podlagi izdelala skico ledenika. Od teh merilnih točk so vsa kasnejša leta merili horizontalno in/ali vertikalno oddaljenost od ledenika.V letu 1946 je ledenik meril približno 15 ha. Za prvo povojno desetletje je bilo značilno močno krčenje ledenika. Potem ko se je v prvih letih predvsem močno tanjšal, pa je prišlo v zadnjih letih tega desetletja na spodnjem delu tudi do močnega vodoravnega umika. Tako se je ledeniški jezik pod Glavo v tem razdobju umaknil za 23,5 m, na merilni točki 14 vzhodno od tod pa celo za slabih 50 m. Izjemo sta predstavljali le leti 1948 in 1951, ko se je ledenik nekoliko povečal (Meze, 1955). Močno krčenje ledenika se je nadaljevalo vse do konca petdesetih let, v tem času se je umaknil še za nadaljnjih 28 m (Šifrer, 1963) (slika 1).

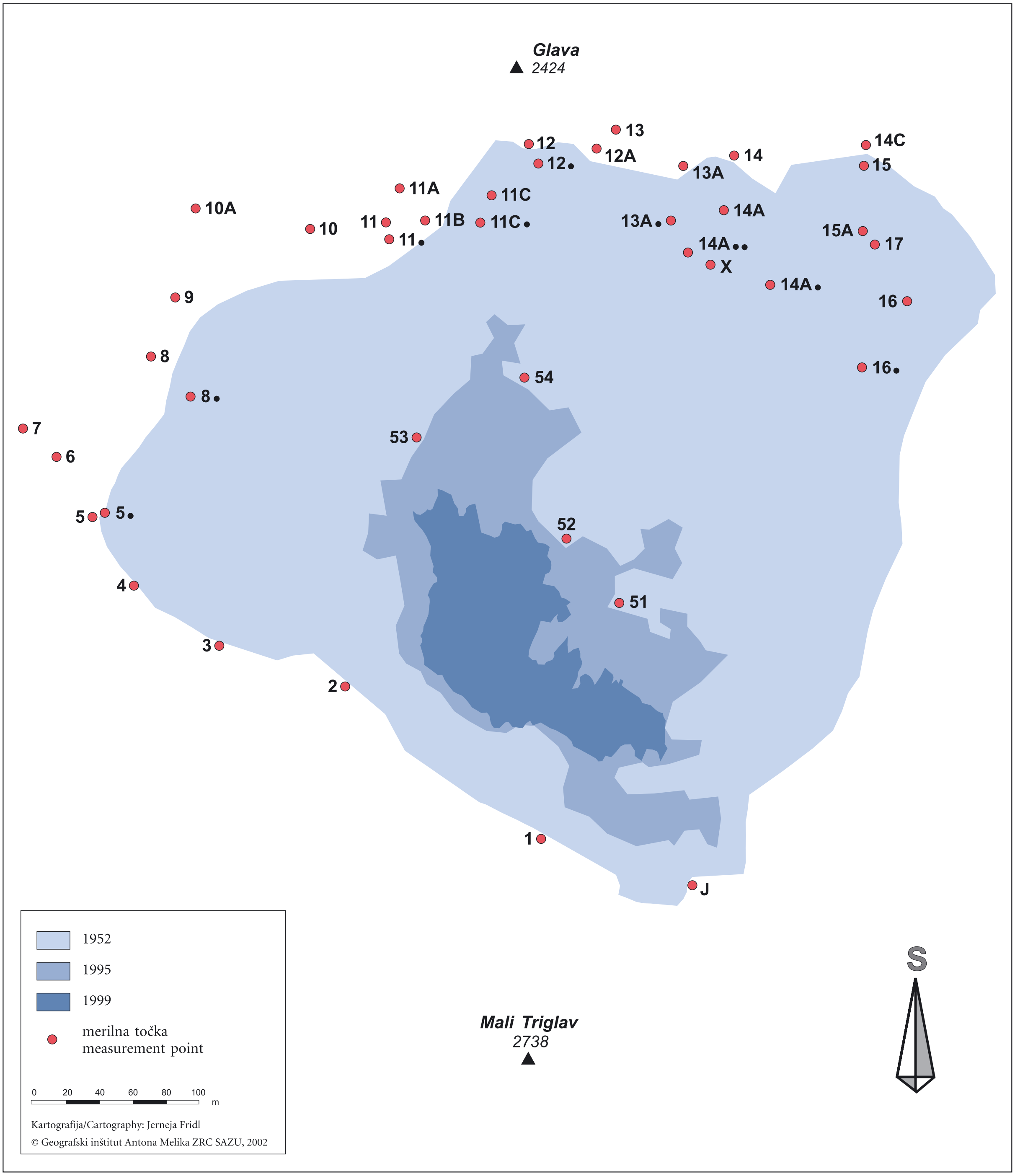
Leto 1960 pomeni pomembno prelomnico v razvoju ledenika. Za šestdeseta leta 20. stoletja je bila namreč značilna nadpovprečna debelina snežne odeje. Sneg se je tako na ledeniku zadrževal

in the glacier is also interesting. The author estimated that the glacier had thinned by two thirds in the next 25 years. Next year *Planinski vestnik* brought another article by the same author entitled in an alarming tone The Triglav Glacier in Agony?, where he wrote: “In August the glacier appeared to be extremely bare, modest and compressed between the barren Mt. Glava above the Stena and the Triglav massif. It became evident that its former size had diminished so that only one quarter of the basin between Mt. Kredarica, the Stena and Mt. Triglav remained under ice.” (Kunaver, 1950).

## RESEARCHES ON THE GLACIER AFTER THE WORLD WAR II

Regular annual observations of the Triglav glacier began in 1946. They had been financially supported by the Slovenian Academy of Sciences and Arts even before the Geographical Institute (the present Anton Melik Geographical Institute) was established. Its first researchers were the best students of geography of the time (Melik, 1955). Since then, the associates of the Geographical Institute have performed regular annual measurements and published their observations and results in *Geografski Zbornik* (Meze, 1955; Šifrer, 1963, 1976, 1987; Gabrovec, 1998). Summarised in the following paragraphs are the essential results of these studies.

The glacier was measured for the first time in 1946; this was done by Milan Šinkovec and Stanko Fon (Meze, 1955), who also installed the first measuring points at its edges. They measured distances between the points by means of a compass and rope and made a sketch of the glacier on this basis. From the same measuring points, horizontal and/or vertical distances from the glacier were measured through the following years. In 1946, the glacier measured about 15 hectares. In the first post-War decade an intense ablation of the glacier occurred. During the first post-War years, the glacier thinned considerably, while in the following years its lower part retreated horizontally as well. Thus, the glacier’s tongue under Mt. Glava retreated by 23.5 meters during this time, and at the measuring point 14, east of the foregoing location, nearly by 50 meters. There were only two exceptions to this process of steady ablation, when in 1948 and 1951 the glacier slightly increased (Meze, 1955). Intense decline of the glacier continued until the end of the 1950s; during this time the glacier retreated by further 28 metres (Šifrer, 1963) (Figure 1).




Slika 1: Obseg Triglavskega ledenika v letih 1952, 1995 in 1999 z vrisanimi merilnimi točkami
*Figure 1: The size of the Triglav glacier in 1952, 1995 and 1999, with indicated measuring points*

The year 1960 was crucial for the development of the glacier. The 1960s were marked by an above–average thickness of snow cover. Thus the snow remained on the glacier through the major part of the melting season, i.e. in late spring and summer. The decline of the glacier did continue, but it was essentially slower. During the first 14 years of observations the glacier thus shrank by 3 meters on average while during the following 14 years, i.e.

še v večjem delu talilne dobe v pozni pomladi in poleti. Krčenje ledenika se je sicer še nadaljevalo, vendar pa je bilo bistveno počasnejše. Tako se je ledenik v prvih 14 letih opazovanja v povprečju letno skrčil za tri metre, v naslednjih 14 letih – med 1960 in 1973 – pa v povprečju le za 0,8 m. Zanimivo pa je, da je do umika prišlo v glavnem le v letih 1964 in 1967, ko je sneg iz preteklih zimskih obdobij povsem skopnel (Šifrer, 1976). V drugi polovici sedemdesetih let se je umikanje ledenika še bolj upočasnilo oziroma skoraj povsem ustavilo. V teh letih je bil spodnji del ledenika ob koncu talilne dobe večinoma pokrit s snegom, razkrit pa je bil le manjši osrednji del ledenika. V tem času je povprečna debelina snežne odeje ob koncu redilne dobe ledenika v mesecu aprilu znašala več kot 4,5 m, medtem ko je bilo v razdobju od leta 1955 do 1962 povprečje le 297 cm (Šifrer, 1987).

Do preobrata pa je prišlo v letu 1983. Takratne raziskave so pokazale močno skrčenje in stanjšanje ledenika, ki ju je povzročilo izjemno toplo poletje. Ledenikov obseg je bil najmanjši dotlej, kar pomeni, da je bilo tudi najnižje stanje po letu 1600. V naslednjih letih pa je bilo krčenje še posebej močno. Leta 1986 je izpod ledenika na spodnjem vzhodnem koncu pogledal širok živoskalni prag, ki je ločil spodnji jezik ledenika od njegovega osrednjega dela. Za naslednja leta je bilo značilno tudi močno tanjšanje ledenika, predvsem v njegovem zgornjem delu. Ledenik se je letno stanjšal za 1 do 2 metra. Zaradi intenzivnega tanjšanja se je obseg skalnih grbin, ki so pogledale izpod ledu v prejšnjih letih, tako povečal, da je ledenik razpadel na več delov (Gabrovec, 1996 b).

Pri razpadanju ledenika je bilo prelomno leto 1990, ko se je od ledenika povsem ločil njegov spodnji, severovzhodni del, ves zahodni del pa je z osrednjim delom povezoval le 30 cm širok pas ledu. V letu 1991 se je zaradi večje debeline snežne odeje v pozni pomladi (sredi junija je bilo na snegomeru pod ledenikom še vedno 570 cm snega) umikanje ledenika prehodno ustavilo. V letih 1992 in 1993 se je ledenik spet stanjšal, vsakokrat za 2 metra, skalne grbine sredi ledenika in med njegovimi posameznimi deli pa so postajale vse obsežnejše. Spodnji del ledenika je od osrednjega dela v letu 1990 ločil le trimetrski skalni skok, v letu 1993 pa je bila med njima že nekaj deset metrov široka skalnata pregrada. Poleg tega je ta spodnji del v veliki meri prekril grušč. Prvotne merilne točke na spodnjem robu ledenika so tako postale povsem neuporabne. V letu 1995 so bile zato na tedanjem spodnjem robu ledenika določene štiri nove merilne točke. V tem letu

between 1960 and 1973, only by 0.8 metres on average. However, it is curious that the retreat mainly took place in two particular years, in 1964 and 1967, when snow of the previous winter seasons melted completely (Šifrer, 1976). In the second half of the 1970s, the retreat of the glacier slowed down further or nearly stopped. During these years, the lower section of the glacier was mainly covered with snow at the end of the melting season and only a smaller portion of the central part of the glacier was not covered with snow. In this time, the average thickness of snow cover was over 4.5 metres at the end of the accumulation period of the glacier, in April, while the average of the 1955–1962 period amounted to only 297 centimetres (Šifrer, 1987).

A turning point occurred in 1983. The investigations then revealed an intense shrinking and thinning of the glacier, which were due to the exceptionally warm summer. The size of the glacier reached a minumum, which also means that it was at its smallest since the year 1600. During the following years the decline of the glacier was exceptionally strong. A broad rocky threshold appeared from under the glacier at its lower eastern end in 1986 and separated the lower tongue of the glacier from its central part. During the following years a strong decline of the glacier took place, especially in its upper part, so that the glacier thinned by 1–2 metres annually. Because of this thinning the size of outcropping rocks from under the ice in the previous years increased so much that the glacier disintegrated into several parts (Gabrovec, 1996 b).

A turning point in the disintegration process occurred in 1990, when the lower north-eastern part of the glacier completely separated from the main body of ice, while the entire western part was connected to the central part with a narrow strip of ice, only 30 centimetres wide. Due to a thicker snow cover in the late spring of 1991 (there was still 570 cm of snow in mid-June), the retreat of the glacier temporarily stopped. In 1992 and 1993, the glacier thinned again, by 2 metres each year, and the outcropping rocks in the central part of the glacier and between its individual sections grew larger and larger. In 1990, the lower part was separated from the central one by a three-metre rock step, and in 1993, a ten-metre wide rock barrier was already between them. In addition, the lower part mainly became covered with rubble. The original measuring points at the bottom edge of the glacier thus became completely unviable and four new measuring points were fixed at the bottom edge of the glacier in 1995. In this year the glacier was also measured by means je bil ledenik tudi izmerjen s teodolitom z optičnim razdaljemerom. Njegova površina je bila takrat 3,03 ha. V naslednjih treh letih se je krčenje nadaljevalo. Letno se je stalilo pol metra do en meter ledu, posledica tega pa je bil tudi dvo- do štirimetrski vodoravni umik na spodnjem robu (Gabrovec, 1998).

V letu 1999 smo po štirih letih ponovili geodetske meritve. Površina ledenika je bila samo še 1,375 ha. V štirih letih se je torej skrčil za več kot polovico. Ker so klasične metode merjenja razdalj od merilnih točk ob hitrem spreminjanju obsega ledenika postale povsem neuporabne in ker smo želeli dobiti tudi podatke o spremembi njegove prostornine, smo se v tem letu v sodelovanju z Inštitutom za geodezijo in fotogrametrijo (sedanjim Geodetskim inštitutom Slovenije) lotili fotogrametričnih metod. Tako je bil ledenik s helikopterja posnet s fotogrametrično kamero. Podrobnostim o spremembah prostornine ledenika je namenjeno naslednje podpoglavje. V tem letu smo prvič organizirali tudi georadarske meritve, da bi ugotovili debelino ledu. Meritve je opravil Dimitrij Najdovski s sodelovanjem Tomaža Verbiča. Na dveh prerezih smo tako dobili podatke o izoblikovanosti pobočja oziroma kotanje, v kateri leži ledenik. Največja debelina ledu v teh dveh prerezih je bila med sedmimi in osmimi metri (Peršolja, 2000). V letu 2000 smo georadarske meritve ponovili na 14 prerezih, tokrat jih je opravil Tomaž Verbič, in tako dopolnili podatke o podledeniškem reliefu. Na posameznih mestih je debelina ledu presegla 9 metrov (Poročilo ..., 2001). Krčenje ledenika se je nadaljevalo v podobnem obsegu kot v preteklih letih.

Leto 2001 je bilo izjemno zaradi obilice snežnih padavin. Na meteorološki postaji na Kredarici je bila izmerjena največja debelina snega v celotnem obdobju meritev, to je 700 cm (Vrhovec in Velkavrh, 2001). Zaradi slemenske lege meteorološke postaje na Kredarici je tamkajšnja snežna odeja nižja od snežne odeje na ledeniku. Na snegomeru pod ledenikom je bilo 22. 4. 2001 izmerjeno 740 cm snega (Gartner, 2001 a). V začetku julija je bilo še več kot tri metre snega, do avgusta ga je ostalo še okoli enega metra. Ledenik je tako v celotni talilni dobi ostal prekrit s snegom. V začetku septembra pa je že zapadel nov sneg in talilna doba je bila zaključena (Gartner, 2001 b). Ledenik s širšo okolico je tako ostal prekrit s snegom, njegovo krčenje se je v tem letu prekinilo. Razmere v letu 2001 so bile izjemne. Podobne snežne razmere so bile pred tem v letih 1977 in 1979 (Šifrer, 1987).

of a theodolite with an optical distance meter. The area then measured 3.03 hectares. During the following three years the decline continued; from one half to one metre of ice melted away in a year, which resulted in two to four metres of horizontal retreat at the lower edge (Gabrovec, 1998).

After a four-year break, the survey measurements were re-established in 1999. The remaining size of the glacier was only 1.375 hectares. In four years, the glacier had thus decreased by more than a half. Since the classical methods of measuring distance from the measuring points became entirely useless, due to the fast diminution the glacier, and because the data on the changing volume of the glacier were also required, the Anton Melik Geographical Institute, in co-operation with the Institute of Geodesy, Cartography and Photogrammetry (the present Geodetic Institute of Slovenia), began to employ photogrammetric methods. The glacier was photographed from a helicopter with a photogrammetric camera. Details on the changes in the glacier's volume are described in the next sub-chapter. In the same year, georadar measurements were organised for the first time, in order to establish the thickness of the ice. The measurements were performed by Dimitrij Najdovski in association with Tomaž Verbič. Along two cross-sections, data were obtained on the configuration of the slope, or the depression, where the glacier lies. The thickest ice on these two cross sections measured between seven and eight metres (Peršolja, 2000). Georadar measurments were undertaken again by Tomaž Verbič in 2000, this time at 14 cross-sections, so the data on the sub-glacier relief were further completed. At individual sections, the ice was thicker than 9 metres (Poročilo ...., 2001). The glacier kept shrinking at a similar rate as it had done in the years before.

The year 2001 was exceptional for the great amount of snow. At the weather station on Mt. Kredarica the thickest snow in the entire period of observations was measured, i.e. 700 centimetres (Vrhovec & Velkavrh, 2001). Because of its position on a ridge, the snow cover at the Kredarica weather station is thinner than that on the glacier. A snow gauge at the lower part of the glacier read 740 centimetres of snow on 22nd April, 2001 (Gartner, 2001 a). There were still more than three metres of snow at the beginning of July, and by August about one metre remained. So the glacier was covered with snow throughout the melting season. As early as the beginning of September new snow fell and the melting season was over (Gartner, 2001 b). The glacier and its wider surroundings remained snow–

Triglavski ledenik 26. septembra 1995 (Foto: Matej Gabrovec)
*The Triglav Glacier on September 26, 1995 (Photo: Matej Gabrovec)*

covered and its shrinking was temporarily stopped in that year, thanks to exceptional snow conditions. Similar snow conditions had been earlier registered in 1977 and 1979 (Šifrer, 1987).

## SPREMINJANJE PROSTORNINE LEDENIKA

S klasično metodo merjenja smo dobili le podatke o spremembah v eni dimenziji – spremembi dolžine ali debeline ledenika na posameznih točkah. S pomočjo teh podatkov so bile izrisane preproste skice in na njihovi podlagi je bila izračunana tudi površina ledenika v posameznih letih (Meze, 1955). Točen podatek o površini ledenika pa smo dobili šele z geodetskimi meritvami v letih 1995 in 1999, ko je bil natančno izmerjen obod ledenika (Gabrovec, 1998; Peršolja, 2000). Površina ledenika se je v petdesetih letih zmanjšala na desetino prvotne, še mnogo večji pa je bil upad prostornine. Ledenik je imel na začetku opazovanja izrazito konveksno obliko, v zadnjih letih pa postaja vedno bolj konkaven. Ledenik se je tako na sredini bistveno bolj stanjšal kot na robovih. Tako bi se tudi ob nespremenjeni površini njegova prostornina bistveno zmanjšala.

Ena izmed možnosti proučevanja prostorninskih sprememb je uporaba fotogrametričnih metod, to je pridobivanje metričnih podatkov s pomočjo

## CHANGES IN THE GLACIER'S VOLUME

The classical method of measuring could only provide us with the data on the changes in a single dimension, i.e. the changes in the length or thickness of the glacier at individual points. On the basis of these data simple sketches were drawn which provided assistance for the calculation of the glacier's area in individual years (Meze, 1955). Exact data on the glacier's size were only obtained by means of surveying measurements made in 1995 and 1999, when the outline of the glacier was accurately measured (Gabrovec, 1998; Peršolja, 2000). In fifty years, the area of the glacier decreased to one tenth of its former size, and the decline in its volume was even much steeper. At the beginning of the observations, the glacier's form was explicitly convex, while in recent years it has become ever more concave. This means that the central part of the glacier has thinned far more than its edges. Even if its area had remained unchanged, the volume of the glacier would nevertheless have radically decreased.

One way of studying changes in the volume is fotografij. Ta metoda je bila pri proučevanju alpskih ledenikov že uporabljena, na primer na ledeniku Caresèr (Giada in Zanon, 1995). Raziskovalci so v tem primeru uporabili letalske posnetke za leta 1967, 1980 in 1990. Na pobudo Milana Orožna Adamiča je geografski inštitut Antona Melika v sodelovanju z meteorologi na Kredarici organiziral redno fotografiranje Triglavskega ledenika z dveh stalnih stojišč v bližini planinskega doma na Kredarici. Redno fotografiranje, približno enkrat mesečno, poteka vse od leta 1976. Posnetki so narejeni z ruskim panoramskim fotoaparatom Horizont s snemalnim kotom $180^0$. Fotoaparat ima posebno konstrukcijo vrtečega se objektiva. Rekonstrukcija tridimenzionalne površine ledenika iz teh posnetkov predstavlja poseben strokovni izziv za fotogrametrično stroko. V prvi fazi je bilo potrebno kalibrirati fotoaparat Horizont in ugotoviti geometrične lastnosti fotografij. V letu 1999 in ponovno v letu 2001 je bilo izvedeno snemanje ledenika iz helikopterja v običajni stereo tehniki. Arhivski posnetki so bili tako preko izbranih referenčnih točk povezani z novimi metričnimi fotografijami. Za rešitev naloge niso zadoščale standardne fotogrametrične metode, ampak je bilo potrebno obstoječe fotogrametrične programe dopolniti (Triglav in sod., 2000). Do konca leta 2001 so bili rešeni osnovni teoretični problemi, niso pa še končane analize posameznih posnetkov izbranih obdobij.

Na podlagi helikopterskih posnetkov iz let 1999 in 2001 sta bila narejena topografska načrta Triglavskega ledenika iz obeh let v merilu in 1:1000 in digitalni model višin. V letu 2001 je bilo stabiliziranih in izmerjenih z GPS-meritvami devet referenčnih točk. Točke so stalno stabilizirane z vijakom, privitim v skalo in zaščitenim z matico (Elaborat ..., 2001). Topografski načrt in digitalni model višin iz leta 1999 bo predstavljal osnovo za primerjave s kasnejšimi in predhodnimi leti (v letu 2001 je bil ledenik prekrit s snegom in zato podatki iz tega leta ne dajejo dobre možnosti primerjav). V naslednjih letih načrtujemo redno fotogrametrično snemanje iz helikopterja in s pomočjo analize teh posnetkov stalno spremljanje sprememb prostornine ledenika. Za pretekla leta imamo v tem trenutku na voljo le digitalni model višin iz leta 1992, narejen na podlagi posnetka cikličnega aerosnemanja na Geodetskem inštitutu Slovenije. Prvi izračuni kažejo, da se je samo na območju, kjer se je ohranil ledenik do leta 1999, v sedmih letih stalilo okoli 100.000 $m^3$ ledu. Tu gre za predhodne podatke, ki jih je potrebno še dodatno preveriti, in morda posnetke ponovno orientirati.

Dragocen vir za primerjavo prostornin pa nam

to use photogrammetric methods, which means that the metric data are obtained by means of photographs. This method was already employed in the study of certain Alpine glaciers, such as the Caresèr glacier (Giada & Zanon, 1995). The researchers in this case made use of aerial photographs of 1967, 1980 and 1990. The Anton Melik Geographical Institute, inspired by a suggestion of Milan Orožen Adamič, organised in co-operation with meteorologists from Mount Kredarica weather station, regular photographing of the Triglav glacier from two fixed standpoints. The points are near the mountain resort on Kredarica and photographing has been performed approximately once a month ever since 1976. Photographs have been taken with a Russian panoramic camera, Horizont, with a view angle of 180°. The camera has a specially constructed rotating lens. A three-dimensional reconstruction of the glacier's surface, made from these photographs, is a special challenge to photogrammetry experts. The first step was to calibrate the Horizont camera and to establish geometric features of the photographs. In 1999 and 2001 photographs of the glacier were taken from a helicopter in the conventional stereo-technique. Archival photographs were then matched with the new metric photographs by means of the selected control points. Standard photogrammetric methods were not adequate for such a task, so the existing programmes had to be improved (Triglav *et al.*, 2000). By the end of 2001, essential theoretical problems were solved, though the analyses of individual photographs from the selected periods have not been completed yet. In 1999 and 2001 photogrammetric photographing from a helicopter was done. These photos served as a basis for a topographic map of the Triglav glacier, one for each year, in the scale of 1:1000, and a digital elevation model. In 2001, nine control points were fixed and surveyed with the GPS measurements. The control points are permanently fixed, with a screw driven into a rock and protected with a nut (Elaborat ..., 2001). The topographic plan and the digital elevation model (DEM) of 1999 will both serve as a basis for comparison with the following and the previous years (in 2001, the glacier was snow–covered throughout the year, so these data can not make a representative basis for comparisons). Our plan for the following years is to take photogrammetric photographs from a helicopter regularly and obtain a follow-up of changes in the glacier's volume through the analysis of such photographs. For the past years we only have a DEM of 1992, which was made on the basis of a photograph daje topografski načrt, ki ga je izdelal M. Jenko na podlagi geodetskih meritev ledenika v začetku oktobra leta 1952. Na načrtu v merilu 1:2500 so izrisane plastnice z ekvidistanco 5 m. Prve primerjave med letoma 1952 in 1999 kažejo, da se je ledenik na posameznih mestih stanjšal za več kot 35 m.

taken during cyclic aerial photographing of the Geodetic Institute of Slovenia. First calculations show that only in the area where the glacier was preserved until the year 1999, about 100,000 cubic metres of ice melted away in seven years. These are just the preliminary data which will have to be checked again and, if necessary, the photographs will be re-oriented.

Triglavski ledenik 14. septembra 1999 (Foto: Matej Gabrovec)
*The Triglav Glacier on September 14, 1999 (Photo: Matej Gabrovec)*

A precious source of comparing the volumes is provided by a topographic map, made by M. Jenko, derived from surveying measurements of the glacier at the beginning of October 1952. The map, drawn at the scale of 1:2500, includes 5-metre isolines. First comparisons between 1952 and 1999 show that the glacier thinned by more than 35 metres at individual locations.

## POVEZAVA PODNEBNIH DEJAVNIKOV S KOLEBANJEM LEDENIKA

Že od vsega začetka opazovanj Triglavskega ledenika so raziskovalci razpravljali o pomenu različnih podnebnih dejavnikov za njegovo ohranitev. Manohin (1959) je dokazoval, da je za gorski sneg in led najbolj pogubno toplo deževno vreme poleti in pičle množine padavin v hladni polovici leta.

## CORRELATION BETWEEN CLIMATIC FACTORS AND THE OSCILLATION OF THE GLACIER

Ever since the monitoring of the Triglav glacier began, its researchers have discussed the role that various climatic factors may have in the glacier's continuation. V. Manohin (1959) concluded that most damaging to snow and ice in the mountains was warm rainy weather in summer and scarce

Nasprotno pa naj bi lepo in ustaljeno poletno vreme bistveno ne škodovalo ledenikom. V nasprotju z njim je Gams (1959) na podlagi različnih tujih opazovanj dokazoval, da je za taljenje ledu najpomembnejša sončna radiacija. Ivan Gams je razpravo nadaljeval 35 let pozneje. Takrat je izračunaval korelacijske koeficiente med izbranimi podnebnimi prvinami in letnim gibanjem spodnjega roba ledenika. Največja povezava je bila s poletno temperaturo zraka. Izračunan korelacijski koeficient je bil –0,4362. Gamsa (1994) preseneča slaba korelacija med poletnim številom ur sončnega obsevanja in spremembami v obsegu ledenika. Moč sončnega obsevanja na Kredarici poleti pogosto zmanjšuje popoldanska oblačnost. Kadar je popoldne Triglavski ledenik v senci, takratna oblačnost ne zmanjša moči sončnega obsevanja na ledeniku. Zaradi povečanega difuznega obsevanja je učinek prej nasproten. Po teoretičnih izračunih (Gabrovec, 1996 a) je tako na primer v zadnji tretjini julija ob treh popoldne ob jasnem vremenu moč sončnega obsevanja na Kredarici 663 $Wm^{-2}$, na ledeniku, ki je takrat v senci, pa le 45 $Wm^{-2}$. Če je nebo povsem prekrito z oblaki, pa je na Kredarici moč sončnega obsevanja 171 $Wm^{-2}$, na Triglavskem ledeniku pa 159 $Wm^{-2}$.

Na ledeniku Morteratsch so tri leta merili njegovo taljenje in temperaturo zraka, moč in smer vetra, sončno obsevanje, zračni tlak in temperaturo snega. Povprečni toplotni tok na površini v času taljenja je bil 191 $Wm^{-2}$, k temu je neto kratkovalovno sevanje prispevalo 177 $Wm^{-2}$ (Oerlemans, 2000). Za Kredarico, ki leži v neposredni bližini ledenika, so za več kot 40 let na voljo urni podatki o trajanju sončnega obsevanja. S pomočjo tovrstnih podatkov je bila za celotno Slovenijo izdelana karta poprečne letne energije kvaziglobalnega obsevanja. Uporabljeni so bili povprečni podatki za razdobje 1961–1990 (Gabrovec, 1996 a). Z enako oziroma deloma izpopolnjeno metodologijo načrtujemo izračun energije sončnega obsevanja na Triglavskem ledeniku po posameznih letih. Tak teoretičnin izračun bomo nato lahko primerjali z rezultati terenskih opazovanj. Morebitne večje razlike bodo opozorile na posebnosti Triglavskega ledenika. Na marsikatere med njimi so že opozarjali dosedanji opazovalci v svojih poročilih. Podčrtali so na primer pomen erozijskega delovanja vode na ledeniku. Tako so v nekaterih letih že na začetku talilne dobe nastali številni žlebovi. Ti so dosegli globino do dveh metrov. Voda v veliki meri prenaša grušč in tako se njena erozijska moč še poveča (Šifrer, 1963). Seveda je količina staljenega ledu v talilni dobi odvisna tudi

amounts of precipitation in the cold half of a year, whereas fine and steady summer weather conditions were not supposed to harm glaciers. In contrast, Ivan Gams (1959), from several observations made abroad, came to a conclusion that it was solar radiation that was most decisive in ice melting. Gams resumed this thesis 35 years later, when he calculated correlation coefficients between selected climatic parameters and yearly oscillations of the lower edge of the glacier. The highest correlation existed in relation to the summer air temperatures; the calculated correlation coefficient was –0.4362. Gams (1994) was surprised at the low correlation between the summer hours of insolation and the changes in the glacier's size . The hours of solar radiation in summer are often reduced by afternoon cloudiness. But being in the shade in the afternoon, the Triglav glacier is not affected by cloudiness at this time of a day because the energy of insolation it receives is not diminished. Due to increased diffuse radiation, the effect is rather the opposite. According to theoretical calculations (Gabrovec, 1996 a) the power of solar radiation in the last decade of July at 3 p.m. in clear weather, for example, amounted to 663 $Wm^{-2}$ at Kredarica, and 45 $Wm^{-2}$ on the glacier which was in the shade at that time. When the sky is completely covered with clouds the power of solar radiation amounted to 171 $Wm^{-2}$ at Kredarica and 159 $Wm^{-2}$ on the glacier.

On the Morteratsch glacier, the following parameters were measured for three years: ice melting, air temperature, wind force and direction, solar radiation, air pressure and snow temperature. The average warming of the glacier's surface in the melting season was 191 $Wm^{-2}$, to which net shortwave radiation contributed 177 $Wm^{-2}$ (Oerlemans, 2000). For Mt. Kredarica, which lies in the near proximity of the Triglav glacier, data on the hours of solar radiation are available for more than 40 years. Utilising these kind of data, a map of the entire area of Slovenia was made, with the average annual energy of quasi–global radiation. The data applied were the average values of the 1961–1990 period (Gabrovec, 1996 a). We plan to make calculations of the amount of solar radiation on the Triglav glacier by individual years by employing the same, partly improved methodology. It will be possible then to compare this theoretical calculation with fieldwork results. Possible major differences will call attention to some peculiar features of the Triglav glacier. Several of them have already been discussed by the researchers in their reports. They highlighted, for example, the role of water erosion od količine snega ob koncu redilne dobe. Taljenje ledenika se pač lahko začne šele potem, ko se na njem stali ves sneg predhodnih zim. V devetdesetih letih 20. stoletja se je led pokazal izpod snega navadno v drugi polovici julija (Gabrovec, 1998), meteorološki opazovalci na Kredarici pa so v prvem desetletju delovanja te postaje (ustanovljena je bila leta 1954) poročali, da se je led navadno pokazal v avgustu (Šifrer, 1963). V letu 2001 je ledenik celo poletje ostal prekrit s snegom.

Količina snega je praviloma na ledeniku bistveno večja kot na Kredarici, kjer se zaradi vetrovne lege ne more obdržati. Na ledeniku se odlaga tudi sneg, ki ga nanesejo južni in jugovzhodni vetrovi s Kredarice in Rži. Poleg tega se nanj usiplje tudi sneg z ostenja Triglava nad njim. Pomembno vlogo imajo tudi plazovi, ki se navadno ustavljajo na spodnjem, položnejšem delu ledenika (Šifrer, 1963). Šifrer (1976, 1987) na podlagi dotedanjih opazovanj opozarja na presenetljivo ujemanje med različno debelino snežne odeje v posameznih letih in ustrezno večjim ali manjšim krčenjem ledenika. Ob tem pa opozarja, da ne smemo zanemariti vloge drugih klimatskih dejavnikov, ki lahko v posameznih primerih močno modificirajo vlogo snežnih padavin.

## ZAKLJUČKI

Spreminjanje obsega ledenika je posledica zapletenega součinkovanja različnih podnebnih dejavnikov v topli in hladni polovici leta oziroma v njegovi talilni in redilni dobi. V nekaj sto letih je ledenik nastal in skorajda izginil. V začetku 20. stoletja je še segal do zgornjega roba Triglavske stene. Takrat je meril okoli 30 ha, najstarejše fotografije kažejo ledenik z značilnimi prečnimi razpokami. Sto let kasneje je meril le poldrugi hektar, njegova debelina pa je bila v povprečju le okoli 7 m. Če se bo nadaljeval trend krčenja iz zadnjih 10 let, bo v naslednjih desetih letih povsem izginil.

on the glacier. In certain years numerous rills occurred early in the melting period and reached the depth of up to two metres. Water also transports rubble, by which its erosive power is further increased (Šifrer, 1963). The quantity of ice melted in the melting season certainly also depends on the amount of snow at the end of accumulation period. The melting of the glacier can only begin after all the snow of the preceding winters has melted away. In the 1990s, ice usually appeared from under the snow in the second half of July (Gabrovec, 1998), while the weather observers at Mt. Kredarica kept reporting in the first decade of the operation of this weather station (established in 1954) that ice usually appeared in August (Šifrer, 1963). In 2001, the glacier remained covered with snow throughout the summer.

The amount of snow on the glacier is essentially greater than at Mt. Kredarica, where snow cannot last because of the windy position. The snow brought by the south and south-east winds from Mts. Kredarica and Rž also accumulates on the glacier. In addition, the glacier also receives the snow flowing from the escarpments of Mt. Triglav above. Avalanches also play an important role; they usually stop at the lower part of the glacier, which is more level (Šifrer, 1963). From earlier observations, M. Šifrer (1976, 1987) calls attention to the surprising agreement between the thickness of snow cover in individual years and the correspondingly stronger or lesser decline of the glacier. However, he also stresses the importance of other climatic factors which should not be ignored because they can strongly modify the role of snow precipitation in individual cases.

## CONCLUSIONS

Oscillations of the Triglav glacier are the result of complicated combined effects of various climatic factors in the warm and cold periods of a year, i.e., in its melting and accumulation seasons. In a few hundred years the glacier came into being and nearly vanished. In the early 20th century it still extended to the upper edge of the Triglavska severna stena. It measured about 30 hectares then, and the earliest photographs show typical transversal fissures on it. A century later, it only measured a hectare and a half and was only about 7 metres thick on average. If the process of decline in the last decade continues, the glacier will vanish completely in the course of ten years.

# Poglavje 4 Chapter

# Geografska lega in opis jezer

# Geographical Location and Description of the Lakes

Jurij DOBRAVEC* & Milijan ŠIŠKO**

Visokogorska jezera Julijskih Alp bi lahko razdelili na različne načine. Glede na njihovo lego se najlažje odločimo za tri skupine, ki jih morda malo na silo poimenujemo Triglavska, Kriška in Krnska jezera (slika 1). Še najbolj ustrezno ime nosi srednja skupina, torej Kriška jezera. Vsa jezerca namreč res ležijo na območju, ki mu enotno rečemo Kriški podi. Naziv Triglavska jezera je relativno sodoben in se je uveljavil zaradi slikovite planinske poti na vrh Triglava, oziroma, če sodimo po številčenju jezer od najvišjega proti najnižjemu, zaradi poti s Triglava. Prvotna imena Za jezerom, Jezerska dolina in še kakšno pozabljeno so se prenehala uporabljati z zatonom tamkajšnjega pašništva. Izraz Krnska jezera uporabljamo zgolj iz praktičnih razlogov, ker vsa tri ležijo v bližnji okolici Krna.

V preteklosti mnoga jezera najbrž niso bila poimenovana s posebnimi imeni, ampak so se imenovala po ledinskih imenih v neposredni okolici ali po imenih značilnih okoliških vrhov. Vsako od njih je bilo preprosto "jezero"; ali še bolje "Jezero". Tako poimenovanje je v planšarski kulturi običajno, saj je bila z gospodarskega stališča v nekem predelu bistvena paša, voda pa le izredno uporabna pritiklina, ki je gorskemu pašniku močno zvišala vrednost. Lokalnim uporabnikom v preteklosti, ko so bile povezave med posameznimi naselji relativno slabe, zato ni bilo treba nikomur razlagati, za katero jezero gre, saj so uporabljali le eno. Zato so rekli, da gredo "k Jezeru". Izjemoma so rekli tudi, da gredo "k Jezerom", kar je konkretno pomenilo, da gredo na Zgornjo Komno v Dolino Triglavskih jezer. Če

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Various criteria could be applied to divide the high-mountain mountain lakes of the Julian Alps into groups. Regarding their geographical location, the lakes can be divided into three groups which are, perhaps somewhat artificially, called the Triglav Lakes, the Križ Lakes and the Krn Lakes. Among them, Kriška jezera (the Križ Lakes) is the group which seems to deserve its name best because all the lakes are located in an area commonly known as Kriški podi. The name Triglav Lakes is relatively recent and probably derives from a picturesque mountain trail, which runs to the top of Mt. Triglav or down from Triglav, if we consider that the first Triglav Lake is the one which lies highest. The original names Za jezerom ('Behind the Lake'), Jezerska dolina ('Lake valley') and a few already forgotten names have fallen from use since pastoral grazing in these areas ceased. The expression 'Krnska jezera' (the Krn Lakes) is used for merely practical reasons since all the lakes in the group are located in the close vicinity of Krn.

In the past many lakes might not have had their own names, but were named after the geographic names in the sourrounding areas or after the neighbouring mountain peaks. Every lake was simply called 'jezero' (lake) or, even better, 'Jezero' (Lake). Nomenclature of this kind was quite common in pastoral culture because grazing was the main economic activity of many areas, and water was a very useful accessory which significantly increased the value of a mountain pasture. The local lake users never had to explain which 'lake' they

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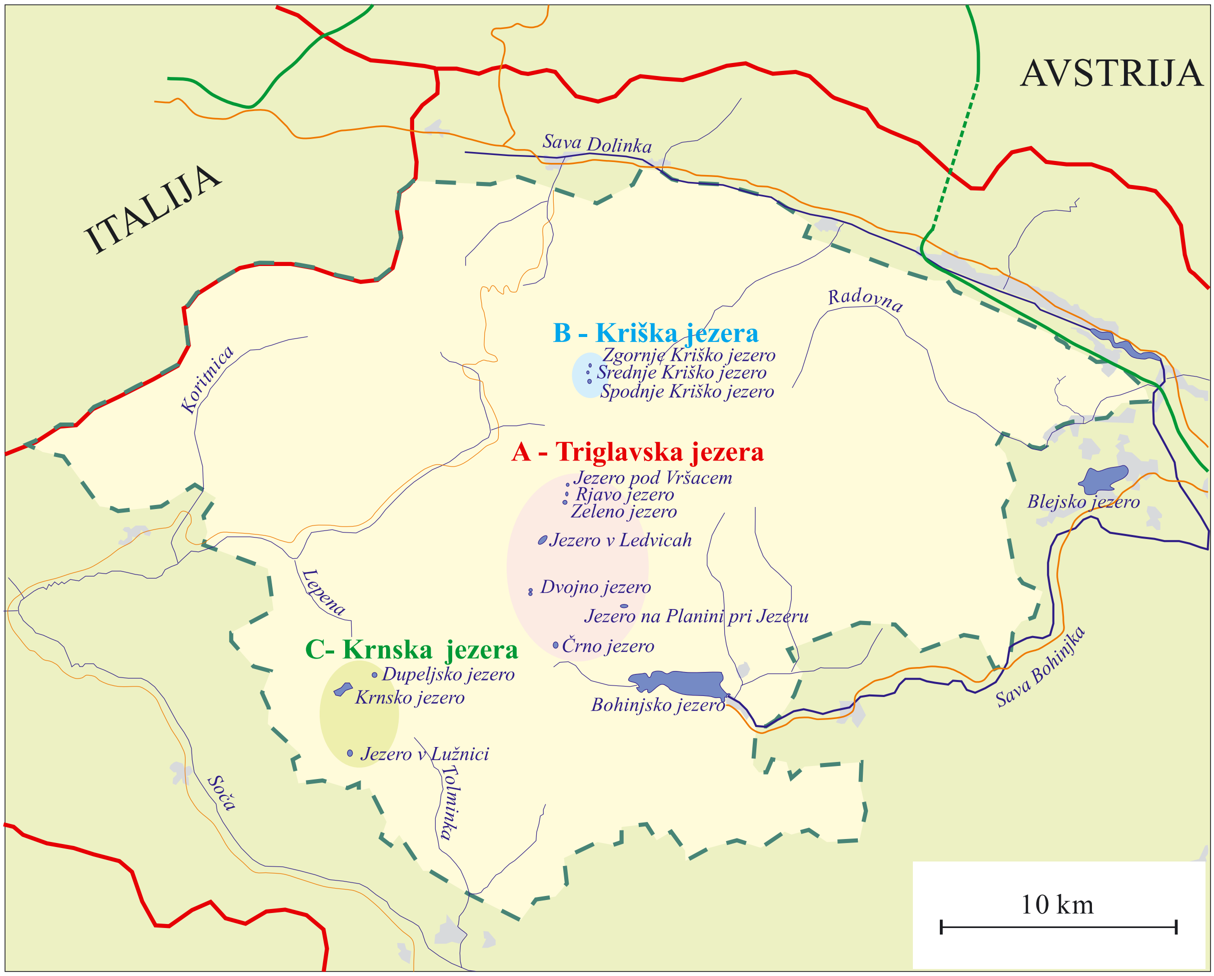



Slika 1: Lega visokogorskih jezer na območju Triglavskega narodnega parka (Slovenija) – A: Triglavska jezera; B: Kriška jezera; C: Krnska jezera

*Figure 1: Position of high-mountain lakes within the Triglav National Park (Slovenia) – A: Triglavska jezera; B: Kriška jezera; C: Krnska jezera*

bi jezera imela posebna imena, bi bila ta nedvomno zelo stara, tako kot so imena rek, potokov in hudournikov, ki imajo še predslovanske korenine.

*Triglavska jezera*

Med Triglavska jezera v najširšem smislu prištevamo vse stoječe vode Zgornje Komne, Lopučniške doline in Fužinskih planin.

Zgornja Komna je rahlo proti jugozahodu odprta dolina v osrčju slovenskega dela Julijskih Alp. Razteza se od 1200 do 2200 m nadmorske višine. Na severu jo zapirata Vodnikov Vršac in Kanjavec, proti zahodu se počasi dvigajo lašti proti grebenu Špičja, na vzhodu pa jo s strmimi stenami, pod ka-

were referring to because the road links between settlements were relatively poor and people only used one lake. They simply said that they were going to 'the Lake'. Occasionally, people also said they were going to 'the Lakes', which meant that they were going to Zgornja Komna to the Triglav Lakes Valley. If the lakes had been assigned special names, they would probably be very archaic, much the same as the names of the rivers, brooks and even torrents, which have pre-Slavonic origin.

*The Triglav Lakes*

In its widest sense, the lake group called the Triglav Lakes comprises all standing waters of Zgornja Komna, valley of Lopučnica and the pastures of Fužinske planine.

Located in the very heart of the Slovenian part of the Julian Alps, Zgornja Komna (Upper Komna) is a valley which, opening slightly towards the south-west, stretches from 1200 to 2200 m above sea level. The valley is framed by VodnikovVršac and terimi so nastala obsežna melišča, razteza greben Vršakov, Zelnaric in Tičaric. Nadmorska višina se po dnu doline spušča precej enakomerno do Bele skale, kjer se Zgornja Komna združi z manj izrazito dolino Lopučnico.

Geološko podlago pretežno tvori triasni apnenec (Grimšičar, 1962). Jurske sklade v večjem obsegu najdemo na vzhodnem robu. Glavne značilnosti območja so močna zakraselost in visokogorski kraški pojavi. Na prelomih med skladi različnih obdobij se pojavljajo za kraško visokogorje precej močni studenci. Od Močivca proti jugu voda tudi prodre na površje, bolj severno pa se verjetno zgubi pod melišči in v grohnatem dnu doline.

Habitatni tipi so značilno visokogorski. Dno doline in položnejša območja pokriva vegetacija. Drevesne vrste so omejene na smreko (*Picea abies* (L.) Karsten), rušje (*Pinus mugo* Turra) in macesen (*Larix decidua* Mill.). Polgrmičasto rastje pripada skupini habitatnih tipov s slečem in slečnikom (*Rhododendretum hirsuti* Ludi). Travniške združbe značilno predstavljajo sintaksoni z modriko in vednozelenim šašem (*Seslerio–Caricetum sempervirentis* Br. – Bl. in Br. – Bl. et Jenny). Kjer so travišča sklenjena in cvetje poleti bujno pisano, gre najpogosteje za združbe iz skupine *Seslerio–Caricetum.* Nesklenjena travišča pogosto označuje čvrsto šašje (*Gentiano terglouensis–Caricetum firmae* T. Wraber), melišča pa združbe z mlahavo bilnico (*Festucetum laxae* (Aichinger) T. Wraber) ali mošnjakovje (*Papaveri julici–Thlaspeetum rotundifolii* T. Wraber). Gole skale, na katerih uspeva lišajska flora, so ponekod presekane z razpokami, v katerih se razvijejo značilne rastlinske in živalske združbe skalnih razpok.

Dolina Lopučnica, ki jo na jugu zaključujeta Črno jezero in skalna stopnja Komarče, je jugovzhodno in južno od Zgornje Komne. Razen v zgornjem delu, kjer je vegetacija značilno visokogorska, nekaterih melišč in območij, ki so ostala posekana za potrebe planšarstva, prevladuje z gorskim gozdom porasčena pokrajina. Na prisojah se pojavljajo bukov gozd in toploljubne gabrove združbe.

Fužinske planine ležijo na gorski planoti, ki jo značilno oblikujejo kraški pojavi. Vrtačast svet je večinoma porasčen z gorskim iglastim gozdom, ki ga prekinjajo skoraj izključno umetno izkrčene površine planinskih pašnikov. Le v nekaterih kotanjah, kjer se pojavlja tudi ruševje, so travišča zaradi temperaturnega obrata naravnega izvora. Na tem območju sta najbolj izraziti stoječi vodi Jezero na Planini pri Jezeru in Mlaka v Dolu pod Stadorjem.

Značilen pojav, ki dolgoročno vpliva na jezera, predvsem na njihovo globino, je bočno zasipavan-

Kanjavec on the north, on the west the limestone pavements slowly rise towards to the ridge Špičje, and to the east the valley is closed off by steep rock faces and extensive screes of Vršaki, Zelnarica and Tičarica. The altitude decreases slowly along the bottom of the valley to Bela skala, where Zgornja Komna meets a less distinctive valley of Lopučnica.

The bedrock mainly consists of Triassic limestone (Grimšičar, 1962). The Jurassic strata are more common at the eastern edge of the valley. The area is characterised by its distinctive karstic character and high-altitude karst phenomena. Where strata from different geological periods meet, streams, quite well defined for high-altitude karst, have formed. To the south of Močivec, water penetrates to the surface, but further north the water is probably lost under the screes and in the conglomerate terrain.

Habitat types are typical of high mountains. The floor and the gentle slopes of the valley are covered by vegetation. The tree species are limited to spruce (*Picea abies* (L.) Karsten), dwarf mountain pine (*Pinus mogo* Turra) and larch (*Larix decidua* Mill). Low bushes form the habitat type group with *Rhododendretum hirsuti* Ludi. Grass associations are typically represented by syntaxons with *Seslerio–Caricetum sempervirentis* (Br. – Bl. and Br. – Bl. et Jenny ). Areas overgrown with uninterrupted grasslands and lush summer flowers usually belong to *Seslerio–Caricetum* associations. Interrupted glasslands are often characterised by *Gentiano terglouensis–Caricetum firmae* T. Wraber associations, while the screes are overgrown with *Festucetum laxae* Aichinger T. Wraber or *Papaveri julici–Thlaspeetum rotundifolii* T. Wraber. In some places bare rocks harbouring lichen vegetation are interrupted with fissures, in which plant and animal associations typical of rock fissures can thrive.

The Lopučnica valley, which is closed off in the south by Črno jezero (the Black Lake) and a rock face of Komarča, lies to the south-east and south of Zgornja Komna. Except for the valley's upper part with typical mountain vegetation, some screes, and areas which have remained unforested for the needs of pastoral grazing, the landscape is mainly overgrown with mountain forests. On the sunny slopes beech forest and thermophille hornbeam associations prevail.

The pastures Fužinske planine lie on a mountain plateau, which has been modified by karst phenomena. The terrain, rich in karst hollows, is largely covered with mountain coniferous forest, only interrupted by artificially created mountain meadje. Del grušča se vali po bližnjih meliščih navzdol neposredno v jezero in ga s tem bočno zasipa. Pozimi in zgodaj spomladi, ko so jezera še pokrita z ledom in snegom, se del tega grušča ustavi na ledu. Ob taljenju se nekaj časa prevaža po jezerski površini na kosih plavajočega ledu in šele ko se plošča stopi, pade v vodo. Tako se jezera zasipavajo tudi z vrha in ne samo s strani. Pojav lahko opazujemo pozno pomladi ali zgodaj poleti na jezerih, ki ležijo tik pod strmimi melišči.

*Krnska jezera*

Jezera v okolici Krna na primorski strani Julijskih Alp so si bolj vsaksebi kot ostali dve skupini. Doline, kjer ležijo jezera, so ledeniškega izvora. Geološka podlaga je pretežno triasna (Ramovš, 1985), v precej večji meri pa se ob prelomih kažejo jurske in tudi kredne kamnine. Z izjemo Dupeljskega jezera, ki ga delno že obdaja gozd, je vegetacija visokogorska – sklenjeni ali nesklenjeni rušnati travniki ter rušje. Prevladujejo pa skalovje in melišča.

*Kriška jezera*

Na Kriških podih so v obsežnih visokogorskih vrtačah nastala tri jezera. Ležijo na nadmorskih višinah od 1900 do 2150 m in so pri nas najvišje ležeče stoječe vode. Poleg njih se v sosednjih vrtačah pojavljajo občasna snežna jezerca. Pode obkrožajo visoki vrhovi: Planja, Razor, Križ, Stenar, Bovški Gamsovec in Pihavec. Melišča so skromna, značilne pa so skalne police. Od vegetacije se pojavljajo le redki grmiči rušja ter revni alpski pašniki. Geološka podlaga je triasna (Ramovš, 1985).

**Legenda k fotografijam in skicam**:

*Zgoraj*: posnetek jezera iz zraka (oktober 2000)
*Sredina*: linija horizonta okoli jezera in navidezna pot sonca po nebu ob poletnem (zgornja črta) in zimskem sončevem obratu (spodnja črta) ter pomladanskem in jesenskem enakonočju (srednja črta)
*Spodaj*: batimetrična karta (osnova: Gams, 1962)
*Posnetki iz zraka in batimetrične karte so bile narejene ob različno visokem vodostaju!*

**Legend to the photos and the figures**:

*Top*: aerial photo of a lake (October 2000)
*Middle*: sky–line around a lake and virtual travel of the sun at midsummer (top line) and midwinter (lower line) solstice and vernal and spring equinox (middle line)
*Bottom*: bathymetric map (based on Gams, 1962)
*Aerial photos and bathymetric maps were made at different water levels!*

ows. Only in some depressions which boast occasional dwarf mountain pine have natural grasslands been preserved as a result of temperature inversion. The most characteristic bodies of standing water in this area are Jezero na Planini pri Jezeru (Lake on Planina pri Jezeru) and Mlaka (Pond) in Dol below Stador.

A typical phenomenon which has a long-term effect on the lakes and their depth in particular is lateral deposititioin. Gravel from the nearby screes rolls down to the lake, filling up the lake basin from the sides. In winter and early spring, when the lakes are still covered with snow and ice, part of this gravel comes to rest on the ice cover. When the snow starts to melt, some gravel floats on the lake surface for a time and falls into the water when the supporting ice melts down. This explains why the lakes receive sediment deposition from the top as well as from the sides. The phenomenon can be observed in late spring or early summer in the lakes which lie directly under steep screes.

*Krnska jezera (the Krn Lakes)*

The lakes in the vicinity of Krn on the Primorsko side of the Julian Alps lie farther apart than the lakes in the other two groups. They are located in valleys of glacial origin. The geologic substratum originates largely from the Triassic period (Ramovš, 1985), although Jurassic and Cretaceous rocks can also be found along rock faults. With the exception of the Dupeljsko jezero (Duplje Lake), which is partly surrounded by forests, the other Krn Lakes support mountain vegetation – uninterrupted or interrupted mountain meadows and dwarf mountain pine stands. Nevertheless, rocky areas and screes predominate.

*Kriška jezera (the Križ Lakes)*

In large high-altitude depressions on Kriški podi three lakes have formed. Their altitude ranges from 1900 to 2150 m and they are the highest-altitude standing waters in Slovenia. Apart from these lakes, snow 'lakelets' occasionally form in the neighbouring depressions. Kriški podi is surrounded by a ring of high peaks: Planja, Razor, Križ, Stenar, Bovški Gamsovec and Pihavec. The screes here are poor, and rock shelves are a typical feature of the landscape. Vegetation comprises some small patches of dwarf mountain pine and interrupted mountain pastures. The geological substratum is from the Triassic period (Ramovš, 1985).

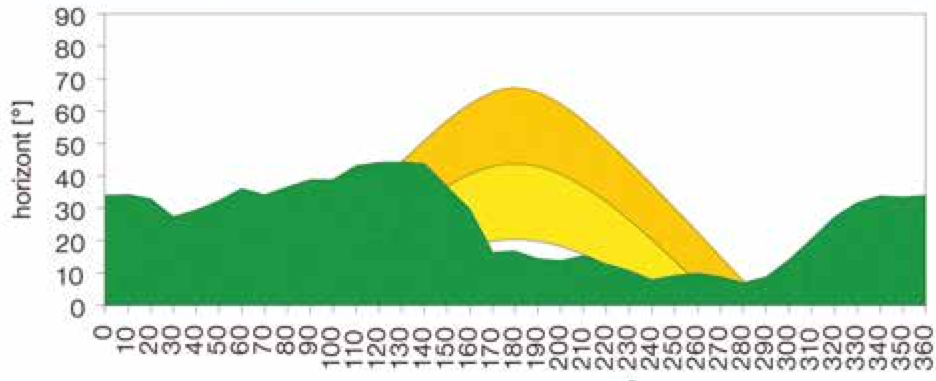
## TRIGLAVSKA JEZERA

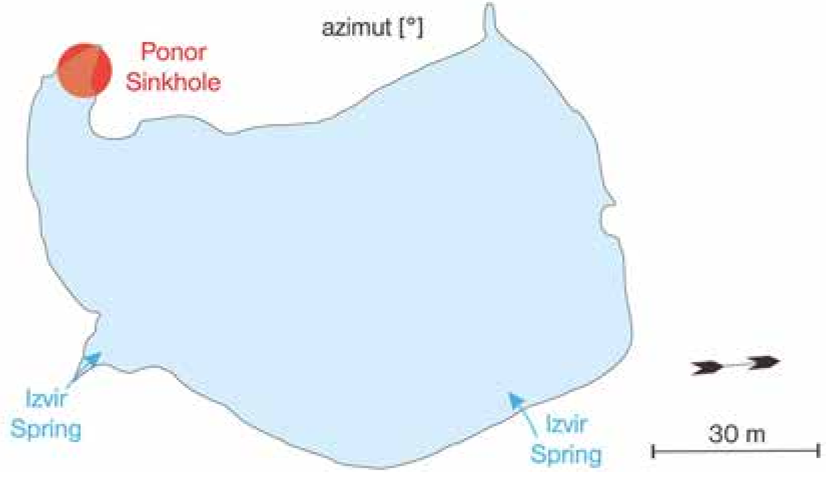
## THE TRIGLAV LAKES

**Jezero pod Vršacem**
*Sinonim*: Prvo Triglavsko jezero

**Jezero pod Vršacem (Lake below Vršac)**
*Synonym*: The First Triglav Lake

**Jezero pod Vršacem** (Foto/Photo: Anton Brancelj)




Lega / *Geographical position*: N 46° 21' 36'', E 13° 48' 10''
Nadmorska višina / *Height above sea level:* 1993 m
Srednja površina / *Median area:* 0,558 ha
Srednji obseg / *Median perimeter*: 260 m
Največji premer / *Maximum diameter:* 95 m
Največja globina / *Maximum depth:* 7 m
Srednji vodostaj / *Average depth:* 6 m
Vodozbirno območje (ocena) / *Catchment area (estimate):* 54 ha

Najvišje ležeče Triglavsko jezero leži pod južnimi ostenji Vodnikovega Vršaca in Kanjavca. Vanj se s pobočij spuščajo melišča. Če je pozimi veliko snega, se po teh meliščih v jezersko kotanjo prožijo plazovi, zato sneg takrat ostane še dolgo v poletje. Zaradi hladnih razmer je jezero tudi dolgo pod ledom. Južni in jugovzhodni breg je peščen in delno skalnat. Tu prevladujejo jurski apnenci.

Jezero je nepravilno okrogle oblike. Breg se v podvodnem delu hitro spusti do precej ravnega dna z mestoma kotanjastimi poglobitvami. Na območju, kjer jezero zasipavajo melišča, je dno gruščnato. Značilne so večje skale. Jezersko dno je sicer pokrito le z nekaj centimetrov debelo plastjo mulja. To je verjetno posledica njegove dolgoletne pokritosti z ledom v preteklosti. Jezero ima stalen pritok iz dveh potočkov. Eden priteka izpod grušča na zahodni strani jezera, drugi pa iz skalne razpoke na severni strani. Ob dolgotrajni suši običajno presahneta. Odtok zasledimo skozi skalne razpoke na vzhodni strani jezera, kjer se začenja obširna ravnica. Prav zato niha gladina vode za največ en meter. Voda je sicer nekoliko motna zaradi suspendiranih mineralnih delcev, vendar sega svetloba ob srednjem vodostaju do dna.

V smeri proti sedlu Prehodavci leži še manjše vodno telo, imenovano Mlaka v Laštah. Poleti običajno presahne.

The highest–lying Triglav Lake is located below the southern slopes of Vršac and Kanjavec. Screes from the slopes fall into it. Provided a winter is rich in snow, avalanches start from these screes and slide into the depression where snow usually stays long into summer. Cold weather conditions cause the ice-cover to persist. The southern and southeastern shores are sandy and partly made up of rock material. Jurassic limestones prevail.

The lake has an irregular circular shape. The littoral declines quickly to a relatively flat bottom with occasional hollow–like depressions. In places where the scree deposits fall into the lake, the lake bottom is made of gravel. Large–sized rocks are a typical feature of the lake. The lake bottom is covered with just a few centimetres of silt because the lake was ice–covered for a long period of time. The lake is permanently fed by two streams. One of them flows in from the gravel on the western side of the lake, and the other comes from a rock fissure on the northern side of the lake. Both streams dry up in long periods of drought. An outlet can be observed, draining water through a rock fissure on the eastern side of the lake where an extensive plain begins. This is why the water level fluctuates by 1 m at most. The water is slightly turbid because of suspended mineral particles, but at median water levels the light still reaches to the bottom.

**Rjavo jezero**
*Sinonimi*: Drugo Triglavsko jezero, Rjava mlaka

Zahodno od Poprovca, med velikim temnim gruščem, leži Rjavo jezero. Glavna značilnost jezera je veliko nihanje vodne gladine, ki znaša celo do 10 m. Ob nizkem vodostaju, pozno poleti in zgodaj jeseni, ima le nekaj metrov obsega, ob visokem vodostaju, pozno pozimi in spomladi, pa se premer večkratno poveča. Breg je zato težko določljiv. Le ob najvišjem vodostaju lahko rečemo, da je severni breg skalnat. Melišč, ki povečini zasipajo vsa ostala jezera v pogorju, tu praktično ni. Dno jezera je na najglobji točki pokrito z okoli 20 cm debelo plastjo svetlega mulja. Površina sedimenta vsebuje le 71 % vode, od trdnih delcev pa je le ena desetina (12 %) organske snovi, kar kaže, da je okolica jezera neporasla, pa tudi alge in zooplankton so v njem redki. Jezero nima stalnih površinskih pritokov, pa tudi odtoka ni moč določiti. Zaradi kristalno čiste vode in majhne globine ob srednjem vodostaju seže večina dnevne svetlobe do dna.

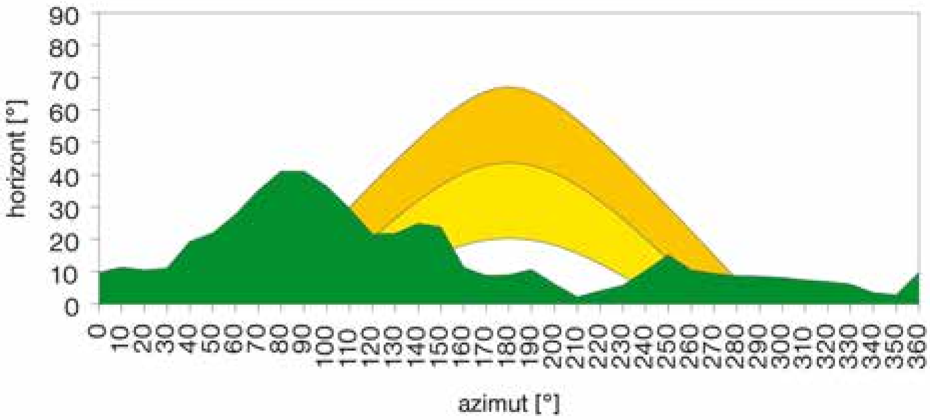
**Rjavo jezero (the Brown Lake)**
*Synonyms*: The Second Triglav Lake, Rjava mlaka

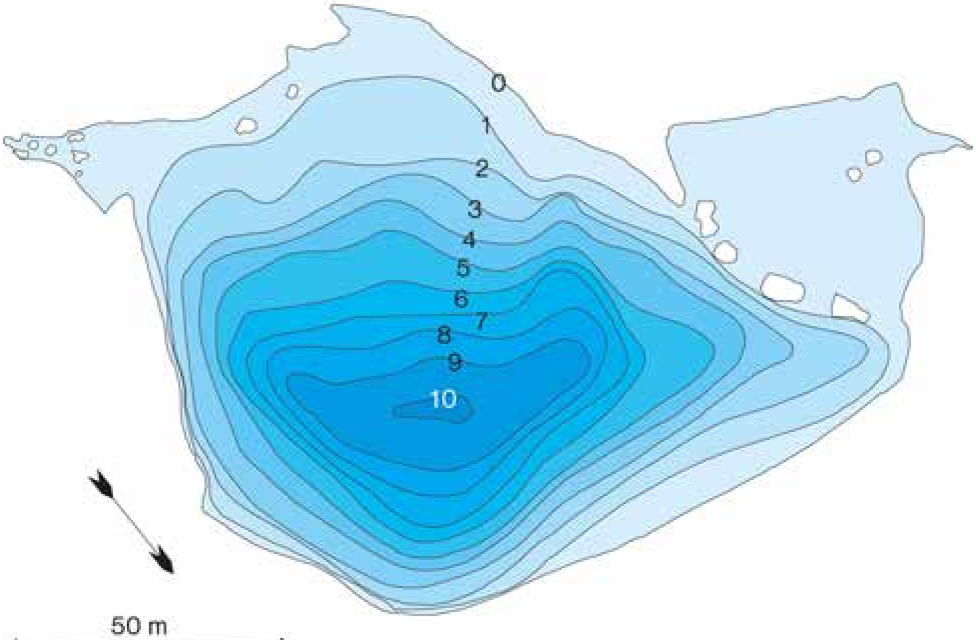
To the west of Poprovec, surrounded by large dark gravel slopes, lies Rjavo jezero (the Brown Lake). The main characteristic of Rjavo jezero is the fluctuation in water level. At low water level, in late summer and early autumn, the lake is only a few meters in size, but in late winter and in spring, its diameter increases many-fold. The shore is hard to define. Only at highest water levels can the northern lake shore be described as rocky. Screes which are filling up all the other mountain lakes do not surround Rjavo jezero. At its deepest point, the lake bottom is covered with a 20 cm layer of light–coloured silt. The surface of the sediment contains only 71 % water, and only one tenth (12 %) of solid matter is organic material, which indicates that the surrounding area of the lake is not overgrown and that both algae and zooplankton are rare. The lake has no surface tributaries, and its outlet is hard to define. Owing to crystal clear water and low depth, most of the sunlight reaches the lake bottom at median water level.

**Rjavo jezero** (Foto/Photo: Anton Brancelj)

Lega / *Geographical position:*
N 46° 21' 20'', E 13° 48' 00''
Nadmorska višina / *Height above sea level:* 2002 m
Srednja površina / *Median area:* 1,338 ha
Srednji obseg / *Median perimeter:* 350 m
Največji premer / *Maximum diameter:* 140 m
Največja globina / *Maximum depth:* 10 m
Srednji vodostaj / *Average depth:* 3 m
Vodozbirno območje (ocena) /
*Catchment area (estimate):* 36 ha

In the direction towards the Prehodavci pass, there is another small waterbody, called Mlaka v Laštah (Pond at Lašte). It usually dries up in summer.



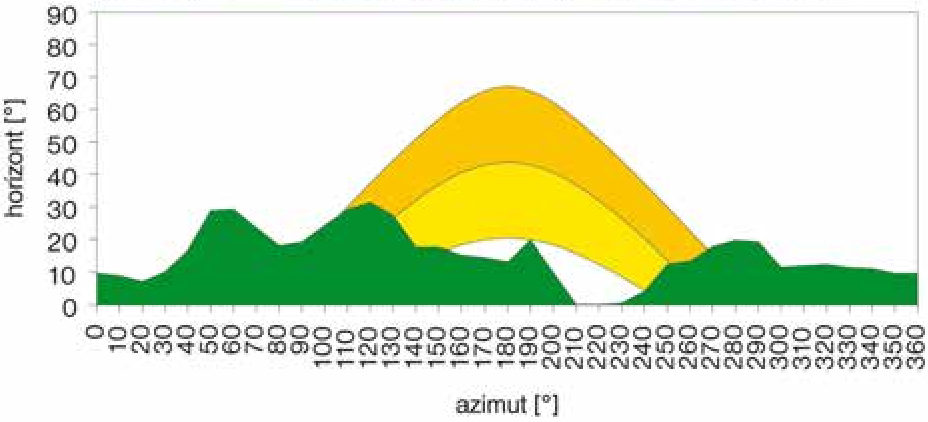
**Zeleno jezero**
*Sinonimi*: Tretje Triglavsko jezero, Zelena mlaka

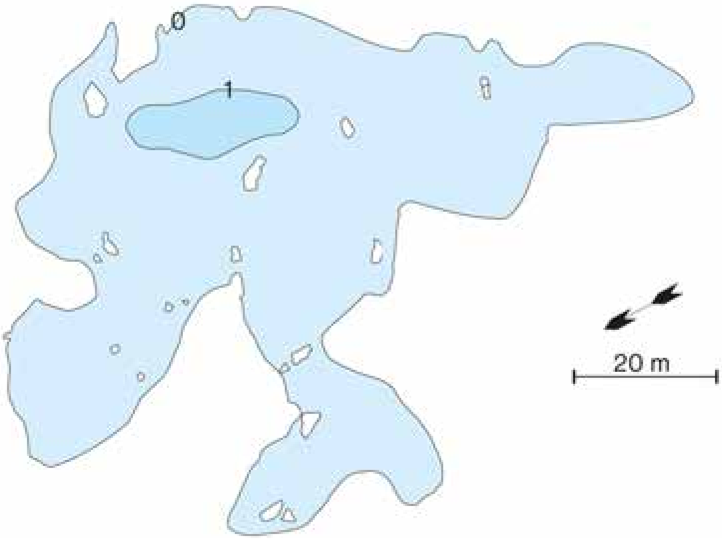
Jezerce z najbolj razgibanim bregom je Zeleno jezero. Leži na manjši planjavi med Zadnjo Lopo in

**Zeleno jezero (the Green Lake)**
*Synonyms*: The Third Triglav Lake, Zelena mlaka

Zeleno jezero (the Green Lake) is different from other lakes by the diverse morphometry of its shore.

**Zeleno jezero**
(Foto/Photo: Anton Brancelj)




Lega / *Geographical position:*
N 46° 21' 05'', E 13° 47' 57''
Nadmorska višina /
*Height above sea level:* 1983 m
Srednja površina /
*Median area:* 0,609 ha
Srednji obseg /
*Median perimeter:* 410 m
Največji premer /
*Maximum diameter:* 95 m
Največja globina /
*Maximum depth:* 3 m
Srednji vodostaj /
*Average depth:* 2 m
Vodozbirno območje (ocena) /
*Catchment area (estimate):* 24 ha

Vršaki, kjer se dolina že prevesi. Izpod Hribaric se vanj spušča že precej porašćeno melišče, sicer pa so po jezeru posajeni večji skalni balvani. Ime ima nedvomno po vegetaciji, ki porašča praktično celotno dno. Dno je plitvo, redko doseže globino dveh metrov in je zmerno razgibano. Gladina niha za 1 do 2 m. Jezero nima stalnih površinskih pritokov ali odtokov. Večji del vodnih izgub je verjetno na račun izhlapevanja, le manjši pa na račun ponikanja v porozno podlago. Dno je pokrito s sivim muljem, ki je na površini porasel z rastlinami. Površina sedimenta vsebuje 87 % vode, od trdnih delcev pa je skoraj tretjina (32 %) organske snovi. Zaradi kristalno čiste vode in majhne globine ob srednjem vodostaju seže večina dnevne svetlobe do dna.

Pod Vršaki, v dolinici, ki jo od Zelenega jezera ločuje manjši skalni hrbet, ležijo Mlake pod Vršaki. To so manjša jezerca, ki se spomladi napolnijo s snežnico bližnjih snežnih plazov, poleti pa običajno presahnejo.

It lies on a small plain between Zadnja Lopa and Vršaki. From below Hribarice, a relatively overgrown scree descends into it, and there are a few boulders scattered close to the lake. The lake is undoubtedly named after the vegetation growing over the entire lake bottom. The lake floor is shallow, rarely reaching 2 metres, and of average undulation. The water level fluctuates between 1 and 2 metres. The lake has no surface tributaries or outlets. Loss of water probably occurs largely by evaporation, and only a small portion sinks into the porous bedrock. The lake bottom is covered with gray silt, the surface of which is overgrown with vegetation. The surface of the sediment contains 87 % water, and almost one third (32 %) of solid matter is organic material. Owing to crystal clear water and low depth, at median water level most of sunlight reaches the lake bottom.

Below Vršaki, in a little valley separated from Zeleno jezero only by a low mountain ridge, lies Mlake pod Vršaki. This is a group of small 'lakelets' which fill up with snow water from neighbouring snow avalanches in the spring, and usually dry up during summer.

**Jezero v Ledvicah**

*Sinonimi*: Jezero v Ledvici, Četrto Triglavsko jezero, Črno jezero, Veliko črno jezero, Veliko jezero, Ledvička

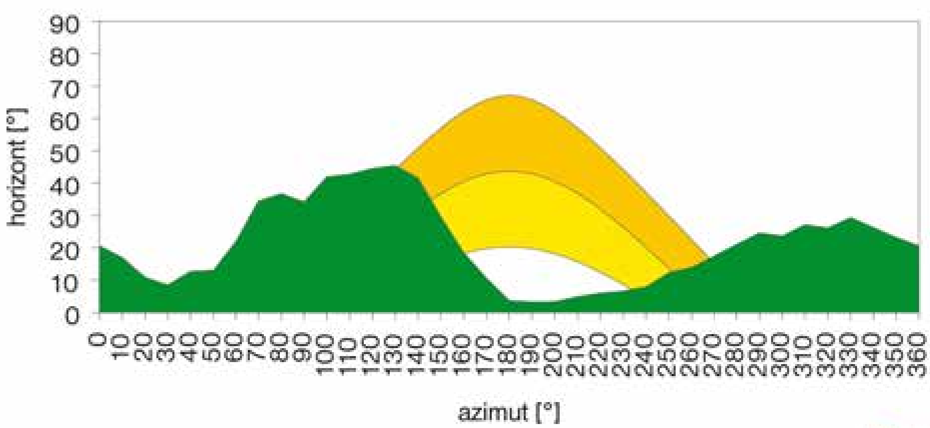
Največje jezero Doline Triglavskih jezer leži v območju, ki se mu reče v Ledvicah. Izpod Zelnaric se proti njegovemu vzhodnemu bregu spuščajo obsežna melišča, ki jezero počasi zasipavajo. Čez ta melišča vodi pot na Triglav. V meliščih so dobro vidne hudourniške struge iz ostenij nad jezerom, po katerih teče voda v jezero. Ena med njimi je še posebej velika in kaže na to, da se je pred kratkim sprožil kamnit plaz, ki je delno zasul severni del jezerske kotanje in je nastala razmeroma velika plitvina. Severozahodni breg je skalnat. Skale so gole, višje proti Špičju pa prevladujejo skalne police z nesklenjeno travniško vegetacijo. Nekaj metrov se strmo spuščajo tudi v globino jezera. Južni del brega je peščen in kaže na ustaljenost vodne gladine. Tu sega vegetacija do brega. Okoli jezera rastejo posamezni macesni, ki se le na nekaj mestih zgostijo v manjše skupine. Dno je muljasto in precej zravnano na območju, kjer je jezero najširše. Gladina vode lahko niha za okoli 2 m. Stalnega površinskega pritoka jezero nima, pač pa ima zelo močan podvodni dotok na severnem delu brega. Občasen površinski dotok je še s pobočij na zahodni strani jeze-

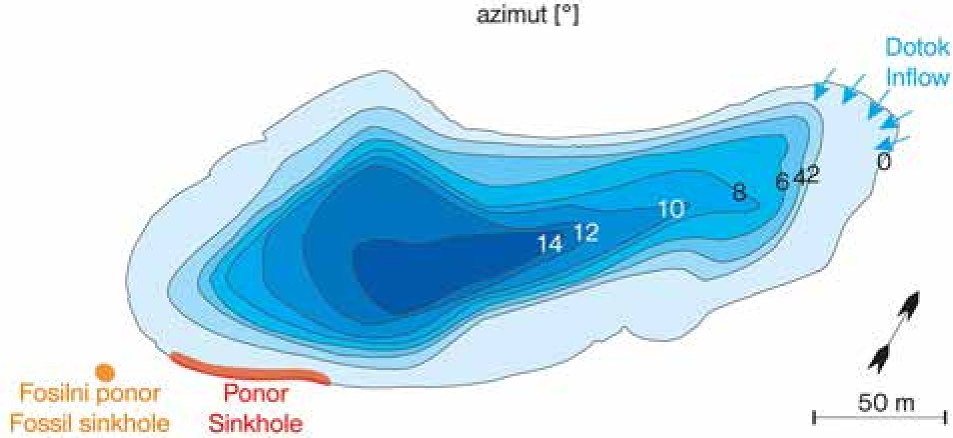
**Jezero v Ledvicah (Lake at Ledvicah)**

*Synonyms*: The Fourth Triglav Lake, Jezero v Ledvici, Črno jezero, Veliko črno jezero, Veliko jezero

The largest in the group of Triglav Lakes lies in the area called Ledvice. From the slopes below Zelnarice extensive screes descend towards the lake's eastern shore, slowly filling up its basin. Across these screes runs a mountain trail to Triglav. On the screes, torrential riverbeds from the ridges above the lake can be seen, functioning as channels through which water can flow into the lake. One channel is especially sizeable and it seems that not long ago an avalanche started there and partly filled up the northern part of the lake depression, thus creating a relatively extensive shallow area. The north-western shore is rocky. The rocks are bare, but higher up towards Špičje rock shelves with interrupted scree vegetation prevail. They descend steeply into the deepest part of the lake. The southern part of the shore is sandy and indicates the stability of the water level. In this area, vegetation reaches to the shore. Around the lake, some larch trees grow and in a few places thicken into small stands. The lake bottom is silt–covered and quite flat in the widest part of the lake. The water level may fluctuate by about 2 metres. The lake has no permanent surface tributary, but a very active un-

**Jezero v Ledvicah**
(Foto/Photo:
Anton Brancelj)




Lega / *Geographical position:* N 46° 20' 25'', E 13° 47' 12''
Nadmorska višina / *Height above sea level:* 1830 m
Srednja površina / *Median area:* 2,187 ha
Srednji obseg / *Median perimeter:* 775 m
Največji premer / *Maximum diameter:* 330 m
Največja globina / *Maximum depth:* 15 m
Srednji vodostaj / *Average depth:* 14 m
Vodozbirno območje (ocena) / *Catchment area (estimate):* 175 ha

ra in pa melišč na vzhodnem bregu. Odtok je ob nizkem vodostaju skozi grušč na južni strani jezera. Okoli 3 m nad srednjim nivojem vodne gladine je še ponor, povsem zasut z gruščem in vejevjem. Skozenj odteka voda le ob izjemno visokih vodah. Dno je od globine 10 m navzdol pokrito z debelo plastjo rahlega mulja, temno rjave barve. Površina sedimenta vsebuje 94 % vode, od trdnih delcev pa je več kot polovica (59 %) organske snovi. Voda v jezeru je bistra, tako da sega ob srednjem vodostaju svetloba do dna.

Nekateri trdijo, da izvira ime jezera od ledvici podobne skale na severnem bregu jezera. Drugi spet, da zaradi rahlega zoženja doline, ki naj bi bilo podobno kot pri človeku v ledvenem delu. Oblika jezera kaže malo anatomske podobnosti z živalsko ledvico. Zelo verjetno so pastirji nekoliko razbrazdane skalne lašte v okolici imenovali ledvice in dali predelu tako ledinsko ime.

derwater inlet has been discovered in its northern part. A periodical surface inlet tributary collects water from the western side of the lake and from the screes above the eastern shore. At low water level the water drains through the gravel on the southern side. About 3 m above the median water level there is another sinkhole, completely jammed with gravel and branches. Water drains through it only at exceptionally high water. From a depth of 10 m, the lake bottom is covered with a thick layer of fine dark brown silt. The surface of the sediment contains 94 % water, and more than a half (59 %) of solid matter is organic material. The lake water is clear so that at median water level sunlight reaches to the lake bottom.

Some people say that the lake was named after a kidney–shaped rock on the northern side of the lake. Others, however, claim that the name portrays a slight narrowing of the valley which seems to resemble the waistline of a human body. The shape of the lake shows little similarity to the animal kidney. The shepherds may have called the limestone pavements ('lašti') in the surroundings *ledvice* (kidneys) and consequently the entire area has been named after them.

**Dvojno jezero**
*Sinonimi*: Peto in Šesto Triglavsko jezero

Peto in Šesto Triglavsko jezero pod Tičaricami tvorita skupaj Dvojno jezero. Ob visoki vodi se namreč obe jezeri združita v eno, ob nizki, torej poleti in jeseni, pa sta to dve ločeni jezeri. Geološka podlaga v okolici je precej pestra, saj poleg triasnih apnencev najdemo tudi obilo jurskih peščenjakov in skrilavcev. Vzhodno in južno od jezer je morenski hrbet, ki ga delno pokriva melišče, v bistvu pa prav zaradi tega obe jezeri nista podvrženi zasipavanju. Ledeniškega nastanka je tudi greben, ki jezeri prečno ločuje, in severni breg. Zahodni breg Petega jezera z značilnim kljukastim zalivčkom je prepadno skalnat. Za okolico so značilne rdečkaste ilovice.

Vsako od jezer je nepravilne ovalne oblike. Proti dnu se globina bolj ali enakomerno spušča. Izrazitejše razgibanosti dna ni opaziti, razen večjih skalnih balvanov, ki jih opazimo tudi na bregu. Vodna gladina lahko niha za 2 do 3 m.

Jezeri nimata stalnih površinskih dotokov. V Peto jezero občasno, ob visoki vodi, priteka voda po strugi iz Močivca, ki leži okoli 150 m severno od jezera, nekaj pa tudi iz lukenj na zamočvirjenem

**Dvojno jezero (Double Lake)**
*Synonyms*: The Fifth Triglav Lake and The Sixth Triglav Lake

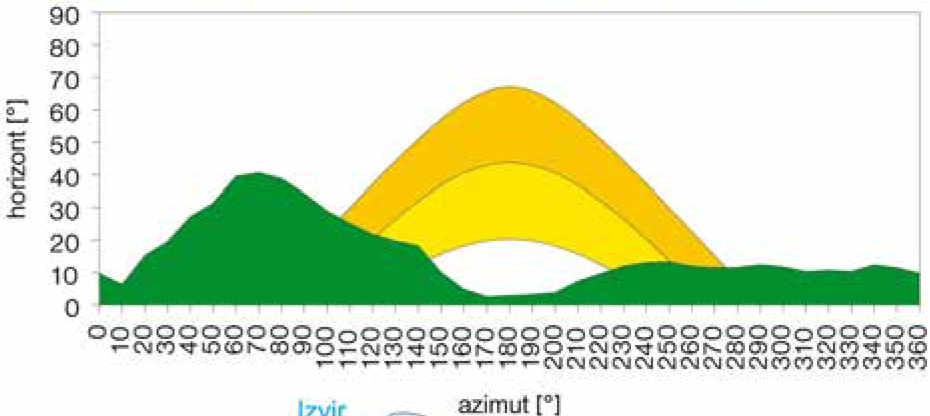
The Fifth and the Sixth Triglav Lakes below Tičarice together form Dvojno jezero (Double Lake). At high water level the two lakes form a single body of water, but at low water, that is in summer and autumn, there are two separate lakes (*named also the north and the south basin in the rest of this book*). Geological sub-stratum in the vicinity is quite diverse, composing Triassic limestone and much Jurrasic sandstone and slate. To the east and south of the lakes there is a moraine, partly covered by screes which actually preserve both lakes from being in-filled. The ridge separating the lakes as well as the northern shore are of glacial origin. The western shore of the Fifth Triglav Lake with its characteristic hook–shaped bay is marked by precipitous rock faces. The surrounding area is characterised by reddish clay.

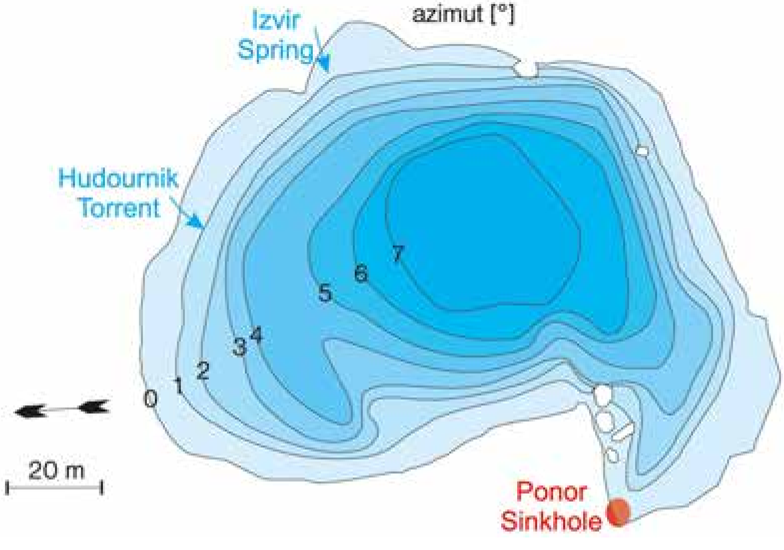
Each of the two lakes is of irregular oval shape. The depth of the lake decreases gradually towards the bottom. Except for some large boulders, which can also be found along the shore, the morphology of the lake bottom is not very diverse. Water level may fluctuate between 2 to 3 metres.

terenu blizu severnega brega jezera. Stalen, a šibek, podvodni dotok je le pod velikim balvanom tik ob jezeru na vzhodni strani. Šesto jezero ima prav tako stalen (Gams, 1962), a šibak podvodni dotok blizu

The lakes have no permanent surface tributaries. Periodically, at high water level, the lakes are fed by the water from Močivec about 150 m north of the lake, and some water flows from the holes in the

**Peto Triglavsko jezero / The Fifth Triglav Lake**
(= the north basin)
(Foto/Photo: Anton Brancelj)



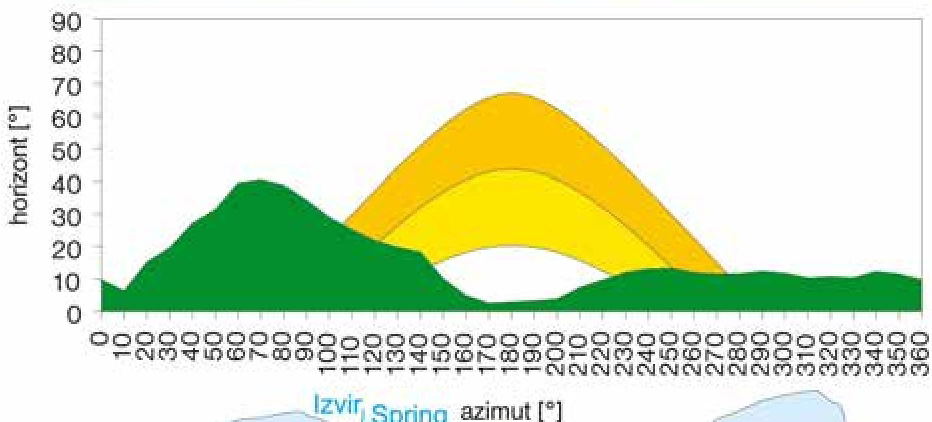

Lega / *Geographical position:*
N 46° 19' 03'', E 13° 47' 03''
Nadmorska višina / *Height above sea level:* 1669 m
Srednja površina / *Median area:* 1,002 ha
Srednji obseg / *Median perimeter:* 520 m
Največji premer / *Maximum diameter:* 120 m
Največja globina / *Maximum depth:* 11 m
Srednji vodostaj / *Average depth:* 8 m
Vodozbirno območje (ocena) / *Catchment area (estimate):* 90 ha (skupno / *both lakes*)

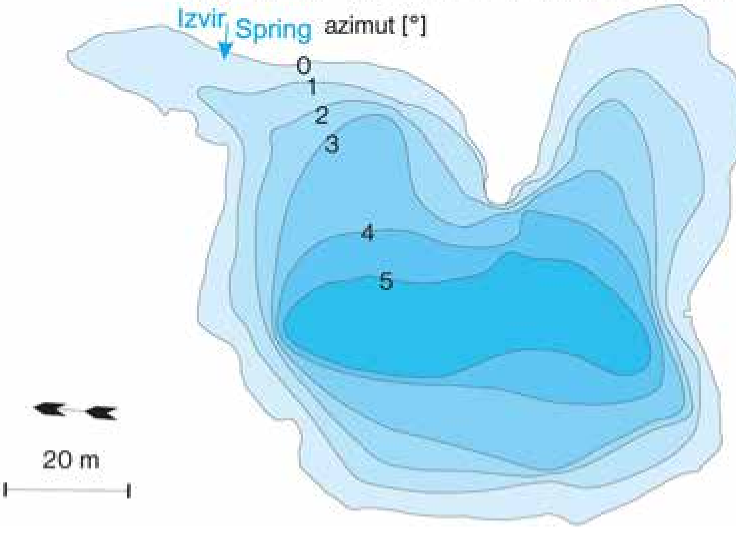
velikega balvana na vzhodni strani brega. Površinskih odtokov ni. Ima pa Peto jezero močan podzemni odtok skozi ponor na začetku kljukastega zalivčka, tik pod prepadno steno. Dno je od globi-

swamp area near its northern shore. The only permanent yet weak underwater inlet flows from below a large boulder on the eastern side of the lake.

There are no surface outlets. The Fifth Triglav

**Šesto Triglavsko jezero / The Sixth Triglav Lake**
(= the south basin)
(Foto/Photo:
Anton Brancelj)




Lega / *Geographical position:*
N 46° 18' 57'', E 13° 47' 03''
Nadmorska višina /
*Height above sea level:* 1669 m
Srednja površina /
*Median area:* 0,662 ha
Srednji obseg /
*Median perimeter:* 350 m
Največji premer /
*Maximum diameter:* 105 m
Največja globina /
*Maximum depth:* 9 m
Srednji vodostaj /
*Average depth:* 6 m
Vodozbirno območje (ocena) /
*Catchment area (estimate):*
90 ha (skupno / *both lakes*)

ne 5 m navzdol pokrito s plastjo rahlega mulja temno rjave barve. Površina sedimenta v Petem jezeru vsebuje 92 % vode, od trdnih delcev pa je več kot polovica (54 %) organske snovi. Površina sedimenta v Šestem jezeru se od predhodnega precej razlikuje, saj v sedimentu prevladujejo mineralne sestavine. Tako je v površinski plasti precej manj vode (84 %), organskih delcev pa je le dobra petina (21 %). Ob srednjem vodostaju je voda v Šestem jezeru sicer motna, a svetloba še prodre do dna. V Petem pa se je prosojnost jezera po naslitvi rib zmanjšala, tako da sega svetloba le še do globine 6 do 7 m.

V okolici Dvojnega jezera je še več občasnih pojavov stoječih voda. Pod izvirom Močivec, severno od jezera, je zdaj majhno akumulacijsko jezero za potrebe oskrbe bližnje planinske koče. V preteklosti se je na kratki razdalji – le nekaj deset metrov – od izvira do ponora tvorila plitva naravna mlaka.

Še bolj severno, na hrbtu proti dolini Lopučnica, sta vsaj dve izravnavi, ki ju občasno preplavi voda. Palinološke raziskave kažejo na ostanke barij.

Na sredi poti med Dvojnim jezerom in Jezerom v Ledvicah, neposredno ob poti na Veliko špičje, je v manjši kotanji še občasna, vendar kar globoka mlaka. Možno je, da je nastala iz umetno izdelanega kala, ki je služil napajanju živine z bližnje opuščene planine.

Lake, however, has an active underwater outlet through a sinkhole at the beginning of a hook–shaped bay, just below the precipitous rock face. From a depth of 5 m, the lake bottom is covered with a thick layer of fine dark brown silt. The surface of the sediment in the Fifth Triglav Lake contains 92 % water, and more than a half (54 %) of solid matter is organic material. The surface of the sediment in the Sixth Triglav Lake is different from the Fifth, as the mineral component dominates in the sediment. Consequently, the surface layer contains much less water (84 %), and only a fifth (21 %) of solid matter is organic material. At median water level the water in the Sixth Triglav Lake is turbid, but the light still reaches to the bottom. In the Fifth Triglav Lake the transparency of the lake water has been reduced following stocking with fish so that now sunlight reaches only to a depth of 6 to 7 metres.

In the surroundings of Dvojno jezero there are a number of standing waterbodies. Below the Močilec source, north of the lake, there is a small accummulation lake which supplies the needs of the nearby mountain lodge. In the past a natural shallow pond formed on a short stretch of land from the source to the sinkhole.

Further to the north, on a ridge running to the Lopučnica valley, there are at least two plains which are ocassionally flooded by water. Palinological research indicates the remains of a bog in this area.

Midway between Dvojno jezero and Jezero v Ledvicah, directly by the trail to Lepo Špičje, there is a periodic, yet quite deep pond. It may have evolved from an artificial pond which was used for feeding the cattle from the nearby abandoned pasture.

**Črno jezero**

*Sinonimi*: Sedmo Triglavsko jezero, Malo črno jezero, Jezero nad Komarčo

V okolico Črnega jezera se stekata dve dolini: od severozahoda Dolina Triglavskih jezer, ki se ji pod Belo skalo pridruži Lopučniška dolina, od vzhoda pa Dol pod Stadorjem. Jezero je najjužnejše v skupini Triglavskih jezer. Ker leži na najnižji nadmorski višini, se sneg in led spomladi hitro stopita. Južni breg sestavlja izrazita prepadna skala, podaljšek bližnjega Orliča, delno v čvrsti obliki delno kot podor. S severa zasipava jezero obsežno melišče izpod Stadorja. Melišče je precej nestabilno, v spodnjem delu so na njem večje skale, ki kot balvani sestavljajo tudi del brega. Podlaga in vsa bližnja okolica sta v celoti apneniški. Gladina jezera med letom moč-

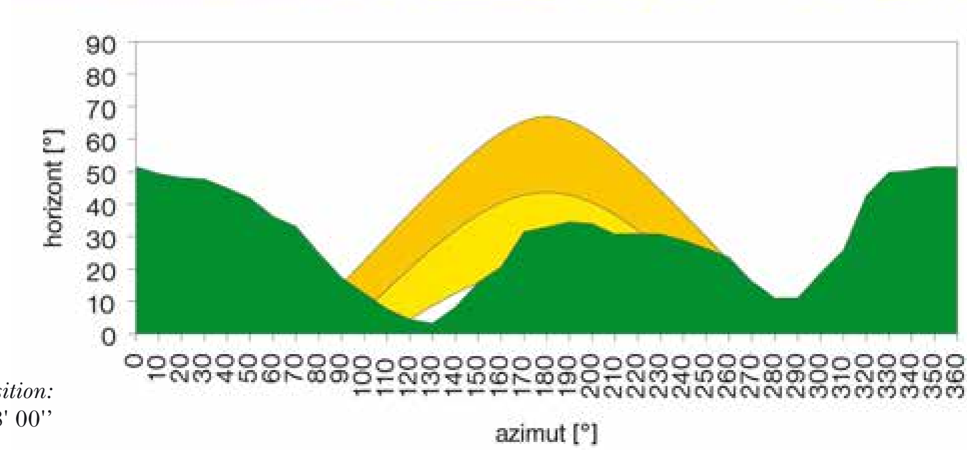
**Črno jezero (the Black Lake)**

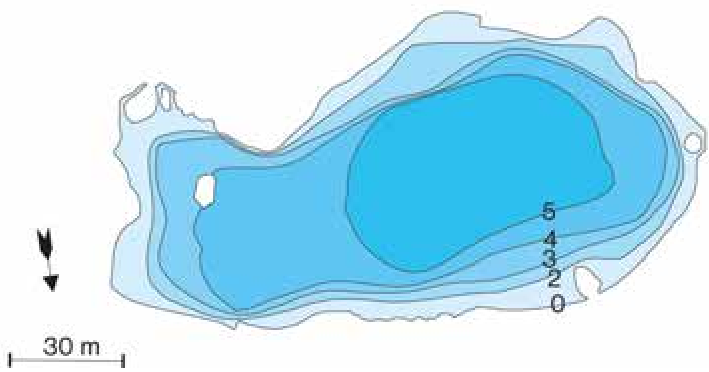
*Synonyms*: The Seventh Triglav Lake, Malo Črno jezero, Jezero nad Komarčo

Two valleys meet in the vicinity of Črno jezero: from the north-east runs the Triglav Lakes Valley, which is joined by Lopučnica below Bela skala, while the second valley, Dol pod Stadorjem, comes from the east. Črno jezero is the southern-most in the group of the Triglav Lakes. It is the lowest–lying lake in the group, and snow and ice melt quickly here. The southern shore consists of a precipitous rock face, an extension of the nearby peak Orlič, partly as an outcrop and partly as rockfall. From the north the lake is filled up with the material from the large scree below Stador. The scree is relatively unstable. Its lower part consists of large rocks which lie as no niha, v povprečju med 4 in 5 metri. Jezero nima stalnega površinskega pritoka ali odtoka, ampak voda razpršeno doteka iz več smeri, odteka pa verjetno skozi špranje ob bregu jezera. Del vode pa se izgubi tudi zaradi izhlapevanja. Dno je pokrito z

boulders along part of the lakes shore. The underlying bedrock and the immediate surroundings are entirely made of limestone. The water level fluctuates strongly during the year, on average between 4 and 5 metres. The lake has no permanent surface

**Črno jezero**
(Foto/Photo:
Jurij Dobravec)




Lega / *Geographical position:*
N 46° 17' 56'', E 13° 48' 00''
Nadmorska višina /
*Height above sea level:* 1325 m
Srednja površina /
*Median area:* 0,864 ha
Srednji obseg /
*Median perimeter:* 440 m
Največji premer /
*Maximum diameter:* 170 m
Največja globina /
*Maximum depth:* 9 m
Srednji vodostaj /
*Average depth:* 6 m
Vodozbirno območje (ocena) /
*Catchment area (estimate):* 140 ha

debelo plastjo rahlega mulja, a le v najglobljih delih. Površina sedimenta v jezeru vsebuje 89 % vode, od trdnih delcev pa je nekaj manj kot polovica (47 %) organske snovi. Visok delež organske snovi v sedimentu je po eni strani posledica neposredne bližine gozda, po drugi pa tudi bogate rasti alg in drobnih organizmov v jezeru. Voda je prosojna in ob srednjem vodostaju sega svetloba do dna.

Okolica je zaradi nižje nadmorske višine že porasčena z gostim gorskim smrekovim gozdom, na prisojnih predelih tudi z listavci.

V Dolu pod Stadorjem, sredi gozda pod Rigljem in Vrtcem, sta še dve mlaki. Severna je praktično že zasuta z meliščem in se voda v njej zadržuje le neposredno po deževju. Južna mlaka je precej večja in se ob daljših sušah prav tako posuši. Dno je glineno in brez vidne vegetacije.

inlet or outlet, water flows in from many directions and drains through the fissures along the shore. A part of the water is lost due to evaporation. The lake bottom is covered with a thick layer of fine silt, but only at its deepest parts. The surface of the sediment in the lake contains 89 % water, and a little less than a half (47 %) of solid matter is organic material. The high percentage of organic material in the sediment results from the immediate vicinity of the forest on the one hand but it is also caused by rich growth of algae and minute organisms in the lake. The lake water is transparent so that at median water level the sunlight reaches to the lake bottom.

Owing to a lower altitude, the surrounding area is covered with thick mountain spruce forest and deciduous trees which grow on sunny slopes.

In Dol pod Stadorjem (Dol below Stador), in the forest below Rigelj and Vrtec, two ponds can be found. The northern pond is practically covered with scree material and water lies there only after heavy rain. The southern pond is much larger and dries up in long periods of drought. The pond bottom is clay and without any visual evidence of vegetation.

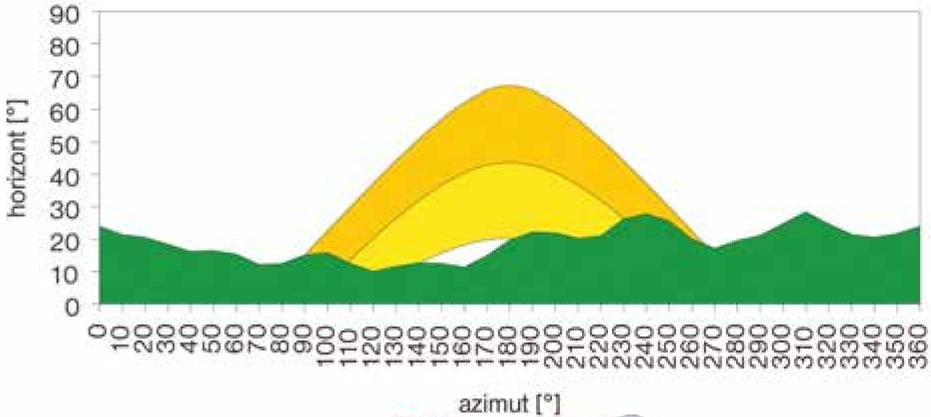
**Jezero na Planini pri Jezeru**
*Sinonim*: Jezero

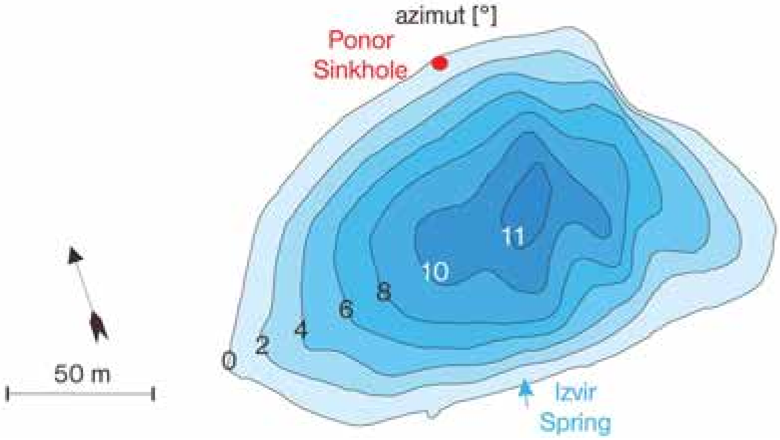
Na Planini, ki se enostavno imenuje Pri Jezeru, leži v njenem najglobljem kotanjastem delu razmeroma globoko jezero pravilne elipsaste oblike. Z južne strani se vanj spušča planinski pašnik, na severu pa poleg skalnih balvanov prevladuje gost smrekov gozd. Na vzhodu je manjše obrežno močvirje s togim šašem (*Carex elata* L.). Jezero ima šibak površinski pritok, in sicer je to majhen izvirček, ki so ga za oskrbo planinske koče zajeli kot vir pitne vode, višek vode pa odteka v jezero. Voda odteka iz jezera skozi z gruščem zasut ponor na severni strani, tik pod veliko skalo. Prav zaradi ponora gladina vode ne niha močno, v povprečju manj kot meter. Dno je na debelo pokrito z rahlim muljem, izrazito črne barve, kar je posledica pomanjkanja kisika v spodnjih plasteh jezera. Površina sedimenta v jezeru vsebuje 94 % vode, od trdnih delcev pa je skoraj polovica (45 %) organske snovi. Voda je motna, tako da lahko svetloba prodre le 1 do 3 m globoko.

**Jezero na Planini pri Jezeru**
**(Lake on Planina pri Jezeru)**
*Synonym*: Jezero

On the pasture Planina, which is simply called Pri Jezeru (by the lake), in the deepest part of the depression a relatively deep eliptical lake has formed. From the southern side a mountain meadow descends into the lake, while in the north spruce forest and boulders prevail. In the east there is a small marsh overgrown with tufted sedge (*Carex elata* L.). The lake has a weak surface tributary, a small spring which has been dammed as a source of drinking water for a lodge, and the surplus of water has been left to flow into the lake. The water drains from the lake through a gravel–jammed sinkhole on the northern side of the lake, just below a large rock. Because of this sinkhole fluctuations in the water level are slight, on average less than 1 metre. The lake bottom is covered with fine silt of a distinctive black colour, which is a consequence of a lack of oxygen in the lower layers of the lake. The surface of the sediment in the lake contains 94 % water, and almost a half (45 %) of solid matter is organic material. The water is turbid so sunlight can only reach 1 to 3 metres deep.

**Jezero na Planini pri Jezeru**
(Foto/Photo: Anton Brancelj)




Lega / *Geographical position:* N 46° 18' 40'', E 13° 49' 56''
Nadmorska višina / *Height above sea level:* 1430 m
Srednja površina / *Median area:* 1,562 ha
Srednji obseg / *Median perimeter:* 460 m
Največji premer / *Maximum diameter:* 160 m
Največja globina / *Maximum depth:* 11 m
Srednji vodostaj / *Average depth:* 10 m
Vodozbirno območje (ocena) / *Catchment area (estimate):* 95 ha

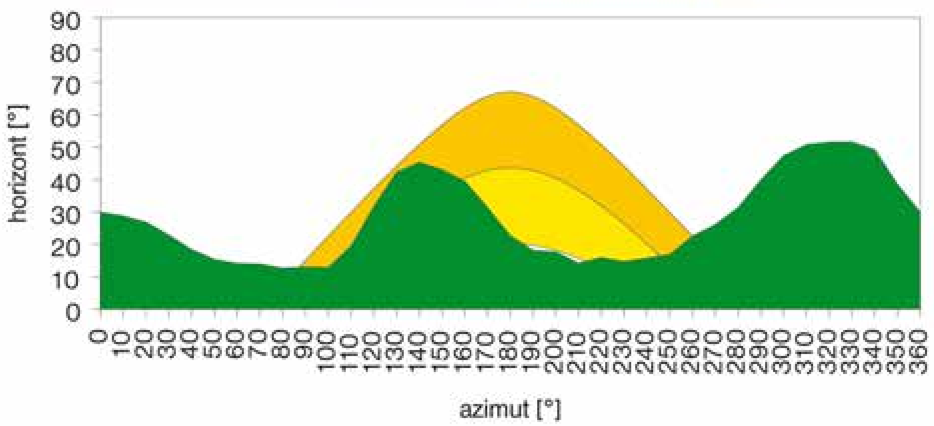
## KRNSKA JEZERA

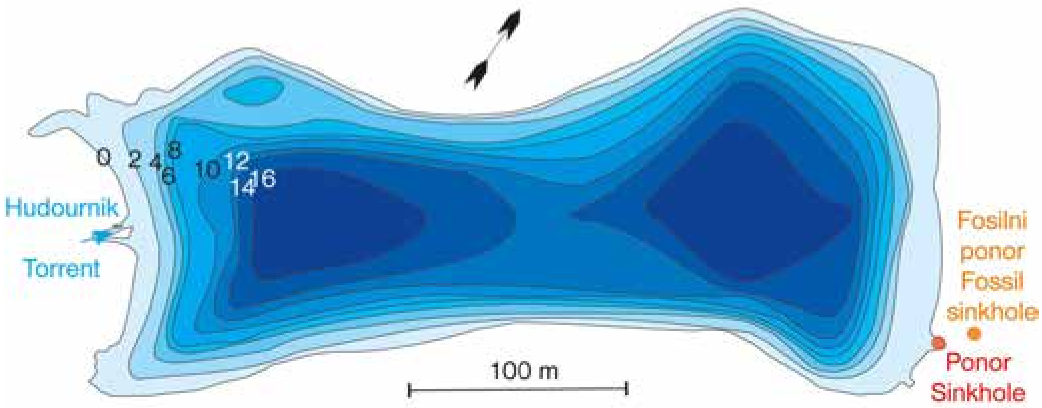
## KRNSKA JEZERA (THE KRN LAKES)

**Krnsko jezero**
*Sinonimi*: Veliko jezero, Veliko Krnsko jezero, Jezero na Polju

**Krnsko jezero (Lake Krn)**
*Synonyms*: Veliko jezero, Veliko Krnsko jezero, Jezero na Polju

**Krnsko jezero**
(Foto/Photo: Anton Brancelj)



Lega / *Geographical position:* N 46° 17' 09'', E 13° 41' 08''
Nadmorska višina / *Height above sea level:* 1383 m
Srednja površina / *Median area:* 4,534 ha
Srednji obseg / *Median perimeter:* 1050 m
Največji premer / *Maximum diameter:* 350 m
Največja globina / *Maximum depth:* 18 m
Srednji vodostaj / *Average depth:* 15 m
Vodozbirno območje (ocena) /
*Catchment area (estimate):* 550 ha

Krnsko jezero je največje slovensko visokogorsko jezero. Napajajo ga vode severnega pobočja Krna – doline Zelenic in sosednjih hribov Velikega Lemeža in Velikega Šmohorja, med katerima leži. Jezerska kotanja je ledeniškega nastanka. Na južni strani jo dokaj intenzivno zasipata hudourniški prod neposredno izpod Krna in melišča izpod bližnjih vrhov. Večino okolice sestavljajo triasni apnenci, le redko bomo v okolici jezera videli tudi jurske ali kredne. Značilni rdečkasti jurski skladi, ki zagotavljajo tudi nepropustnost jezerskega dna, so zlasti opazni na hrbtu pred severnim bregom.

Krnsko jezero je podolgovate oblike, dolgo približno dvakrat toliko kot široko. Osrednji del je ožji, nekako stisnjen med skalne pomole, ki molijo iz sosednjih vrhov. Zunanja oblika jezera je posledica oblike dna. Jezero ima namreč dve kotanji, ki sta med seboj ločeni s kamnitim hrbtom. Jugozahodni breg je prodnat oziroma gruščnat. Prod, ki je izdaten tudi zaradi precejšnjih in intenzivnih padavin, na tem delu relativno hitro zasipava jezero. Ostali del brega je trdnejši, bodisi da je ustaljeno melišče z vegetacijo ali skalnat. Pod Lemežem je breg izključno skalnat. Severovzhodni del je peščen in delno travnat, s položnim naklonom proti jezeru. Voda niha za 2 do 3 m. Dno je na najgloblji točki pokrito z debelo plastjo plastovitega mulja, v katerem je razmeroma malo organskih delcev. Površina sedimenta vsebuje 87 % vode, od trdnih delcev pa je le 21 % organske snovi. Jezero nima stalnih površinskih pritokov. Edini vidni dotok je hudournik. Odtoka iz jezera sta dva, oba ponorna. Višji leži tik pod strmo steno, okoli 3 m nad običajnim nivojem vodne gladine, in je povsem zasut z gruščem, listjem ter vejami. Le ob zelo visoki vodi del vode odteka skozi ta ponor. Drugi ponor je le nekaj metrov stran, tik pod veliko skalo, v neposredni bližini obvestilne table. Tudi ta ponor je povsem zasut z gruščem ter vejevjem. Ob srednji vodi ponika v ponor manjši potoček, ki se ob nižjem vodostaju posuši. Zaradi množice planktonskih alg je prosojnost jezera zmanjšana in svetloba sega v povprečju le do globine 5 m.

Lake Krn is the largest mountain lake in Slovenia. It is fed by the waters draining from the northern Krn slope, that is from the valleys below Zelenica and from the neighbouring hills of Veliki Lemež and Veliki Šmohor, between which the lake lies. The lake lies in a glacier–shaped depression. On the south the lake's depth is being rapidly reduced by torrential stream deposits from below Krn and by scree material from below the nearby peaks. The bedrock primarily consists of Triassic limestone, and Jurassic and Cretaceous limestones are rarely found. The characteristic red Jurassic rocks which are responsible for the impermeability of the lake bottom are clearly visible on the ridge in front of the northern shore.

Lake Krn is longitudinal in shape, and approximately twice as long as wide. Its main section is narrow, somehow squeezed between the rock piers jutting out from the neighbouring peaks. The outward appearance of the lake reflects the form of its basin. The lake has formed in two depressions, which are separated by a rock ridge. The south-eastern shore consists of gravel. Abundance of gravel is a results of intensive weathering of the slopes above the lake and it is depositing the lake basin. Other parts of lake shore are firmer, consisting of either stable screes or rocks. Below Lemež, the shore consists of rocks only. The north-eastern part is sandy and partly covered with grass, and the immediate catchment slopes gently towards the lake. Water level fluctuates between 2 and 3 metres. At the deepest point the bottom is covered with a thick layer of silt, which is relatively poor in organic matter. The surface of the sediment contains 87 % water, and 21 % of solid matter comprise organic material. The lake has no permanent surface tributaries. The only visible inlet is a temporary torrent. There are two outlets, however, both disappearing into a sinkhole. The upper outlet lies just below a steep rock face, about 3 m above the usual water level and is completely jammed with gravel, leaves and branches. Water drains through this sinkhole only at very high water level. The other outlet is just a few metres away, below a big rock, in the close vicinity of an information board. This sinkhole is jammed with gravel and branches as well. At median water level a small stream, which dries at lower water levels, sinks into the sinkhole. Owing to an abundance of planktonic algae the lake transparency is reduced and on average light reaches only to a depth of 5 metres.

**Dupeljsko jezero**

*Sinonimi*: Jezero pod Monturo, Malo jezero, Malo Krnsko jezero

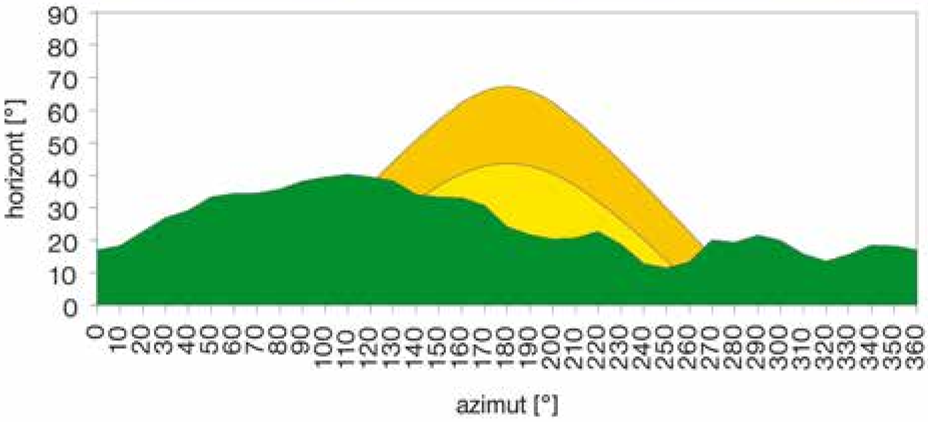
Neposredno pod planinsko kočo pri Krnskih jeze-

**Dupeljsko jezero (Duplje Lake)**

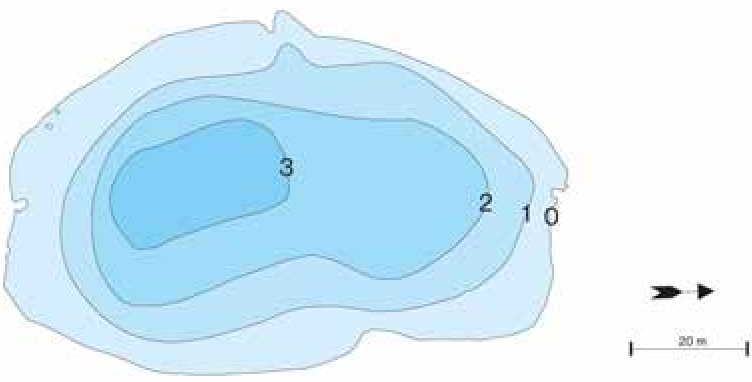
*Synonyms*: Jezero pod Moturo, Malo jezero, Malo Krnsko jezero

Directly below the mountain lodge at the Krn Lakes

**Dupeljsko jezero**
(Foto/Photo:
Anton Brancelj)




Lega / *Geographical position:*
N 46° 17' 21'', E 13° 42' 10''
Nadmorska višina /
*Height above sea level:* 1340 m
Srednja površina /
*Median area:* 0,247 ha
Srednji obseg / *Median perimeter:* 200 m
Največji premer /
*Maximum diameter:* 75 m
Največja globina /
*Maximum depth:* 3,6 m
Srednji vodostaj / *Average depth:* 2 m
Vodozbirno območje (ocena) /
*Catchment area (estimate):* 46 ha



rih leži Malo jezero, zaradi planine imenovano tudi Dupeljsko. Leži v isti dolini kot Krnsko jezero, v razširjeni kotanji pod Malo Monturo. Kotanja nima nobenih strmejših bregov, breg je na vzhodu stabilno melišče, drugod pa kamnit oziroma pokrit z deloma nesklenjeno vegetacijo. Tudi plitvo dno jezera je izrazito porašćeno z vegetacijo. Kot geološka podlaga, ki je opazna na površini, se pojavlja triasni apnenec. Voda niha za 1 do 2 m. Dno je na najglobljі točki pokrito z okoli 20 cm debelo plastjo močno zaglinjenega mulja, v katerem je razmeroma malo organskih delcev. Površina sedimenta vsebuje 87 % vode, od trdnih delcev pa je okoli 27 % organske snovi. Jezero nima stalnih površinskih pritokov, pa tudi odtoka ni moč določiti. Jezero je bilo do leta 1995 vir pitne vode za kočo pri Krnskih jezerih. Zaradi majhne globine svetloba ob srednjem vodostaju še sega do dna, vendar je zaradi množice planktonskih alg njena intenzivnost že močno zmanjšana.

### Jezero v Lužnici

*Sinonimi*: Luža, Lužnica, Malo jezero

Lužnica je manjša dolina v Krnskem pogorju. Od severozahoda proti jugovzhodu se nadmorska višina dna doline počasi spušča od Praga (Batogniškega sedla) do najnižje točke, kjer leži manjše jezero. Kamninska sestava v okolici jezera je za naše razmere precej pestra. Skladoviti dachsteinski apnenec z vmesnimi dolomitnimi skladi je na nekaj mestih prekinjen z oolitnimi in mikritnimi apnenci iz jure, ki jih prepoznamo po rahlo rdečkasti barvi. Nekaj je tudi krednih apnencev. Prisojno pobočje pod Peski je izrazito meliščno.

Jezero je rahlo ovalne oblike. S severovzhodne strani ga zasipajo melišča izpod Škofiča, jugozahodni del pa je skalnat in večinoma prekinjeno porasel z gorskim traviščem. Nekaj metrov zahodnega brega je peščenega. Vodna gladina niha za 1 do 2 m in ob večjem vodostaju voda odteka površinsko skozi razpoko na zahodnem delu jezerske kotanje. Dno je na najglobljі točki pokrito z debelo plastjo rahlega mulja, v katerem je veliko organskih delcev. Površina sedimenta vsebuje 93 % vode, od trdnih delcev pa je kar 81 % organske snovi. Voda v jezeru je prozorna, tako da ob srednjem vodostaju sega svetloba do dna.

lies Malo jezero, called also Dupeljsko jezero after the pasture on which it is located. It lies in the same valley as Lake Krn, in a wide depression below Montura. The depression has no steep slopes, the shore consists of stable scree in the east, and is rocky or covered with partly interrupted vegetation in other areas. The shallow lake basin is overgrown with rich vegetation. The surface geology is Triassic limestone. Water level fluctuates between 1 and 2 metres. At the deepest point, the bottom is covered with 20 cm of silt, which is relatively poor in organic material. The surface of the sediment contains 87 % water, and 27 % of the solid matter is organic. The lake has no surface tributaries and the water outlet is hard to determine. Until the year 1995, the lake had been a source of drinking water for the lodge at the Krn Lakes. Owing to low water depth, sunlight can reach the lake bottom at median water level, but an abundance of plankton algae reduces its intensity significantly.

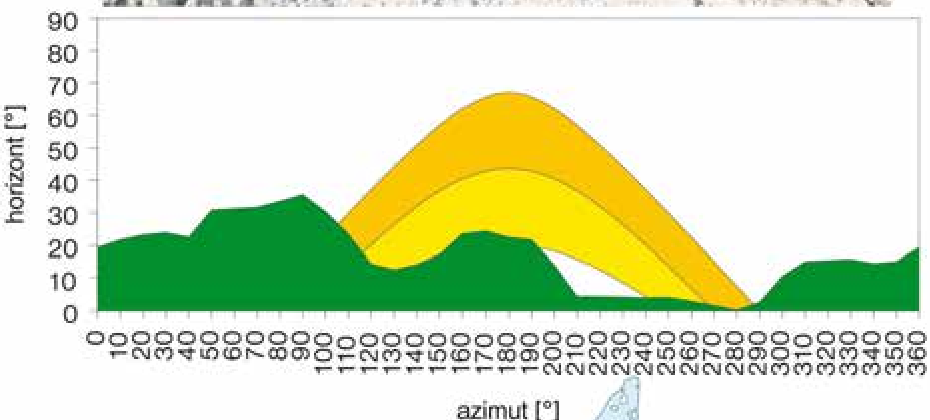
### Jezero v Lužnici (Lake in Lužnica)

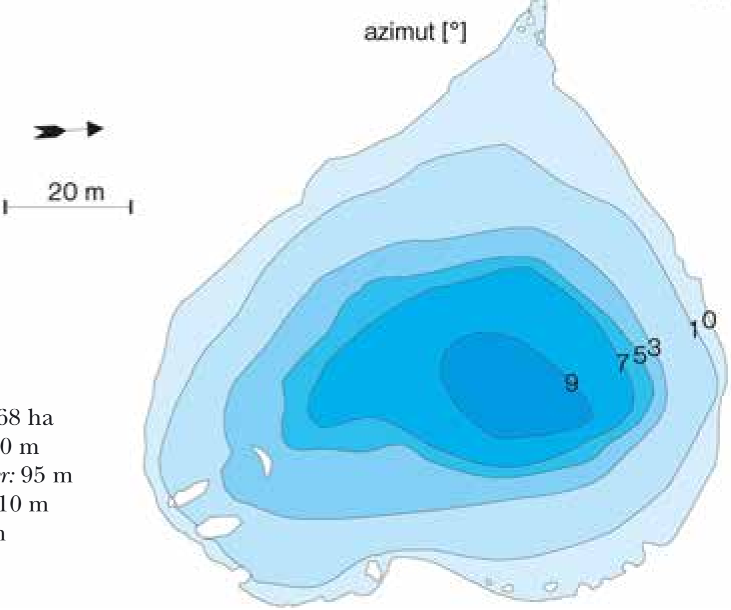
*Synonyms*: Luža, Lužnica, Malo jezero, Malo Krnsko jezero

Lužnica is a small valley in the Krn mountain range. In line with its north-west / south-east orientation, the altitude of the valley bottom slowly decreases from the Prag pass (Batogniško sedlo) to the lowest point of the valley where a small lake has formed. The geology of the area surrounding the lake is relatively diverse. Strata of Dachstein limestone with intermittent dolomite layers are interrupted in places with oolithic and micritic Jurassic limestones, which can easily be identified by their reddish colour. Some Cretaceous limestones can also be found. Screes are a characteristic feature of the sunny slope below Peski.

The lake is slightly oval in shape. From the north-east the lake basin is filled up by scree material from below Škofic, whereas the south-eastern part is rocky and supports interrupted mountain grassland vegetation. Sand only covers a few metres of the western lake shore. The water surface fluctuates significantly and at high water level it drains through a fissure on the western side of the lake basin. The water level fluctuates between 1 and 2 metres. At the deepest point the bottom is covered with a thick layer of silt, which contains an abundance of organic particles. The surface of the sediment contains 93 % water, and 81 % of solid matter comprises organic material. The lake water is so transparent that at medium water level the sun light reaches to the lake bottom.

**Jezero v Lužnici**
(Foto/Photo: Anton Brancelj)




Lega / *Geographical position:*
N 46° 15' 20'', E 13° 41' 26''
Nadmorska višina /
*Height above sea level:* 1800 m
Srednja površina / *Median area:* 0,468 ha
Srednji obseg / *Median perimeter:* 260 m
Največji premer / *Maximum diameter:* 95 m
Največja globina / *Maximum depth:* 10 m
Srednji vodostaj / *Average depth:* 9 m
Vodozbirno območje (ocena) /
*Catchment area (estimate):* 66 ha

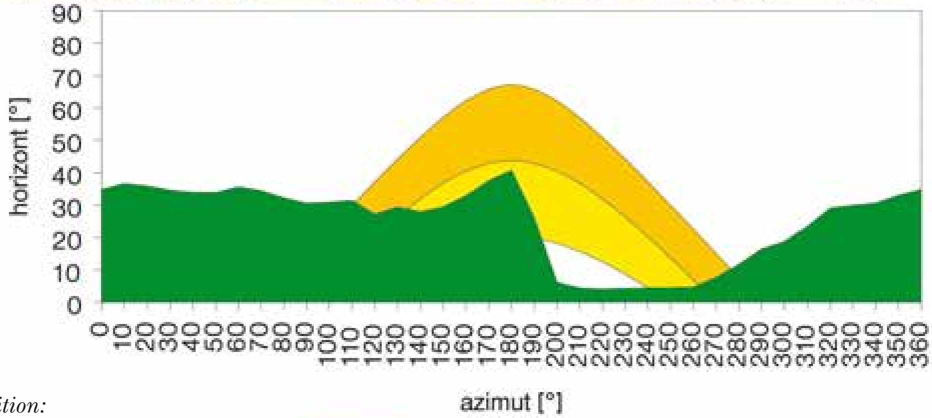
## KRIŠKA JEZERA

## KRIŠKA JEZERA (THE KRIŽ LAKES)

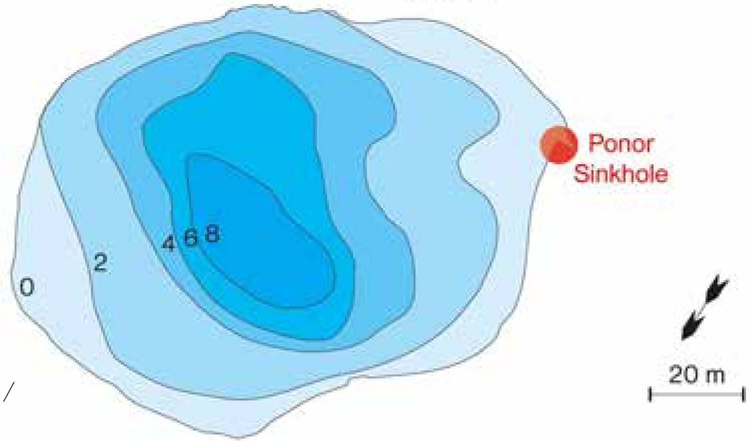
**Spodnje Kriško jezero**
*Sinonimi*: Jezero pri studencu, Prvo Kriško jezero, Tretje Kriško jezero, Jezero pod Šplevto

**Spodnje Kriško jezero (Lower Križ Lake)**
*Synonyms*: Jezero pri studencu, Prvo Kriško jezero, Tretje Kriško jezero, Jezero pod Šplevto

**Spodnje Kriško jezero** (Foto/Photo: Anton Brancelj)




Lega / *Geographical position:* N 46° 23' 59'', E 13° 48' 24''
Nadmorska višina / *Height above sea level:* 1880 m
Srednja površina / *Median area:* 0,862 ha
Srednji obseg / *Median perimeter:* 375 m
Največji premer / *Maximum diameter:* 130 m
Največja globina / *Maximum depth:* 9 m
Srednji vodostaj / *Average depth:* 7m
Vodozbirno območje (ocena) / *Catchment area (estimate):* 13 ha



V ovalni kotanji severno od Šplevte leži Spodnje Kriško jezero. Kotanja je močno odprta proti jugu. Amfiteater označujejo precej strme skale v zgornjem delu in melišča v spodnjem. Melišča s treh strani segajo v jezero – le jugozahodni breg, kjer običajno pridemo do jezera, je zatravljen in kamnit in precej položnejši. Tu so vidne tudi ledeniške morene, ki pa niso primarni vzrok za zajezitev jezera. Skalni breg se pojavlja na kratkem odseku južnega roba, neposredno pod Šplevto.

Jezero je skoraj okrogle oblike, rahlo razširjeno v smeri jugozahod–severovzhod. Melišča ga relativno hitro zasipavajo na jugovzhodni strani. Nihanje vode je zmerno, okoli 1 m. Jezero nima stalnega površinskega pritoka. Iz jezera odteka voda skozi z gruščem zasut ponor na zahodnem bregu. Glede na majhno višinsko razliko med ponorom iz jezera ter izvirom tik pod vrhom poti na Kriške pode je malo verjetno, da se voda iz jezera pojavlja v tem izviru. Dno jezera je v veliki meri pokrito z gruščem in manjšimi skalami, le na najglobljі točki je tanjša plast mulja. Površina sedimenta vsebuje 90 % vode, od trdnih delcev pa je le okoli 18 % organske snovi. Voda je zaradi večjih količin planktonskih alg motna in svetloba sega le do globine okoli 6 m. (V zadnjih nekaj letih se je prosojnost vode povečala.)

In an oval depression north of Šplevta lies Spodnje Kriško jezero (Lower Križ Lake). The depression opens broadly towards the south. The amphitheatre is marked by steep rocks in the upper part and screes in the lower. Screes fall into the lake from three sides and only the south-eastern shore, the usual access to the lake, is grassy with occasional rocks and also less steep. Glacial moraines may be observed, but these are not the primary reason for the damming of the lake. A rocky shore characterises the short section of the southern shore, just below Šplevta.

The lake is almost circular in shape, and widens slightly in a south-west/north-east orientation. Lake sedimentation is occuring relatively quickly especially from the scree to the south-eastern part of the lake. Water level fluctuation is modest, about 1 m. The lake has no permanent surface tributary. The water drains from the lake through a gravel–jammed sinkhole on the western lake shore. The small difference in altitude between the sinkhole and the source just below the route to Kriški podi leaves little possibility for the water to appear in this spring. The lake bottom is largely covered with gravel and small rocks, and a thin layer of silt only collects at the deepest point of the lake. The surface of the sediment contains 90 % water, and 18 % of solid matter comprises organic material. An abundance of planktonic algae reduces the transparency of the water and light only reaches to a depth of 6 metres. (In the last few years the transparency has improved.)

**Srednje Kriško jezero**
*Sinonimi*: Jezero pod Grivo, Drugo Kriško jezero

Griva je vzpetina na Kriških podih, kjer stoji Pogačnikov dom. Severovzhodno od hriba je večja globel, izrazito skalna podolgovata kotanja, ki se vleče v smeri proti Križu. Le na dnu se skalovje kruši v melišča, ki obdajajo jezero. Nastanek kotanje pripisujejo vodni eroziji. Na njenem južnem delu, kjer je tudi najgloblja, leži Srednje Kriško jezero. Če pozimi kotanjo zamede debela plast snega, se jezero pojavi šele zelo pozno poleti, najprej kot mlaka v snežni globeli. Geološka podlaga je triasna, značilne so skalne police in ponekod prepadne stene. V isti globeli, bolj proti severovzhodu, v manjši kotanji občasno nastane še manjše jezerce oziroma mlaka, ki jo nekateri imenujejo Četrto Kriško jezero.

Srednje Kriško jezero je nepravilno okrogle oblike. Na severovzhodu sega v vodo manjši skalni

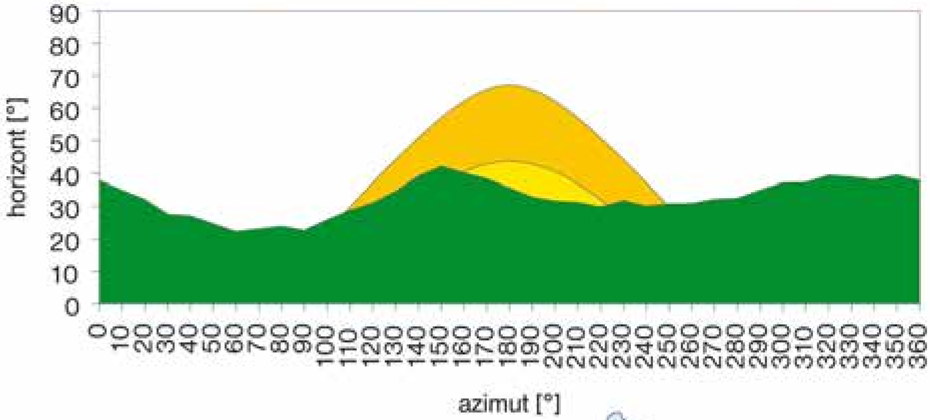
**Srednje Kriško jezero (Middle Križ Lake)**
*Synonyms*: Jezero pod Grivo, Drugo Kriško jezero

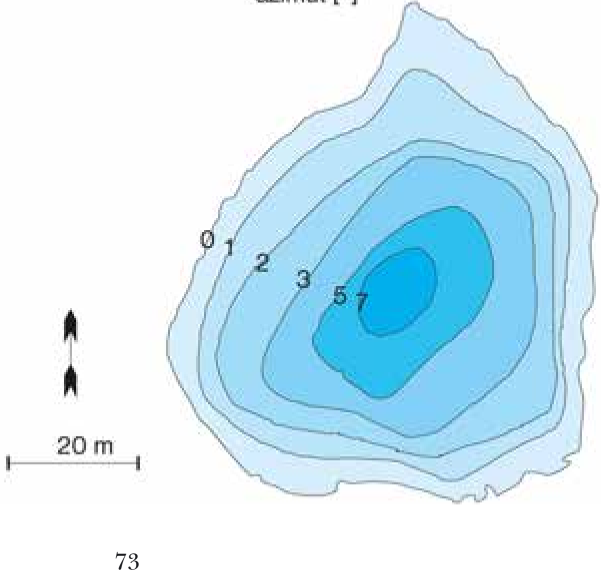
Griva is an elevated area on Kriški podi, where the lodge Pogačnikov dom is located. To the north east there is a large hollow, a rocky longitudinal depression which reaches towards Križ. Only at its foot do the rocks break into scree material surrounding the lake. The depression was probably formed by water erosion. In its southern and deepest part lies Srednje Kriško jezero (Middle Križ Lake). If the depression is covered by a thick layer of snow during winter, the lake does not appear until late summer, first as a pond in a snow–covered depression. The geological sub-stratum is Triassic, with characteristic rock shelves and precipitous rock faces. In the same hollow, slightly more towards the north-east, a small 'lakelet' or a pond occasionally forms, known as Četrto Kriško jezero (the Fourth Križ Lake).

hrbet, ostali breg je skoraj v celoti melišče in le malo poraščen. Neporaslost je deloma posledica kratke vegetacijske sezone. Nihanje gladine je težko ugotovljivo zaradi dolgotrajne pokritosti s snegom in ledom, po oceni pa niha za okoli 1 m. Jezero nima

Srednje Kriško jezero is of irregular circular shape. A small rocky ridge dips into the water in the north-east, while the remaining shore is entirely made up of scree material and barely vegetated. Lack of vegetation partly results from a short grow-

**Srednje Kriško jezero**
(Foto/Photo:
Anton Brancelj)




Lega / *Geographical position:*
N 46° 24' 13'', E 13° 48' 26''
Nadmorska višina /
*Height above sea level:* 1950 m
Srednja površina / *Median area:* 0,292 ha
Srednji obseg / *Median perimeter:* 200 m
Največji premer / *Maximum diameter:* 75 m
Največja globina / *Maximum depth:* 9 m
Srednji vodostaj / *Average depth:* 8 m
Vodozbirno območje (ocena) /
*Catchment area (estimate):* 26 ha

stalnih površinskih dotokov, pa tudi odtok ni jasno določen. Dno je pokrito s plastjo rahlega mulja. Površina sedimenta vsebuje 87 % vode, od trdnih delcev pa je kar ena tretjina (36 %) organske snovi. Voda je običajno kristalno čista, tako da sega svetloba ob srednjem vodostaju do dna.

ing period. Since the lake in snow–covered long into spring, fluctuations in water level are difficult to define but have been estimated at about 1 metre. The lake has no permanent surface tributaries, and no clearly determined outlet. The lake bottom is covered with a layer of fine silt. The surface of the sediment contains 87 % water, and one third (36 %) of solid matter is organic. The lake water is usually crystal clear so at median water level the sunlight reaches to the lake bottom.

**Zgornje Kriško jezero**
*Sinonimi*: Jezero pod Križem, Tretje Kriško jezero, Prvo Kriško jezero

Nedaleč od Kriškega roba leži Jezero pod Križem, najvišje slovensko visokogorsko jezero. Zaradi višine in majhne višinske razlike do okoliških vrhov ga pravzaprav neposredno napaja le deževnica. V severni breg se zažirajo melišča, ki amfiteatralno obdajajo jezero. Na jugu je breg skalnat. Zglajen greben, ki zapira odtok vode, je le nekaj metrov višji od gladine vode. S severne strani ne prodirajo le kamnita melišča, ampak tudi snežni plazovi, ki jezeru in neposredni okolici za več mesecev spremenijo življenjske okoliščine.

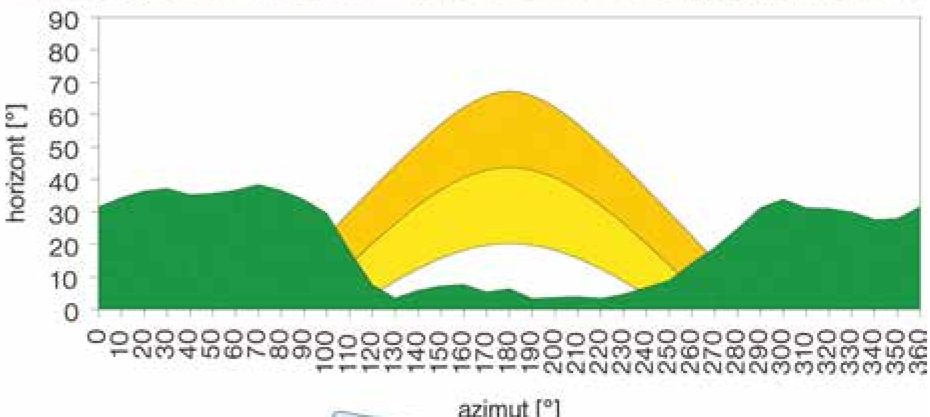
Dno jezera je precej neenakomerno. Z zahodne strani se globina enakomerno spušča, na severovzhodu je opazna večja plitvina kot posledica plazov izpod Križa. Zaradi plazu ima naglobji del jezera obliko polmeseca in je le na najglobji točki pokrito z okoli 40 cm debelo plastjo rahlega mulja. Večji del dna je pokrit z gruščem in manjšimi skalami. Oblika dna se razmeroma hitro spreminja, saj se vsako leto po snegu in ledu skotali na sredo jezera precejšnja količina grušča. Gladina skoraj ne niha. Vzrok je okoli 1 x 0,7 m velika luknja na južni strani jezera, v katero odteka voda. Ponor je dejansko vhod v okoli 200 m globoko stopnjasto brezno, ki je bilo podrobneje raziskano šele v letu 2000. Ali se vode iz Zgornjega Kriškega jezera pretakajo v Srednje Kriško jezero, še ni bilo dokazano. Površina sedimenta vsebuje 89 % vode, od trdnih delcev pa je ena četrtina (26 %) organske snovi. Voda je kristalno čista, tako da sega svetloba ob srednjem vodostaju do dna. Vodo iz jezera uporabljajo za oskrbo Pogačnikovega doma.

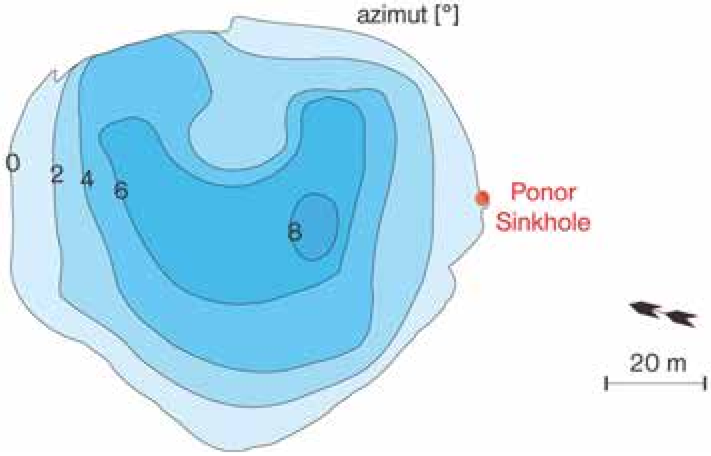
**Zgornje Kriško jezero (Upper Križ Lake)**
*Synonyms*: Jezero pod Križem, Tretje Kriško jezero, Prvo Kriško jezero

Not far from Kriški rob lies Jezero pod Križem, the highest–lying mountain lake in Slovenia. Owing to its altitude and a small difference in elevation between the lake and the neighbouring peaks, Zgornje Kriško jezero can only be directly fed by rainwater. Screes which surround the lake like an amphitheatre eat into the northern lake shore. In the south, the shore is rocky. The smooth ridge which closes off the drainage of water reaches only a few metres above the water surface. From the northern side not only rocky screes but also snow avalanches can enter the lake, changing the environment of the immediate lake vicinity for months.

The lake bottom is relatively uneven. From the west, its depth decreases gradually. A large shallow area, positioned in the northeastern part of the lake, has been created by the avalanches from the slopes below Križ. Avalanches are also the reason why the deepest part of the lake is shaped like a half-moon and is only covered with a 40 cm layer of silt at its deepest point. A large part of the lake bottom is covered with gravel and small rocks. The form of the lake bottom is changing quickly due to large quantities of gravel which are transported every year down the ice and snow–covered slopes into the lake. The water level hardly fluctuates, owing to a 1 m x 0.7 m hole in the southern part of the lake, into which the water drains. The sinkhole is actually an entrance into a 200 m deep levelled pit, which was first explored in detail in the year 2000. It has not yet been proved, however, that the waters from Zgronje Kriško jezero actually flow into Srednje Kriško jezero. The surface of the sediment contains 89 % water, and one quarter (26 %) of solid matter is organic material. The water is crystal clear so that at median water level the light reaches the lake bottom. The water from the lake is used to supply the lodge Pogačnikov dom.

**Zgornje Kriško jezero**
(Foto/Photo:
Anton Brancelj)

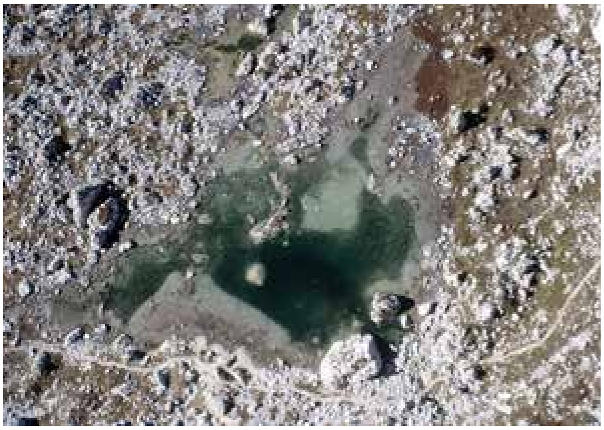



Lega / *Geographical position:* N 46° 24' 32'', E 13° 48' 34''
Nadmorska višina / *Height above sea level:* 2150 m
Srednja površina / *Median area:* 0,662 ha
Srednji obseg / *Median perimeter:* 275 m
Največji premer / *Maximum diameter:* 100 m
Največja globina / *Maximum depth:* 9 m
Srednji vodostaj / *Average depth:* 8 m
Vodozbirno območje (ocena) /
*Catchment area (estimate):* 16 ha








*Poglavje* 5 *Chapter*

# *Hidrološke povezave med nekaterimi jezeri v dolini Triglavskih jezer*

# *Hydrological Connections Between Some Lakes in the Triglav Lakes Valley*

Janko URBANC* & Anton BRANCELJ**

## GEOLOŠKA ZGRADBA OBMOČJA

Območje Triglavskih jezer je zgrajeno v glavnem iz triasnih in jurskih karbonatnih kamnin, apnencev ter dolomitov (Ramovš, 1974; Buser, 1986; Jurkovšek, 1986). Jurske kamnine so zaradi lapornih vložkov dokaj neprepustne in so po vsej verjetnosti poglavitni vzrok za nastanek Triglavskih jezer. V okolici Triglavskih jezer najdemo tudi nekaj pleistocenskih sedimentov ter holocenskega grušča.

## PREGLED DOSEDANJIH RAZISKAV

Na območju bohinjskih planin je bil v letu 1996 izveden sledilni poizkus, katerega namen je bila podrobnejša določitev razvodnic v kraškem masivu (Trišič in sod., 1997). Fluorescentni barvili uranin in rodamin sta bili injicirani v ponore na Planini pri Jezeru ter na Planini v Lazu.

Sledilo, injicirano na Planini pri Jezeru, se je pojavilo v Savici ter izviru Govic nad Bohinjskim jezerom. Iz Planine v Lazu je bila dokazana povezava s potokom Suha, barvilo pa se je pojavilo tudi v izviru Savica.

## SLEDILNI POIZKUSI

Namen sledilnih poizkusov v Dolini Triglavskih jezer je bil ugotavljanje hidravličnih povezav med

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## GEOLOGICAL COMPOSITION OF THE AREA

The area of the Triglav Lakes is mainly formed of Triassic and Jurassic carbonate rocks, limestones and dolomites (Ramovš, 1974; Buser, 1986; Jurkovšek, 1986). Jurassic rocks are rather impermeable due to marl inlays, most probably this caused the formation of the Triglav Lakes. Some Pleistocene sediments and Holocene gravels can also be found in the vicinity of the Lakes.

## OVERVIEW OF PREVIOUS INVESTIGATIONS

A tracer experiment was carried out in the area of the Bohinj mountains in 1996. It was aimed at providing a more precise determination of the underground watershed in the karst massif (Trišič *et al.*, 1997). Fluorescent dyes uranine and rodamine were injected into sinkholes at Planina pri Jezeru and at Planina v Lazu.

The tracer injected at Planina pri Jezeru was detected in Savica and in the Govic spring above the lake Bohinjsko jezero. A connection with the stream Suha was established from Planina v Lazu, and the tracer was also found in the Savica spring.

## RECENT TRACER EXPERIMENTS

Tracer experiments in the Triglav Lakes Valley were carried out in order to find out hydraulic

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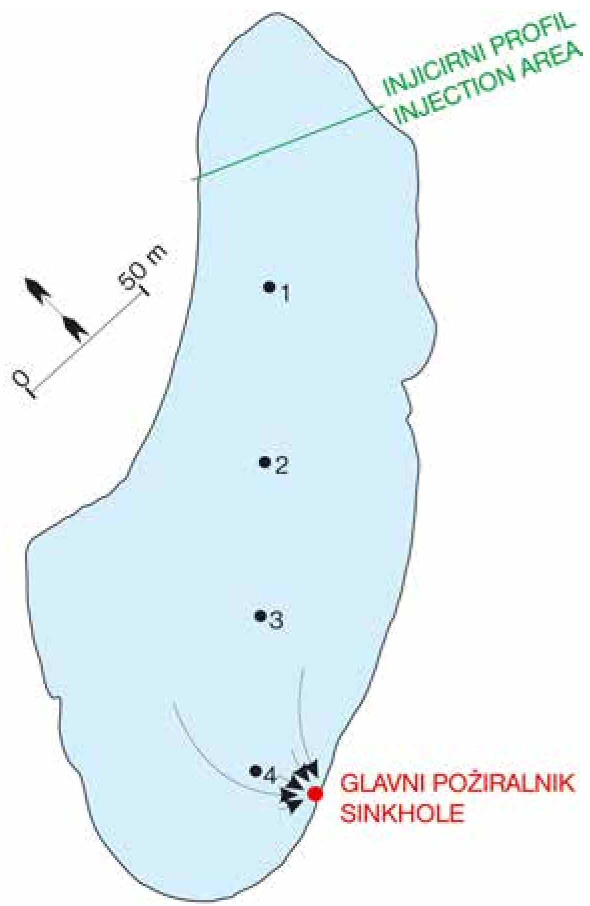
posameznimi jezeri in izvirom Savica ter opredelitev dinamike obnavljanja vode v jezerih.

## Sledilni poizkus na Jezeru v Ledvicah

Sledilni poizkus se je pričel 9. 6. 1999. Kot sledilo je bilo uporabljenih 6 kg uranina, ki je bil vnesen v skrajno severovzhodnem delu jezera. Sledilo je bilo injicirano v ravni liniji čez celotno širino jezera (slika 1). Zaradi podvodnih tokov, ki so posledica podzemnih dotokov v severovzhodnem delu jezera, se je barvilo širilo v obliki intenzivneje obarvanih pasov, najhitreje v osrednjem delu jezera. Barva je potovala vzdolž jezera dva dni, tako da je bila 11. junija jezerska voda dokaj enakomerno obarvana. Zatem je sledilo dokaj hitro razbarvanje jezera. Že 14. junija barva s prostim očesom ni bila več zaznavna.

Za opazovanje sprememb koncentracije barvila v jezeru je bil izbran vzdolžni profil s štirimi meritvenimi točkami, na katerih je potekalo vzorčevanje po celotni globini vodnega stolpca (slika 1). Glo-




Slika 1: Območje injiciranja sledila ter vzorčevalne točke na Jezeru v Ledvicah (Triglavski narodni park, Slovenija)

*Figure1: Tracer injection area and sampling points in the lake Jezero v Ledvicah (Triglav National Park, Slovenia)*

connections between individual lakes and the Savica spring and to the define subsequent lake water dynamics.

## Tracer experiment in Jezero v Ledvicah

The experiment was started on June 9, 1999, with 6 kg of uranine used as a tracer. It was injected in the most north–eastern part of the lake in a straight line crossing the entire width of the lake (Figure 1). Because of lake currents resulting from underground inflows in this part of the lake, the tracer spread in the form of stripes of different intensity, the fastest in the central part of the lake. The dye spread along the lake for two days, so that the water was quite evenly coloured on June 11. A relatively fast discolouring of the lake followed. Already on June 14 the colour could no longer be observed with the naked eye.

Tracer concentration in the lake was monitored along a longitudinal profile with four sampling points, at which samples were taken over the entire depth of the water column (Figure 1). Depth samples of lake water were taken at 3 m intervals. In this way, the entire lake volume was largely covered by the sampling.

In the north–east part of the lake (sampling point 1) the main current of tracer moved in the middle of the water column at depths of about 3 m (Table 1). A very rapid decrease of tracer concentration was observed, which can be explained by a big inflow of fresh water into the lake due to considerable precipitation before and during the tracing experiment.

The tracer sank towards the bottom of the lake at point 2 (Figure 1). A rapid decrease of tracer concentration was also observed at this sampling point. The concentrations at individual points decreased by approximately 50 % each day compared to the day before.

Sampling point 3 was located in the deepest part of the lake, at a depth of 14 m. The main body of the tracer crossed this point at a depth of 9 m. Apparently a pocket of relatively still water outside binski vzorci jezerske vode so bili odvzeti v intervalih po 3 m. Tako je bil z vzorčevanjem pokrit velik del volumna jezera.

V severovzhodnem delu jezera (vzorčno mesto 1) je glavni tok sledila potekal v srednjem delu vodnega stolpca na globinah okoli 3 m (preglednica 1). Ugotovljeno je bilo zelo hitro upadanje koncentracij sledila, kar je posledica velikega dotoka sveže vode v jezero zaradi dokaj intenzivnih padavin, ki so se pojavljale pred poizkusom in tudi v času sledilnega poizkusa.

V točki 2 je sledilo potonilo proti dnu jezera. Tudi v tej točki je opazno hitro zniževanje koncentracij sledila. Z vsakim dnem smo beležili približno 50-odstotno znižanje koncentracije v posamezni točki glede na predhodni dan.

Merska točka 3 je bila v najglobljem delu jezera, kjer jezero doseže globino 14 m. Glavnina barvila je točko prešla na globini okoli 9 m. Očitno je najglobljі del jezera predstavljal žep dokaj mirujoče vode izven glavnega toka jezerske vode.

Meritve temperature vode, ki so bile opravljene neposredno pred začetkom sledilnega poizkusa, so pokazale, da je bila temperatura vode na površini 7,4 °C in je enakomerno upadala do temperature 4,2 °C na globini 8 m, nato pa je bila izmerjena temperatura enaka vse do dna jezera. Vrednosti meritev električne prevodnosti in koncentracije kisika so bile izenačene od površine do globine 11 m (električna prevodnost približno 145 μS $cm^{-1}$; kisik približno 11,5 mg $l^{-1}$). Šele pod to globino so vrednosti električne prevodnosti močno poskočile (na 308 μS $cm^{-1}$na dnu), medtem ko so vrednosti koncentracije kisika tik nad dnom upadle na 1,4 mg $l^{-1}$). To kaže, da je bil vodni stolpec do globine 11 m dokaj enakomerno premešan, kar je omogočalo tudi dokaj enakomerno porazdelitev barvila. Pod globino 11 m pa je ostal žep nepremešane vode, ki je bil tam še od zime.

O starosti in naravi geoloških skladov v Dolini sedmerih jezer pričajo fosilni ostanki živali (na sliki amonit). (Foto: Anton Brancelj)

*The age and origin of geological deposits in the Triglav Lakes Valley are indicated by fossil remains of animals (on the photo an ammonite). (Photo: Anton Brancelj)*

the main lake current forms in the deepest part of the lake.

Measurements of water temperature immediately before the start of the tracer experiment gave a surface water temperature of 7.4 °C. The temperature decreased gradually with depth, reaching 4.2 °C at 8 m and then remained stable to lake bottom. Values of electrical conductivity and oxygen concentration were the same from the surface down to 11 m (el. conductivity approx. 145 μS $cm^{-1}$, oxygen approx. 11.5 mg $l^{-1}$). Only beyond this depth was a marked increase in electrical conductivity measured (reaching 308 μS $cm^{-1}$ at the bottom), while oxygen concentration at the bottom diminished to 1.4 mg $l^{-1}$. This indicates that the water column was relatively well mixed down to 11 m, enabling a relatively homogenous distribution of the tracer. Below 11 m a pocket of unmixed water remained from the previous winter.

At sampling point 4 (Figure 1) the highest tracer concentration was again measured near the bot-

| Datum Date | Globina Depth | Vzorčno mesto / Sampling point 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 13.06.99 | *0 m* | 1.7 | 1.9 | 1.9 | 0.8 |
| | *3 m* | 5.1 | 3.8 | 2.2 | 0.7 |
| | *6 m* | 3.1 | 4.3 | 4.7 | 2.6 |
| | *9 m* | | 4.9 | 4.2 | 2.6 |
| | *12 m* | | | 1.9 | |
| 14.06.99 | *0 m* | 0.8 | 0.8 | 0.8 | 0.0 |
| | *3 m* | 2.0 | 1.8 | 0.5 | 0.0 |
| | *6 m* | 1.3 | 1.5 | 0.5 | 2.7 |
| | *9 m* | | 1.8 | 3.4 | 3.8 |
| | *12 m* | | | 1.1 | |
| 15.06.99 | *0 m* | 0.5 | 0.5 | 0.5 | 0.5 |
| | *3 m* | 0.5 | 0.5 | 0.5 | 0.3 |
| | *6 m* | 0.6 | 0.6 | 0.9 | 0.8 |
| | *9 m* | | 1.05 | 1.9 | 1.5 |

Preglednica 1: Spremembe koncentracije barvila uranin v Jezeru v Ledvicah (v μg $l^{-1}$) na štirih izbranih točkah (1–4) v obdobju od 13. do 15. junija 1999 (Triglavski narodni park, Slovenija)

*Table 1: Changes in uranine concentration in the lake Jezero v Ledvicah (in μg $l^{-1}$) on four sampling points (1–4) during the period from June 13 to 15 1999 (Triglav National Park, Slovenia)*

Obarvano Jezero v Ledvicah 10. junija 1999 (Foto: Jure Andjelič)
*The dyed lake Jezero v Ledvicah on June 10, 1999 (Photo: Jure Andjelič)*

V točki 4 je bila najvišja koncentracija barvila spet izmerjena pri dnu, približno na globini 9 m. Od te točke naprej je bilo možno opazovati obarvane vodne pasove, ki so izginjali v požiralniku ob bregu na južni strani jezera. Tega požiralnika Gams (1962) v pregledu slovenskih visokogorskih jezer sicer ne navaja, čeprav je zelo očiten.

Ob znanem volumnu jezera ter hitrosti zmanjševanja koncentracije sledila je možna ocena pretoka vode skozi jezero. V izračunu je bila upoštevana povprečna koncentracija sledila, izračunana iz podatkov na vseh merilnih mestih (preglednica 2). Razredčenje sledila v jezerski vodi zaradi dotoka nove vode lahko izrazimo z enačbo masne bilance:

tom, at about 9 m. From this point, coloured water "stripes" could be observed, disappearing in the sinkhole near the southern shore of the lake. Although very obvious, this sinkhole is not mentioned by Gams (1962) in his overview of Slovenian high-mountain lakes.

Knowing the lake volume and the rate of reduction of the tracer concentration, an assessment of water flow through the lake can be made. The average tracer concentration, calculated from data obtained at all sampling points, was used in the calculation (Table 2). The dilution of tracer in lake water due to the inflow of new water can be expressed by the mass balance equation:

Preglednica 2: Povprečne koncentracije sledila uranin v Jezeru v Ledvicah na posamezen dan poizkusa (Triglavski narodni park, Slovenija)
*Table 2: Average daily concentrations of uranine in the lake Jezero v Ledvicah (Triglav National Park, Slovenia)*

| Datum<br>Date | Povprečna koncentracija<br>Average concentration |
|---|---|
| 13.06.1999 | 2.9 $\mu g\ l^{-1}$ |
| 14.06.1999 | 1.5 $\mu g\ l^{-1}$ |
| 15.06.1999 | 0.7 $\mu g\ l^{-1}$ |

$$C_{sk} * V_{sk} = C_0 * V_0 + C_s * V_s \quad (1)$$

kjer je:
- $C_{sk}$ ... koncentracija sledila v jezerski vodi po mešanju z novo doteklo (svežo) vodo;
- $V_{sk}$ ... skupni volumen vode v jezeru;
- $C_0$ ... koncentracija sledila v komponenti jezerske vode pred mešanjem s svežo vodo (stara voda);
- $V_0$ ... volumski delež stare vode;
- $C_s$ ... koncentracija sledila v sveži vodi (privzamemo $C_s = 0$);
- $V_s$ ... volumski delež sveže vode.

Iz enačbe 1 izpeljemo volumski delež novo dotekle (sveže) vode:

$$V_s = V_{sk} - \frac{V_{sk} * C_{sk}}{C_0} \quad (2)$$

V izračunu je bil privzet volumen jezera 135.000 m$^3$ (izračunano na podlagi podatkov Gamsa, 1962). Izračun je pokazal, da je med 13. in 14. junijem v jezero priteklo približno 63.000 m$^3$ sveže vode, med



$$C_{sk} * V_{sk} = C_0 *. V_0 + C_s * V_s \quad (1)$$

Where:
- $C_{sk}$ ... tracer concentration in lake water after mixing with new inflow (fresh water);
- $V_{sk}$ ... total lake water volume
- $C_0$ ... tracer concentration in lake water prior to mixing with fresh water (old water)
- $V_0$ ... volume proportion of old water;
- $C_s$ ... tracer concentration in fresh water (adopted value is $C_s = 0$);
- $V_s$ ... volume proportion of fresh water

The volume of new inflow (fresh water) is derived from equation 1:

$$V_s = V_{sk} - \frac{V_{sk} * C_s^k}{C_0} \quad (2)$$

The lake volume adopted in the calculation was 135,000 m$^3$ (calculated on the basis of data from Gams, 1962). The result showed that approximately 63,000m$^3$ of fresh water flowed into the lake be-

Prameni fluorescentnega sledila uranin, usmerjeni proti požiralniku na južni obali Jezera v Ledvicah (Foto: Jure Andjelič)

*Beams of fluorescent tracer uranine directed towards the sinkhole on the southern part of Jezero v Ledvicah (Photo: Jure Andjelič)*

14. in 15. junijem pa še 71.000 $m^3$ . Dotok nove vode v jezero je v opazovanem obdobju tako znašal 0,7–0,8 $m^3 s^{-1}$. Rezultati torej kažejo, da se ob močnejših padavinah v jezeru vsakodnevno zamenja praktično polovica stare jezerske vode s svežo vodo.

## POJAVLJANJE SLEDILA V DOLVODNIH JEZERIH OZIROMA IZVIRIH

Poleg vzorčevanja v Jezeru v Ledvicah so bili pojavi sledila opazovani tudi na nizvodnih jezerih oziroma izvirih, med katerimi pa ni površinskih povezav. Pojavljanje sledila v nižjih jezerih prikazuje slika 2. Sledilo se je najizraziteje pojavilo v izviru Močivec nad kočo pri Sedmerih jezerih. Koncentracija sledila je precej nihala in je 15. junija dosegla preko 9 $\mu g\ l^{-1}$. V Dvojnem jezeru se je sledilo pojavilo 15. junija, višek pa je bil dosežen 18. junija. Zanimivo je, da se je kljub le okoli 100-metrski razdalji med jezeroma največja koncentracija sledila pojavila tri dni kasneje kot v Močivcu. Iz tega se da sklepati, da hidravlična povezava med Jezerom v Ledvicah in Dvojnim jezerom ni tako neposredna, kot je povezava med Jezerom v Ledvicah in Močivcem.

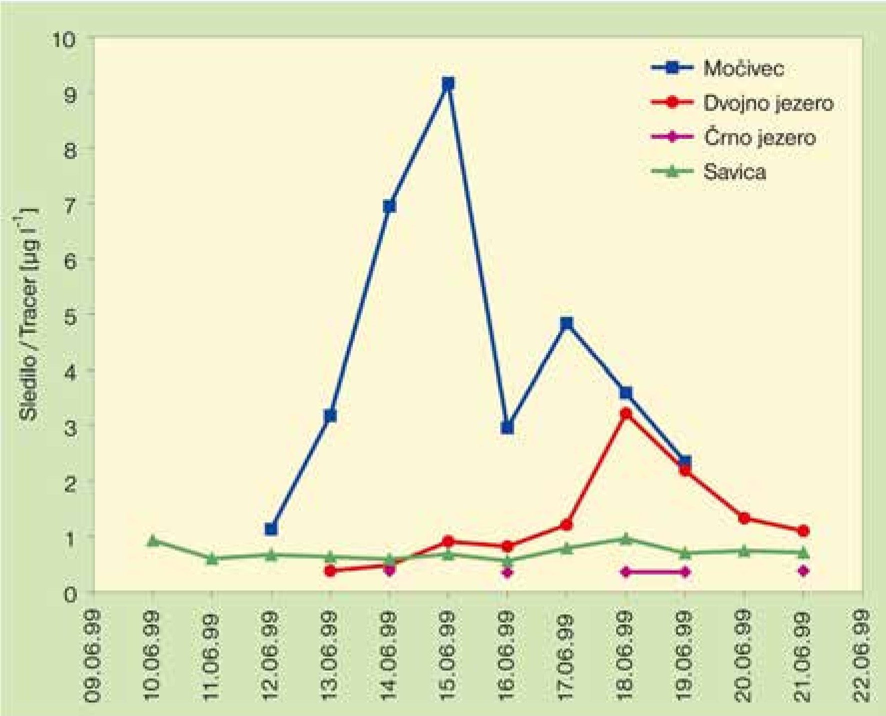
Podzemeljske povezave med Jezerom v Ledvicah ter Močivcem in Dvojnim jezerom, ki smo jih potrdili z barvanjem vode, se ne skladajo povsem z vrstno sestavo zooplanktona v vseh treh jezerih. Je-

tween June 13 and 14, and an additional 71,000 $m^3$ between June 14 and 15. Inflow of the new water in this period was 0.7–0.8 $m^3 s^{-1}$. This indicates that during heavy precipitation about half of old lake water is substituted by fresh water every day.

## OCCURENCE OF TRACER IN DOWNSTREAM LAKES AND SPRINGS

Beside sampling in Jezero v Ledvicah, tracer persistence was also monitored in downstream lakes and springs, which have no surface connections (Figure 2). The most intense tracer concentration was observed in the spring Močivec above the hut at the Triglav Lakes. Tracer concentration varied considerably and reached over 9 $\mu g\ l^{-1}$ on June 15. In Dvojno jezero, the tracer appeared on June 15 and reached its peak on June 18. It is interesting that in spite of only about one hundred meters distance, the highest tracer concentration was reached three days later than in Močivec. This could lead to the conclusion that the hydraulic connection between Jezero v Ledvicah and Dvojno Jezero is not as direct as between Jezero v Ledvicah and Močivec.

Underground connections between Jezero v Ledvicah and Močivec and Dvojno jezero revealed during the tracer experiment do not completely agree with the species structure of zooplankton in the three lakes. In late summer Jezero v Ledvicah




Slika 2: Pojavljanje sledila v opazovanih Triglavskih jezerih ter v izviru Savica (Triglavski narodni park, Slovenija)
*Figure 2: Tracer occurrence in the Triglav lakes and in the Savica spring (Triglav National Park, Slovenia)*

zero v Ledvicah ima v poznem poletju zelo veliko populacijo planktonskih vodnih bolh vrste *Daphnia longispina*. V primeru neposredne povezave z obema nizvodnima jezeroma bi pričakovali pojavljanje te vrste vsaj občasno tudi v obeh jezerih. Kljub intenzivnemu vzorčevanju skozi več let in ob različnih letnih časih, ne v Močilcu ne v Dvojnem jezeru, še nismo našli osebkov te vrste (Brancelj in sod., 1997). Prav tako še nismo našli trajnih jajc te vrste, ki so še posebej odporna na temperaturne in tudi fizične vplive iz okolja in bi zato morala prenesti tudi krajša ali daljša potovanja po podzemlju. Da lahko odrasli osebki te oz. sorodne vrste (*Daphnia pulicaria*) preživijo potovanje po podzemskih vodnih kanalih tudi na večje razdalje, smo lahko opazovali pri lovljenju drifta iz Zgornjega oz. Srednjega Kriškega jezera, ki smo ga lovili v izviru Krajcarica (Brancelj, lastna opazovanja). Vodni tok je iz enega od omenjenih jezer prinesel živali v izvir Krajcarica, ki se nahaja več kot 1400 m nižje.

V Črnem jezeru se sledilo ni pojavilo. Jezero očitno leži povsem izven glavnega toka podzemne

has a very large population of planktonic water fleas *Daphnia longispina*. A direct connection with both downstream lakes, suggests that this species could at least occasionally be expected to occur in both lakes. However, no organisms of this species were found in Močivec or in Dvojno jezero, in spite of intensive sampling over several years during different seasons (Brancelj *et al.*, 1997). Also, no eggs (ephippia)of this species were found. Their eggs are especially resistant to extraneous physical and temperature influences and should therefore be able to withstand a short period of underground transport. The ability of grown-up organisms of this or related species (*Daphnia pulicaria*) to survive underground transport (at greater distances) was observed during drift sampling at Zgornje and Srednje Kriško jezero. The drift was caught in the spring Krajcarica (Brancelj, pers. observ.) and water flow from one of the lakes brought animals into the spring Krajcarica, lying more than 1400 m lower.

No tracer was found in Črno jezero. The lake is apparently situated completely out of the main

Pojav fluorescentnega sledila uranin v Močivcu 15. junija 1999 (Foto: Jure Andjelič)
*Occurrence of fluorescent tracer uranine in Močivec on June 15, 1999 (Photo: Jure Andjelič)*

vode, ki doteka z osredjega ter zgornjega dela Doline Triglavskih jezer.

Rahel pojav sledila je bil opazen tudi v slapu Savica. Največja koncentracija uranina se je pojavila 18. junija, vendar ni presegla 1 μg $l^{-1}$. Znižanje koncentracij sledila je posledica razredčenja zaradi velikih količin podzemne vode, ki se z različnih območij stekajo na to območje. V vodi Savice je bilo izmerjeno višje ozadje koncentracije sledila kot pri ostalih opazovanih vodah. Povišano ozadje je moč razložiti s predhodnimi sledilnimi poizkusi, ki so bili izvedeni v različnih delih Triglavskega pogorja (Trišič in sod., 1997).

path of groundwater flow from the central and upper part of the Triglav lakes valley.

A low concentration of the tracer was also found in the spring of the Savica River. Uranine concentration reached its peak on June 18, but it did not exceed 1 μg $l^{-1}$. Lower tracer concentrations are the result of dilution due to large quantities of groundwater inflow. However, higher background concentrations of tracer were determined in the Savica water. These observations may result from previous tracer experiments, carried out in various parts of the Triglav area. (Trišič *et al.*, 1997).

## SLEDILNI POIZKUS MOČIVEC–DVOJNO JEZERO

Drugi sledilni poizkus na območju Triglavskih jezer je bil izveden v letu 2000. Njegov namen je bil ugotoviti naravo povezave med Močivcem in Dvojnim jezerom. Poizkus je bil izveden na osnovi indikacij, da povezava med jezeroma ni tako neposred-

## TRACER EXPERIMENT AT MOČIVEC–DVOJNO JEZERO

The second tracer experiment in the area of the Triglav lakes was carried out in the year 2000. Its aim was to find out the nature of any connection between Močivec and Dvojno jezero. The experiment was performed on the basis of indications

Injiciranje fluorescentnega sledila uranin v ponor (Foto: Janko Urbanc)
*Injection of fluorescent tracer uranine into the Močivec sinkhole (Photo: Janko Urbanc)*

na, kot bi lahko sklepali iz medsebojne bližine obeh jezer. V tej zvezi je potrebno omeniti predvsem raznolikost živalstva v obeh jezerih, ki bi jo težko pripisali le različnim življenjskim razmeram v obeh jezerih.

Injiciranje v ponor Močivca nad kočo pri Sedmerih jezerih je bilo izvedeno 22. junija 2000 ob 7. uri zjutraj. Uporabljeno je bilo 0,25 kg sledila uranin. Ob času izvajanja sledilnega poskusa je voda iz Močivca odtekala v dva aktivna ponora, ki sta požirala vsak po nekaj litrov vode v sekundi.

Prvi jasen pojav sledila je bil zabeležen istega dne ob 17$^{30}$ v vzhodnem delu jezera na globini 2 metrov. Sledilo se je zatem počasi širilo proti osrednjemu delu jezera, kjer je bila dosežena najvišja koncentracija 24. junija ob 20$^{30}$. Koncentracije sledila so se zatem pričele počasi zmanjševati. Sledilo

that the connection between the lakes is not so direct as might be supposed on the basis of the geographical proximity of the two lakes. In this regard, the diversity of fauna in both lakes appears significantly different, which cannot be attributed solely to different living conditions in both lakes.

Tracer (0.25 kg of uranine) was injected into the sinkhole of Močivec at the hut at the Triglav lakes on June 22 2000 at 7 a.m. During the tracer experiment, water from Močivec was flowing into two active sinkholes at a rate of several litres per second.

The first explicit occurrence of tracer was observed on the same day at 17.30 in the eastern part of the lake at a depth of 2 m. The tracer then slowly spread towards the central part of the lake, where the highest concentration was reached on June 24

| Datum ura / Date hour | Razdalja / Distance → Globina / Depth ↓ | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|---|---|
| 21.06.00 18:00 | 0 m | 2.2 | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.2 |
| | 2 m | 3.1 | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1 |
| | 4 m | | 1.1 | 1.1 | 1.0 | 1.1 | 1.1 | |
| | 6 m | | | 1.0 | 1.0 | 1.1 | | |
| 22.06.00 07:30 | 0 m | 1.4 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 |
| | 2 m | 1.5 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.4 |
| | 4 m | | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | |
| | 6 m | | 1.3 | 1.3 | 1.3 | 1.3 | | |
| 22.06.00 17:30 | 0 m | 3.4 | 1.8 | 1.7 | 1.7 | 1.8 | 1.8 | 2.1 |
| | 2 m | 5.2 | 1.8 | 1.7 | 1.7 | 1.7 | 1.8 | 2.4 |
| | 4 m | | 1.9 | 1.7 | 1.7 | 1.8 | 1.9 | |
| | 6 m | | 1.9 | 1.5 | 1.7 | 1.7 | | |
| 23.06.00 09:00 | 0 m | 4.1 | 1.9 | 1.8 | 1.8 | 1.8 | 2.0 | 3.5 |
| | 2 m | 5.6 | 1.9 | 1.8 | 1.9 | 1.9 | 2.0 | 4.8 |
| | 4 m | | 1.9 | 1.9 | 1.9 | 2.0 | 2.2 | |
| | 6 m | | 9.6 | 10.6 | 5.1 | 2.7 | | |
| 23.06.00 17:30 | 0 m | 2.5 | 1.8 | 1.7 | 1.7 | 1.4 | 1.4 | 1.8 |
| | 2 m | 3.5 | 1.8 | 1.8 | 1.7 | 1.4 | 1.4 | 2.3 |
| | 4 m | | 2.2 | 3.6 | 3.5 | 1.8 | 3.0 | |
| | 6 m | | 8.2 | 7.3 | 9.2 | 4.0 | | |
| 24.06.00 08:30 | 0 m | 1.8 | 1.4 | 1.4 | 1.4 | 1.4 | 1.3 | 1.9 |
| | 2 m | 2.3 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 2.3 |
| | 4 m | | 5.5 | 2.1 | 1.8 | 3.9 | 4.1 | |
| | 6 m | | 10.4 | 7.0 | 6.2 | 7.8 | | |
| 24.06.00 20:30 | 0 m | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| | 2 m | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| | 4 m | | 3.1 | 2.3 | 2.3 | 2.1 | 2.1 | |
| | 6 m | | 9.3 | 10.0 | 11.0 | 10.7 | | |
| 25.06.00 12:30 | 0 m | 1.6 | 1.4 | 1.4 | 1.4 | 1.5 | 1.7 | 2.1 |
| | 2 m | 2.0 | 1.9 | 1.9 | 1.8 | 1.9 | 1.9 | 2.2 |
| | 4 m | | 7.5 | 7.6 | 7.8 | 7.2 | 8.3 | |
| | 6 m | | 7.3 | 8.6 | 9.2 | 10.0 | | |
| 25.06.00 19:45 | 0 m | 1.5 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| | 2 m | 1.9 | 1.3 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 |
| | 4 m | | 3.8 | 4.5 | 4.6 | 4.3 | 4.4 | |
| | 6 m | | 6.8 | 6.9 | 7.9 | 8.5 | | |
| 26.06.00 08:00 | 0 m | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 2.9 |
| | 2 m | 1.9 | 1.6 | 2.1 | 1.9 | 2.0 | 2.0 | 4.1 |
| | 4 m | | 5.7 | 5.4 | 5.8 | 6.0 | 6.3 | |
| | 6 m | | 6.6 | 6.6 | 7.5 | 7.3 | | |
| 26.06.00 15:30 | 0 m | 3.1 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.9 |
| | 2 m | 3.1 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 2.1 |
| | 4 m | | 3.8 | 3.1 | 3.3 | 4.3 | 3.8 | |
| | 6 m | | 5.3 | 5.2 | 5.6 | 6.1 | | |

Preglednica 3: Spremembe koncentracije barvila uranin v Dvojnem jezeru na posameznih globinah v celotnem prečnem profilu jezera (interval 10 m) v obdobju od 21. do 26. junija 2000 (v µg $l^{-1}$). V osenčenih poljih so največje izmerjene koncentracije sledila. (Triglavski narodni park, Slovenija)

*Table 3: Changes in uranine concentration in the lake Dvojno jezero at different depths along the entire transverse profile of the lake (10 m interval) from June 21 to June 26, 2000 (in µg $l^{-1}$). Shaded fields indicate the highest tracer concentrations (Triglav National Park, Slovenia)*

se je širilo samo v globljem delu jezera, pod 4 metre globine, medtem ko ga na površini jezera ni bilo moč zaznati (preglednica 3).

Opazovano počasno potovanje barvila in njegove nizke koncentracije bi lahko nakazovali razlago, zakaj je živalstvo in rastlinstvo v Močivcu drugačno kot v Dvojnem jezeru (Brancelj in Urbanc, 2000).

## IZOTOPSKE RAZISKAVE

Namen izotopskih raziskav vod iz Doline Triglavskih jezer je bil pridobitev novih podatkov o značilnostih pretakanja vode v posameznih jezerih. Izotopske metode predstavljajo dopolnitev hidrokemijskim raziskavam ter sledilnim poizkusom, saj odpirajo nove vidike interpretacije hidrogeoloških pogojev. Merili smo koncentracijo naravnega stabilnega izotopa $^{18}O$ (kisik-18), ki je že dokazal svojo uporabnost v tovrstnih raziskavah. Z uporabo izotopa $^{18}O$ ugotavljamo značilnosti območij napajanja vodonosnih struktur, saj je z njim možno oceniti nadmorsko višino zaledij. S tem izotopom je možno ugotavljati tudi dinamiko obnavljanja zalog podzemne vode, in sicer na osnovi razlik med izotopsko

at 20.30. Then the concentrations started to slowly diminish. The tracer spread only in the deeper part of the lake, under 4 m, and could not be observed on the lake surface (Table 3).

The observed slow tracer movement and its low concentrations could explain why the flora and fauna in Močivec and Dvojno jezero are different (Brancelj & Urbanc, 2000).

## ISOTOPIC INVESTIGATIONS

Isotopic investigations of waters from the valley of the Triglav Lakes aimed to obtain new data about the characteristics of water flow in individual lakes. Isotopic methods are complementary to hydrochemical investigations and tracer experiments, because they open new perspectives for the interpretation of hydrogeological conditions. The concentration of stable natural isotope $^{18}O$ (oxygen- 18) was measured, since the use of this isotope has been tried and tested in previous investigations. Because the isotope $^{18}O$ can be used to assess the altitude of aquifer recharge areas, it is used to determine the characteristics of recharge areas of water-bearing formations. On the basis of the difference between the isotopic composition of oxygen in precipitation and in the outflow from water-bearing formations, recharge dynamics of groundwater can be determined.

Measurements of oxygen isotope composition in the water of the Triglav lakes were carried out in 1999. Samples were taken from all main lakes, along with monitoring of some springs in the region: the spring Izvir pod Rušnato glavo, the spring Krištofo-

Meritve koncentracije sledila po globini Dvojnega jezera (Foto: Janko Urbanc)

*Measurements of tracer concentration along the water column of Dvojno jezero (Photo: Janko Urbanc)* sestavo kisika v padavinah ter v iztoku iz vodonosnih struktur.

Meritve izotopske sestave kisika v vodi Triglavskih jezer so bile opravljene v letu 1999. Vzorci so bili odvzeti v vseh glavnih jezerih, poleg tega pa so bili opazovani tudi nekateri izviri na širšem območju Triglavskih jezer: Izvir pod Rušnato glavo, Krištofojca pri planini Dedno polje ter izvir na planini Viševnik. Vzorčevanje je potekalo od julija do novembra, v tem času so bili opravljeni štirje odvzemi vzorcev.

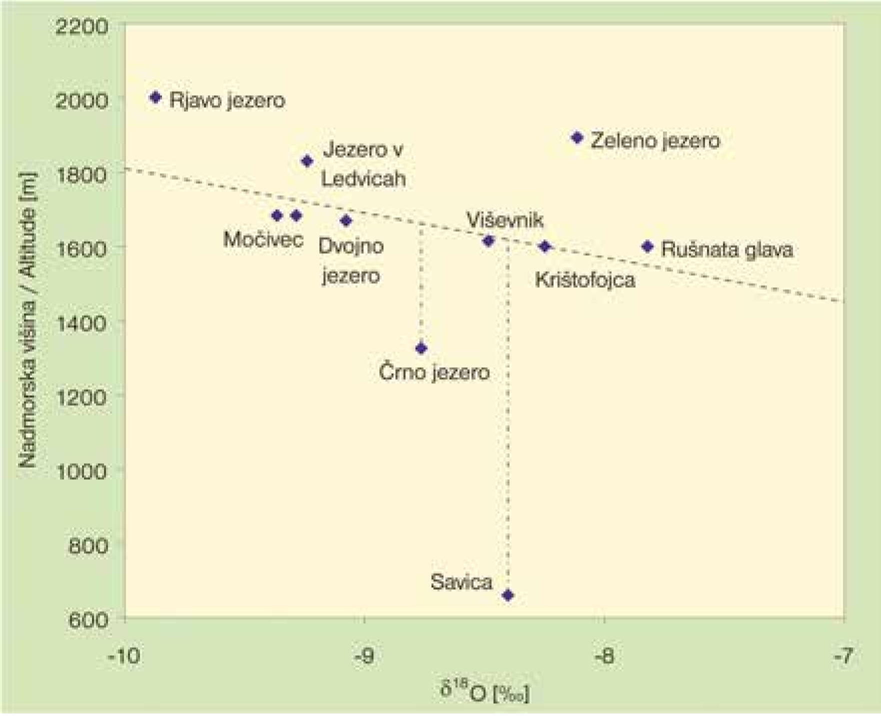
Glavne značilnosti izotopske sestave kisika v opazovanih vodah so prikazane na sliki 3. Prikazana je povprečna vrednost $\delta^{18}O$ na osnovi štirih vzorčevanj. Iz grafa je razvidno, da imajo višje ležeči izviri večinoma bolj negativne vrednosti $\delta^{18}O$, kar si lahko razložimo z višinskim izotopskim efektom. Opazovanja namreč kažejo, da vsebujejo padavine na večjih nadmorskih višinah manj težkega kisikovega izotopa $^{18}O$ (bolj negativne vrednosti $\delta^{18}O$), kar imenujemo višinski izotopski gradient. Večino vzorcev najdemo ob črtkani liniji z izotopskim gradientom okoli 0,47 ‰/100 m višine. Od te zakonitosti izrazito odstopa Zeleno jezero, ki bi moralo glede na svojo lego vsebovati manj težjega kisikovega izotopa. Ocenjujemo, da je vzrok za takšno odstopanje izotopske sestave Zelenega jezera večji delež padavinske vode oziroma manjši delež dotekajočih podzemnih vod. Padavine so imele v času vzorčevanja povprečno izotopsko sestavo okoli –8,4‰.

Od premice višinskega izotopskega gradienta

jca at alp Dedno polje and the spring on the alp Planina Viševnik. Sampling was performed from July to November on four occasions.

The main characteristics of oxygen isotope composition in the investigated waters are given in Figure 3, showing the average value, obtained from four samples. The diagram shows that springs at higher altitudes have mostly more negative $\delta^{18}O$ values, which can be explained by the altitude isotope effect. The observations show more depleted $^{18}O$ values of precipitation at higher altitudes (more negative $\delta^{18}O$ values), which is called the altitude isotope gradient. Most samples can be found along the dashed line with an isotope gradient of about 0.47 ‰/100 m of altitude. An explicit deviation from this average is found in Zeleno jezero, which should with regard to its location, show far more depleted values of the heavy oxygen isotope. It is estimated that this deviation is a result of a greater proportion of precipitation water in the lake and a smaller share of groundwater inflow into the lake. During the sampling period, precipitation had an average isotope composition of about –8.4‰.

The results from the spring Savica and of Črno jezero also show a marked deviation from the altitude isotope gradient. This deviation shows a bigger difference between the altitude of the spring and its recharge area. This means that the major part of the water flows into the spring from considerably higher altitudes. On the basis of data in the




Slika 3: Razmerje med povprečno izotopsko sestavo kisika v jezerih oziroma izvirih ter njihovo nadmorsko višino (Triglavski narodni park, Slovenija)
*Figure 3: Relation between average oxygen isotope composition in the lakes and springs and their altitudes (Triglav National Park, Slovenia)*

izrazito odstopajo tudi rezultati izvira Savice in Črnega jezera. Odstopanja kažejo na večjo razliko med nadmorsko višino izvira ter njegovim zaledjem. To pomeni, da glavnina vode očitno priteče v izvir s precej višjih območij. S pomočjo podatkov iz grafa lahko ocenimo srednjo nadmorsko višino zaledja izvira Savice na okoli 1600 m, medtem ko znaša srednja nadmorska višina zaledja Črnega jezera približno 1700 m.

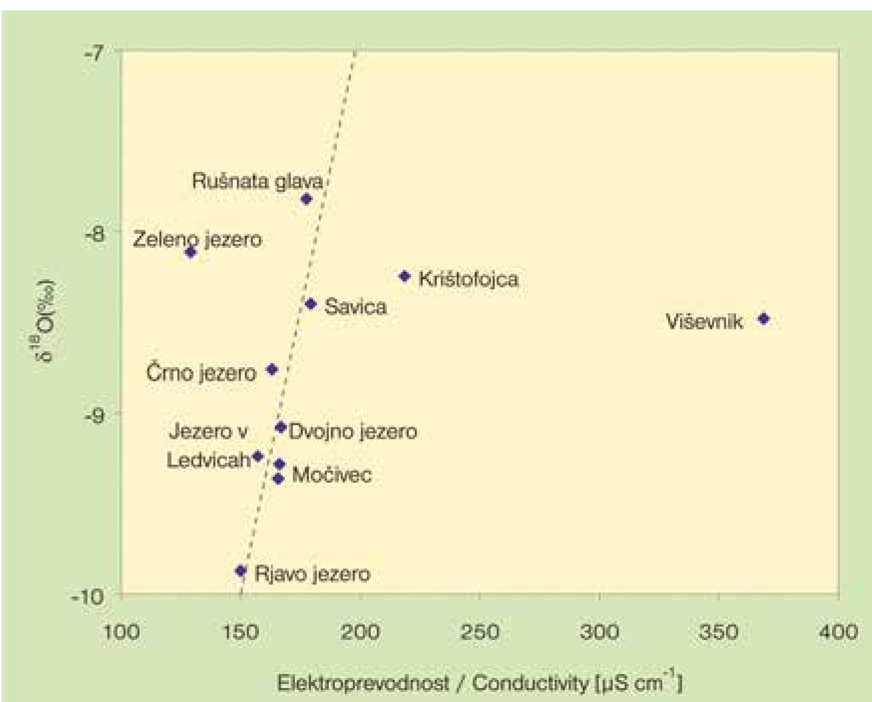
Zanimivo je tudi razmerje med izotopsko sestavo kisika v vodi ter električno prevodnostjo vode. Električna prevodnost pri kemijsko neonesnaženih vodah v glavnem odslikava množino raztopljenih karbonatov v vodi. Iz slike 4 vidimo, da je večina vrednosti razporejena ob premici, na kateri so vode z večjo elektroprevodnostjo obogatene s težjim kisikovim izotopom. Večja elektroprevodnost oziroma količina raztopljenih karbonatov odraža višji parcialni tlak $CO_2$ v tleh območja napajanja, ki je običajno pogojen z višjimi temperaturami tal in z njimi povezanimi intenzivnejšimi procesi razpadanja organskih snovi v tleh. Takšne pogoje lahko pričakujemo v nižjih območjih, kjer pa imajo tudi padavine zaradi višinskega izotopskega efekta bolj pozitivne vrednosti $\delta^{18}O$. Zaradi tega v mnogo primerih najdemo v vodah, ki so obogatene s težjim kisikovim izotopom, tudi večjo množino raztopljenih karbonatov.

Od premice $^{18}O$-elektroprevodnost zopet izrazito odstopajo rezultati vode iz Zelenega jezera; njena elektroprevodnost je nižja, kar potrjuje domnevo

diagram the mean altitude of a catchment area of the spring Savica can be estimated at about 1600 m, while the mean altitude of the catchment area of Črno jezero is approximately 1700m.

The relation between the oxygen isotope composition of water and water conductivity is also very interesting. In chemically unpolluted waters, electrical conductivity mainly reflects the quantity of dissolved carbonates in water. Figure 4 shows that most values are arranged along the straight line, which represents waters with higher conductivity, enriched by the heavier oxygen isotope. Higher electrical conductivity and, respectively, the quantity of dissolved carbonates reflect higher partial pressure of soil $CO_2$ in recharge areas. The partial pressure of soil $CO_2$ is usually conditioned by higher soil temperatures and consequently more intense decomposition processes of organic matter. Such conditions can be expected at lower altitudes, where also precipitation has more positive $\delta^{18}O$ values due to the altitude isotope effect. Consequently, greater quantities of dissolved carbonates are also frequently found in waters, enriched by the heavy oxygen isotope.

A distinctive deviation from the $^{18}O$-electrical conductivity straight line can again be observed in results from Zeleno jezero; its conductivity is lower, confirming the supposition about a more intense influence of precipitation water on this lake. A certain influence in this regard could also be attribut-




Slika 4: Razmerje med povprečno izotopsko sestavo kisika v jezerih oziroma izvirih ter elektroprevodnostjo vode v njih (Triglavski narodni park, Slovenija)

*Figure 4: Relation between average oxygen isotope composition in the lakes and springs and conductivity of water there (Triglav National Park, Slovenia)*

o izrazitejšem vplivu padavinske vode na to jezero. V tej zvezi bi lahko imele določen vpliv tudi rastline, ki s fotosintezo porabljajo ogljikov dioksid iz vode ter s tem vplivajo na karbonatno ravnotežje v vodi.

V smeri povečane elektroprevodnosti vode od premice odstopata izvir Viševnik in manj izrazito Krištofojca. Povišano karbonatno trdoto teh vod po vsej verjetnosti lahko pripišemo debelejši preperinski plasti ter večji količini razgradljivih organskih snovi v tleh, kar je vzrok za višji parcialni tlak talnega $CO_2$ ter posledično s tem več v vodi raztopljenih karbonatov.

## ZAKLJUČKI NA OSNOVI HIDROKEMIJSKIH IN IZOTOPSKIH ANALIZ

Opravljene raziskave kažejo, da so Triglavska jezera dokaj heterogen hidrogeološki sistem. S sledilnimi poizkusi je bila ugotovljena najbolj neposredna povezava med Jezerom v Ledvicah in Močivcem. Prvi pojav sledila iz Jezera v Ledvicah je bil v Močivcu zabeležen štiri dni po začetku sledilnega poizkusa. Pojav sledila je bil zelo izrazit.

V Jezeru v Ledvicah je bilo ugotovljeno zelo hitro zmanjševanje koncentracije sledila, kar kaže na to, da se ob močnejših padavinah voda v tem jezeru zelo hitro menja. Jezero torej očitno deluje kot nekakšen tolmun v hudourniški strugi, čez katerega se ob nalivih pretakajo velike količine vode. Izračun je pokazal, da se ob močnejših deževjih v jezeru zamenja vsak dan skoraj polovica celotnega volumna vode v jezeru, to je preko 60.000 $m^3$. Očitno v tem primeru igra pomembno vlogo neprepustna podlaga Doline Triglavskih jezer.

Tudi Močivec in Dvojno jezero sta med seboj hidravlično povezana, čeprav ne tako izrazito, kot bi glede na njuno medsebojno razdaljo lahko pričakovali. Prvi pojav sledila je bil ugotovljen približno 10 ur po začetku barvanja, največja koncentracija v Dvojnem jezeru pa je bila izmerjena po dveh dneh.

Z barvanjem je bila dokazana tudi povezava med Jezerom v Ledvicah ter izvirom Savica. Sledilo se je pojavilo v izviru Savica, sicer dokaj razredčeno, devet dni po začetku barvanja.

Sledilni poizkus je pokazal, da Črno jezero ni povezano z Jezerom v Ledvicah, Močivcem in Dvojnim jezerom; torej je locirano izven glavnega vodnega toka iz zgornjih jezer. Očitno ima Črno jezero povsem ločeno padavinsko zaledje, na osnovi izotopske sestave kisika je bila opredeljena srednja nadmorska višina zaledja Črnega jezera na okoli 1700 m.

ed to plants, which use carbon dioxide from water in photosynthesis and in this way affect the carbonate balance of water.

A deviation in the direction of higher electrical conductivity can be observed in the spring Viševnik and, less distinctively, in the spring Krištofojca. Higher carbonate values in this water can most probably be attributed to a thicker decomposition layer and a larger quantity of soil organic matter, which lead to higher partial pressures of soil $CO_2$ and consequently to higher values of dissolved carbonates in water.

## CONCLUSIONS ON THE BASIS OF HYDROCHEMICAL AND ISOTOPIC ANALYSES

The investigations indicate that the Triglav lakes are a fairly heterogeneous hydrogeological system. The tracer experiments proved the most direct connection between Jezero v Ledvicah and Močivec. The first occurrence of tracer from Jezero v Ledvicah was observed in Močivec four days after the start of the experiment.

A very rapid decrease of the tracer was observed in Jezero v Ledvicah, leading to the conclusion that water exchange in this lake is very fast during intense precipitation. The lake apparently functions as a pool in the stream channel, carrying large quantities of water during heavy rain. Calculations showed that almost half of the entire lake volume is exchanged during heavy precipitation, that is over 60,000 $m^3$ of water. The impermeable basement geology of the Triglav Lakes Valley probably plays an important role in this respect.

A hydraulic connection has also been found between Močivec and Dvojno jezero, although not so directly as might be expected considering the distance between them. The first occurrence of tracer was observed about 10 hours after dyeing, and the peak concentration in Dvojno jezero was measured after two days.

The tracer experiment proved also the connection between Jezero v Ledvicah and the spring Savica. The relatively diluted tracer was observed in the spring Savica nine days after the start of the experiment.

No connection was established between Črno jezero and Jezero v Ledvicah, Močivec and Dvojno jezero; hence the lake is located outside the main water flow from the upstream lakes. This leads to the conclusion that Črno jezero has a completely separate precipitation recharge area with an esti-

Raziskave kažejo, da je tudi Zeleno jezero izven glavnega toka podzemne vode. Izotopske in hidrokemijske značilnosti vode Zelenega jezera so namreč povsem drugačne kot pri ostalih jezerih. Iz izotopske sestave kisika ter majhne količine raztopljenih karbonatov sklepamo, da gre v Zelenem jezeru za prevladovanje deževnice, ki se zbira z ožjega območja okoli jezera.

Za razliko od Zelenega jezera je voda iz Rjavega jezera bolj podobna vodam ostalih jezer, zato ni izključena tudi morebitna hidravlična povezava z ostalimi jezeri.

mated mean altitude of about 1700 m. The altitude was determined on the basis of oxygen isotope composition.

Research indicates that Zeleno jezero also lies outside the main undergroundwater system. Its isotopic and hydrochemical properties are completely different from other lakes. Oxygen isotope composition and small quantities of dissolved carbonates indicate that precipitation water, gathered from the areas near the lake, prevails in the lake water.

Differently from Zeleno jezero, water from Rjavo jezero is more similar to waters from other lakes, leaving open the possibility of a hydraulic connection with other lakes.

# *Poglavje* 6 *Chapter*

# *Fizikalne in kemijske lastnosti jezerske vode in ledeni pokrov*

# *Physical and Chemical Properties of Lake Water and Ice Cover*

Gregor MURI* & Anton BRANCELJ*

**UVOD IN ZGODOVINSKI PREGLED**

Visokogorska jezera spadajo med najbolj odmaknjena in najmanj motena vodna okolja, ki jih najdemo na Zemlji. Večina je majhnih, zato so to občutljivi ekosistemi, ranljivi na spremembe v okolju. Raziskovalni projekti, ki preučujejo visokogorska jezera, so se razširili v zadnjem času, saj le-ta lahko služijo za zanesljive senzorje sprememb, ki so se zgodile v okolju (Wathne in Rosseland, 2000). Med številnimi različnimi pristopi so se določitve kemijskih in osnovnih fizikalnih lastnosti jezerske vode velikokrat uporabljale za ocenitev stanja teh jezer. Kemijske lastnosti vode so večinoma določene z osnovno kamninsko sestavo pojezerja, vendar se kemizem vode lahko bistveno spremeni zaradi atmosferske depozicije in biološke aktivnosti v vodnem stolpcu. Zaradi tega lahko visokogorska jezera nudijo dragoceno informacijo o posledicah človeškega vpliva na prvobitno okolje.

Starejši podatki o kvaliteti vode, pravzaprav njene fizikalne lastnosti, v jezerih Julijskih Alp so zelo redki in nezanesljivi. Prve podatke pred letom 1990 je zbral Gams (1962) med batimetričnim merjenjem jezer. Podatke je pobral iz večine jezer, vendar je bilo vzorčenje enkratno, zato imajo omejeno vrednost. Meril je temperaturo, pH ter kalcijevo in magnezijevo trdoto. Dobljene vrednosti so bile v okvirih, ki smo jih v zadnjem desetletju zasledili v teh jezerih.

Začetki spremljanja kvalitete vode v slovenskih visokogorskih jezerih segajo v leto 1991. Med 1991 in 1995 smo vodo vzorčevali enkrat letno v vseh 14

**INTRODUCTION AND HISTORICAL OVERVIEW**

High altitude mountain lakes are situated in the most remote and least disturbed environments found on Earth. However, most of them are small and consequently sensitive ecosystems, which are vulnerable to environmental change. Research projects on high-mountain lakes have become more widespread lately, since these lakes can be used as reliable sensors of environmental change (Wathne & Rosseland, 2000). Among many different approaches, the chemistry and basic physical properties of lake water have been frequently used as a powerful tool to assess the condition of these lakes. Although the chemistry is determined predominantly by the basic geology of the lake catchment area, it can be strongly affected and changed by atmospheric deposition processes and biological activity in the water column. Therefore, high-mountain lakes can provide valuable information on the consequences of human impact on a pristine environment.

Older data on water quality – actually the physical properties – of the lakes in the Julian Alps are very scarce and not reliable. The first and the only data before 1990, are those collected by Gams (1962) during his bathymetric mapping of the lakes. Data from most of the lakes were collected only once, so their value is very limited. Temperature, pH, calcium and magnesium hardness were measured and proved to be within the ranges we have obtained over the last decade.

The first attempts to monitor the water quality of Slovenian high-mountain lakes started in 1991.

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jezerih. Vzorčenje je potekalo v zgodnji jeseni, občasno tudi spomladi. V vzorcih smo določili fizikalne in kemijske lastnosti vode.

V letu 1996 pa smo pričeli s serijo domačih in mednarodnih raziskovalnih projektov (glej 1. poglavje), z namenom oceniti splošno stanje slovenskih visokogorskih jezer. Nekaj vzorčenj smo opravili tudi v zimskem času, ko so bila jezera pokrita z debelo plastjo ledu. Poleg tega smo med leti 1996 in 2001 zbirali tudi podatke o trajanju in debelini ledu, v letu 2000 pa smo v pet jezer (Krnsko jezero, Jezero v Ledvicah, Jezero na Planini pri Jezeru, Spodnje in Zgornje Kriško jezero) vložili minitermistorje, s katerimi smo vse leto merili temperaturo vode neposredno pod površino.

From 1991 to 1995, water samples from all 14 lakes were collected once a year, in the early autumn and occasionally in the spring. Physical properties and water chemistry of the samples were determined.

Starting in 1996, a series of national as well as international research projects were initiated (see Chapter 1), with the aim of assessing the overall condition of these lakes. Some samples were also taken in the winter time, when the lakes were covered by thick ice. In addition, data on ice cover, its duration and thickness were collected from 1996 to 2001. In the summer of 2000, five minithermistors were placed in five lakes (Krnsko jezero, Jezero v Ledvicah, Jezero na Planini pri Jezeru, Spodnje and Zgornje Kriško jezero) to record near-surface water temperature over the whole year.

## METODE

Vzorce vode smo jemali s 5-litrskim Van Dornovim vzorčevalnikom (Wildco Ltd., ZDA) nad najglobljim delom jezera. V Krnskem jezeru, Jezeru v

## METHODS

Water samples were collected from the deepest basin of the lakes using a 5 litres Van Dorn sampling device (Wildco Ltd., USA). Samples of the

Zgornje Kriško jezero je bilo leta 1994 še v juniju prekrito z debelo plastjo snega in ledu. Rjave lise na snegu so posledica prahu, ki ga je veter prinesel od blizu in daleč. Po stopitvi snega je potonil na dno jezera. (Foto: Anton Brancelj)

*In June 1994 Zgornje Kriško jezero was still covered with the thick snow and ice. The brown colour of the snow comes from dust, which has origin in surroundings of the lake as well as from long-distance transport. After ice melt it sank to the bottom of the lake. (Photo: Anton Brancelj)*

Ledvicah in Jezeru na Planini pri Jezeru smo vodo vzorčevali na vsakih 2,5 m, v ostalih pa smo jo jemali na 5 m. Vzorce smo shranili v plastične posode (PP, Brand) in prinesli v laboratorij v enem do dveh dneh po vzorčenju. V laboratoriju smo jih shranili pri 4 °C in jih analizirali v najkrajšem možnem času. Prevodnost, koncentracijo in nasičenost kisika ter temperaturo vode smo izmerili na terenu, običajno na globinah, kjer smo jemali vzorce. V treh zgoraj omenjenih jezerih smo te parametre merili na vsakem metru vodnega stolpca. Prosojnost vode (transparenco) smo merili s pomočjo Secchijevega diska s premerom 20 cm. Globino, na kateri diska nismo več razločili, smo označili kot globino prosojnosti jezera oz. globino Secchijeve plošče.

Za kemijske analize vzorcev smo uporabili standardne laboratorijske postopke, ki so opisani v Standardnih metodah (APHA, 1998). pH in alkaliteto smo izmerili takoj, ko smo vzorce prinesli v laboratorij. pH smo merili z digitalnim pH-metrom s stekleno elektrodo. Za umerjanje inštrumenta smo uporabili standardne pufrne raztopine pH 4 in 7. Za določitev alkalitete smo uporabili Granovo titracijo (Gran, 1952). Celotni dušik in fosfor smo določili v dveh korakih. Oba vzorca smo najprej oksidirali s persulfatom. Celotni dušik smo nato določili z merjenjem koncentracije nitrata v vzorcu po razklopu (APHA, 1998) z UV-VIS-spektrofotometrom (Lambda 12, Perkin Elmer). Celotni fosfor smo analizirali tudi spektrofotometrično, z merjenjem koncentracije ortofosfata v vzorcu po razklopu (APHA, 1998). Do konca leta 1999 smo glavne anione in katione določali z UV-VIS-spektrofotometrom. Od začetka leta 2000 pa za analiziranje glavnih ionov uporabljamo ionski kromatograf (761 Compact IC, Metrohm), ki je opremljen z visokotlačno črpalko, dušilcem pulzacije, anionsko in kationsko separacijsko kolono in detektorjem za merjenje prevodnosti. Na anionski separacijski koloni smo analizirali klorid, nitrit, nitrat, fosfat in sulfat. Pred detektorjem je bil instaliran modul za kemijsko supresijo, s katerim se izniči prevodnost raztopine eluenta. Natrij, amonij, kalij, kalcij in magnezij smo določali na kationski separacijski koloni. V tem primeru nismo uporabljali kemijske supresije. Meje detekcije so znašale med 50 in 100 µg $l^{-1}$. Za umerjanje inštrumenta in kontrolo kalibracijskih krivulj smo uporabili standardne raztopine in slepe vzorce.

Pozimi smo v led izkopali okrog 80 cm široko luknjo, da smo lahko pobrali vzorce vode. Vsakič smo zapisali tudi debelino ledu, njegovo strukturo in količino snega. Minitermistorje (tip: 8-bitni MINILOG-TR; Vemco Ltd.) z občutljivostjo 0,1 °C (v območju

water column were taken at every 2.5 m in three lakes i.e., Krnske jezero, Jezero v Ledvicah and Jezero na Planini pri Jezeru, while in other lakes, samples were collected at 5 m intervals. The samples were stored in plastic containers (PP, Brand) and delivered to the laboratory within one or two days after collection. They were stored at 4 °C and analysed as soon as possible. Conductivity, oxygen concentration/saturation and temperature were also measured in the field, usually at the depth where samples were collected. In the above-mentioned three lakes, these parameters were measured at 1 m intervals. Transparency of the water column was measured by means of Secchi disk with a diameter of 20 cm. A depth where the disk was no longer visible was recorded as the depth of transparency, i.e., Secchi disk depth.

Standard laboratory procedures were used for analysing chemical parameters in the samples, according to "Standard methods" (APHA, 1998). The pH and alkalinity were measured immediately on arrival of the samples at the laboratory. A digital pH meter, equipped with a glass electrode, was used for pH analyses. Standard buffer solutions of pH 4 and 7 were used to calibrate the instrument. For alkalinity determination, the Gran titration method was used (Gran, 1952). Total nitrogen and total phosphorus were determined in two steps. Both samples were first oxidised with persulphate. Total nitrogen was then determined by measuring the nitrate concentration in the digestate (APHA, 1998) using an UV-VIS spectrophotometer (Lambda 12, Perkin Elmer). Total phosphorus was also analysed spectrophotometrically by measuring the orthophosphate concentration in the digestate (APHA, 1998). Major anions and cations were determined using a UV-VIS spectrophotometer until the end of 1999. Starting in year 2000, an ion chromatograph (761 Compact IC, Metrohm), equipped with high-pressure pump, pulsation dampener, anion and cation separation columns and conductivity detection cell was used to analyse the concentration of major ions. Chloride, nitrite, nitrate, phosphate and sulphate were determined on an anion separation column. A chemical suppressor module was installed before the detection cell to eliminate the conductivity of the eluent solution. Sodium, ammonium, potassium, calcium and magnesium were analysed using a cation separation column. Chemical suppression was not used in this case. Detection limits ranged from 50 to 100 µg $l^{-1}$. Standard solutions and blank samples were used to calibrate the instruments and check the calibration curves.

Na površini Jezera v Ledvicah je 25. maja 1997 plavalo še nekaj plošč ledu. (Foto: Anton Brancelj)
*The surface of Jezero v Ledvicah was still covered with floes on May 25, 1997. (Photo: Anton Brancelj)*

–4 do +20 °C) smo vložili 1 m pod gladino petih jezer. Postavili smo jih nad najgloblji del jezer. Minitermistorji so beležili temperaturo vode štirikrat dnevno (ob polnoči, 6. zjutraj, opoldne, 6. zvečer) celo leto. Podatke smo pobrali enkrat letno.

Rezultati iz dveh najbolj izstopajočih jezer so obravnavani bolj podrobno. Jezero v Ledvicah spada med najbolj oligotrofna in prvobitna jezera v Julijskih Alpah. Na drugi strani je Jezero na Planini pri Jezeru močno evtrofno, občasno celo hipertrofno.

## FIZIKALNI PARAMETRI

*Temperatura*

Na temperaturo vode na površini jezera vplivajo mnogi različni dejavniki, kot so nadmorska višina, njegova prostornina, prosojnost vode, hidrologija in vsakoletne vremenske razmere. Ker so jezera relativno majhna, je temperatura vode močno odvisna od vremenskih razmer. Celo kratkotrajen

During the winter, we cut a hole, about 80 cm in diameter, through the ice to collect samples. Ice thickness, its structure and snow deposits were recorded on each occasion. Minithermistors (type: 8 bit MINILOG-TR; VEMCO Ltd.) with a resolution of 0.1 °C (range from –4 to +20 °C) were placed 1 m below the surface in five lakes and positioned over the deepest point of the lakes. They record the water temperature four times per day (midnight, 6 AM, noon, 6 PM) during the whole year and data are downloaded once per year.

Results from the two most extreme lakes are discussed in more detail. Jezero v Ledvicah is among the most oligotrophic and pristine lakes in the Julian Alps. In contrast, Jezero na Planini pri Jezeru is highly eutrophic, or sometimes even hypertrophic.

## PHYSICAL PARAMETERS

*Temperature*

Surface water temperature is greatly influenced by many different factors such as lake altitude, lake volume, transparency, hydrology and meteorological characteristics of each year. As the lakes are relatively small, the water temperature depends strongly on weather conditions. Even a short rain event dež lahko občutno vpliva na temperaturo vode, predvsem v plitvih jezerih. Zato je bilo temperaturno območje površinske vode v jezerih široko. Pozimi so bila vsa jezera pokrita z debelo plastjo ledu, zaradi česar je temperatura na površini znašala 0 °C. Zgornji del jezera, ki se imenuje epilimnij in se razteza v globino nekaj metrov, se je poleti v povprečju ogrel do 10–14 °C. Epilimniju sledi metalimnij (uporablja se tudi izraz termoklina), kjer temperatura vode na kratki razdalji pade za nekaj stopinj. Nato sledi plast vode, kjer je temperatura vodnega stolpca nizka in precej konstantna. To plast imenujemo hipolimnij.

Najvišje temperature površinske vode smo izmerili v Jezeru na Planini pri Jezeru in so dosegle 20 °C. Na drugi strani temperature v najvišjih jezerih celo v visokem poletju niso presegle 9 °C (Jezero pod Vršacem). Nihanja v globljih plasteh vodnega stolpca (v hipolimniju) so bila manjša. Pri dnu jezer je bila tako temperatura tudi poleti med 4 in 7 °C, ne glede na položaj jezera. Temperatura hipolimnijske vode običajno ni padla pod 4 °C tudi v mrzlih zimah, razen redkih izjem. Globoki in močni podpovršinski izviri bi lahko v obdobju med pozno jesenjo in pomladjo ohladili vodo pri dnu za okoli 1 °C. V tem času se namreč lahko pojavijo večje količine vode zaradi dežja ali topljenja snega, ki se nato ohlaja, ko teče skozi kraški teren, in ohlajena vstopa v jezero skozi razpoke pod površino jezera.

Večina jezer v Julijskih Alpah je dimiktičnih (vodni stolpec se premeša dvakrat letno), z izjemo najbolj plitvih, ki so lahko polimiktična (vodni stolpec se premeša večkrat letno; Rjavo in Zeleno jezero). Dimiktična narava jezera se kaže v pomladanski in jesenski homotermiji, ko je temperatura celotnega vodnega stolpca v nekem krajšem obdobju konstantna in znaša okrog 4 °C. Vetrovi povzročijo, da se vodni stolpec v tem času premeša, kar omogoča tudi obnovo kisika v globljih plasteh jezera. Čas homotermije je odvisen od vremenskih razmer. V pozni jeseni, ko temperatura zraka pade, se voda na površini ohladi do 0 °C in prične se tvoriti led. Obdobje, v katerem je jezero pokrito z ledom, je zopet odvisno od vremenskih razmer, predvsem od temperature zraka in padavin. Razen z ledom so jezera zaradi nizkih zračnih temperatur prekrita tudi s snegom. Moker sneg lahko zmrzne in prispeva k debeljenju ledu, medtem ko suh sneg deluje bolj kot izolator.

Podrobnejša temperaturna profila v Jezeru v Ledvicah in Jezeru na Planini pri Jezeru sta prikazana na slikah 1 in 2. V jezerih lahko opazujemo sezonski proces, ki ga imenujemo termična stratifi-

can influence the temperature considerably, particularly in shallow lakes. Therefore, a wide variety of surface water temperatures were measured in the lakes. In the winter time, all the lakes were covered by thick ice, keeping the surface water temperature at 0 °C. The upper part of the lake, also called the epilimnion, which extended several meters in depth, normally warmed up to, on average, 10–14 °C during the summer. The epilimnion is followed by the metalimnion (called also thermocline), where temperature drops a few degrees in a short vertical distance. Below this layer, the temperature of the water column is low and quite constant. This part of the lake is also called the hypolimnion.

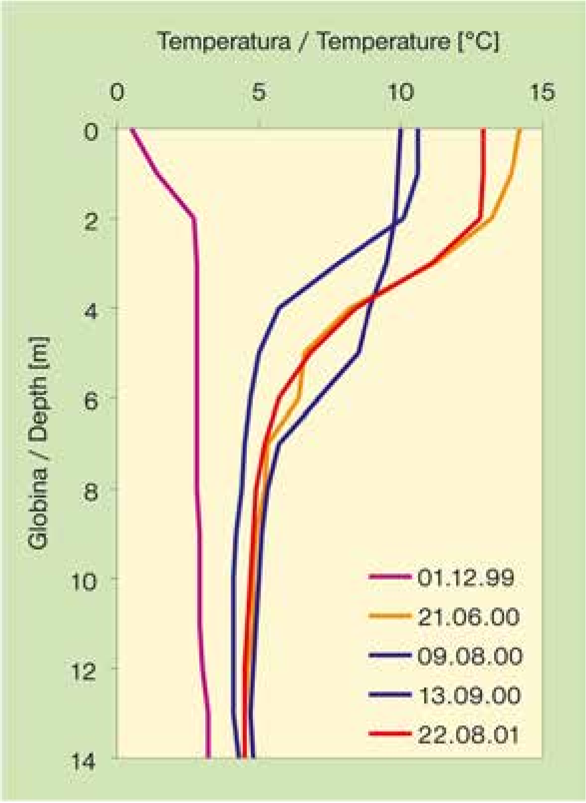
However, maximum surface temperatures as high as 20 °C were measured in the lake Jezero na Planini pri Jezeru. In contrast, the temperature of the highest lakes did not exceed 9 °C, even in high summer (Jezero pod Vršacem). Variations through the hypolimnion were smaller and, at the bottom of the lakes, the average temperature during the late summer was 4–7 °C, irrespective of the location of the lake. Except on some special occasions, water temperature there normally never dropped below 4 $^{oC}$, even in a very cold winter. Deep and strong sub-surface springs could cool water near the bottom by about 1 °C, particularly in the period from late autumn to spring. The reason is the sufficiently large amount of melted water, as well as rain water, which cools down during its flow through karstified limestone strata before entering the lakes through fissures below the lake surface.

Most of the lakes in the Julian Alps are dimictic (water column mixes twice per year), apart from the most shallow ones, which could be polimictic (water column mixes several times per year; Zeleno jezero and Rjavo jezero), and exhibit spring and autumn homothermy. In the dimictic lakes, the temperature of water in the water column remains constant at about 4 °C for a certain period. Mixing of the water column occurs, induced by wind, enabling renewal of oxygen in the deeper part of the lake. The duration of homothermy depends on weather conditions. Late in autumn when the air temperature drops, the water on the surface of the lake cools down to 0 °C and ice starts to form. The duration of the ice depends on weather conditions, particularly on air temperature and precipitation. Apart from ice, lakes are also covered by snow as a result of low air temperatures. Wet snow can freeze and contribute to the overall ice thickness, while dry snow contributes mainly to greater ice insulation.

Detailed temperature profiles for Jezero v Ledkacija. Do tega procesa pride zaradi razdelitve vodnega stolpca na plasti vode, ki se razlikujejo v temperaturi in gostoti (Berner in Berner, 1987). V času, ko je jezera prekrival led, smo najnižje temperature izmerili na površini, in sicer 0–0,1 °C. Temperaturni profil pod globino 2 metrov je bil nato konstanten in je znašal 4 °C (slika 2, apr. 99). Voda ima pri 4 °C najvišjo gostoto, zato je mešanje vodnega stolpca zmanjšano in s tem se voda v jezeru ne ohlaja več. Ko se led stopi, nastopi spomladansko mešanje, ko se voda popolnoma premeša in je temperatura po celotnem profilu 4 °C (slika 2, nov. 99).

Najvišje temperature smo izmerili pozno poleti v epilimniju. V oligotrofnem Jezeru v Ledvicah so bile nižje kot v evtrofnem Jezeru na Planini pri Jezeru. Do razlik je prihajalo zaradi razlik v prosojnosti vode in nadmorske višine. Obe jezeri sta bili poleti termično stratificirani, z izrazito termoklino, kjer je temperatura vode naenkrat padla tudi za 5 °C ali več. Termoklino v Jezeru na planini pri Jezeru smo zasledili na globini med 3 in 4 m. V Jezeru v Ledvicah se je gibala med 3 in 7 m. V zgodnjem poletju je bila bližje površini kot v poznem poletju, ko se je jezero ogrelo. Jeseni se je vodni stolpec ponovno premešal, s čimer se je kisik zopet prenesel tudi v globlje plasti jezera.

V obdobju med julijem 2000 in avgustom 2001



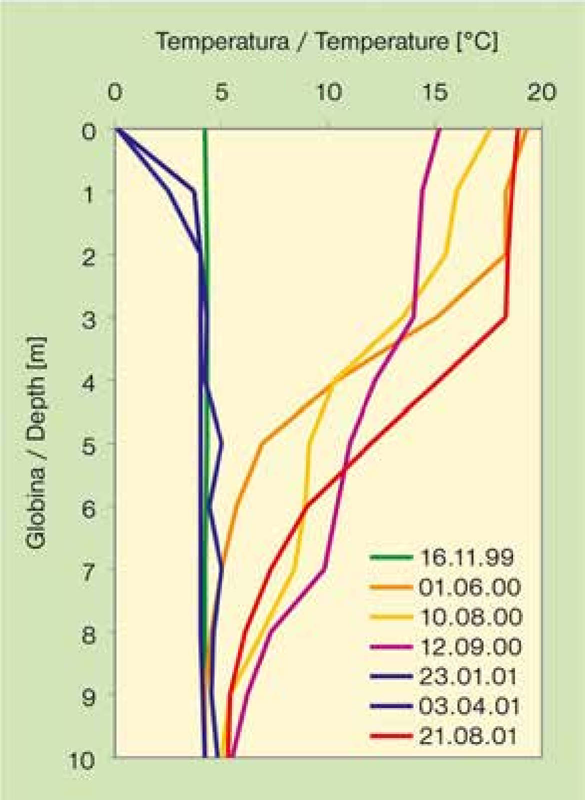

vicah and Jezero na Planini pri Jezeru are shown in Figures 1 and 2. The lakes went through a seasonal process known as thermal stratification. This process occurs as the water column separates into layers due to differences in temperature and density (Berner & Berner, 1987). During the ice cover period, the lowest temperature, 0–0.1 °C, was measured at the surface. Below a depth of 2 m, a uniform temperature profile was observed at 4 °C (Figure 2, Apr. 99). The highest density of water occurs at 4 °C. Therefore, mixing in the water column is reduced and further cooling of the lake water is prevented. After the ice melted, the spring overturn occurred, causing a completely mixed water column with a uniform temperature of 4 °C (Figure 2, Nov. 99).

The highest temperatures were observed in late summer in the epilimnion. They were lower in the oligotrophic lake Jezero v Ledvicah than in the eutrophic lake Jezero na Planini pri Jezeru. Differences occurred due to water transparency and altitude. Both lakes were thermally stratified in the summer with a well developed thermocline where temperature dropped rapidly, by about 5 °C or more. The thermocline in Jezero na Planini pri Jezeru occurred at a depth of 3–4 m while in Jezero v Ledvicah it varied between 3 and 7 m. In early summer, it was closer to the surface than in late summer, when the lake had warmed up. In the autumn, the water column mixed again and the new load of oxygen was transferred into the deeper parts of the lakes.

Long-term records of the sub-surface water temperature at a depth of 1 m, from July 2000 to August 2001 from the five lakes, give additional information on the temperature regimes (Figure 3). The warmest lakes were Krnsko Jezero and Jezero na Planini pri Jezeru, with summer temperatures at the surface close to 20 °C. The water temperature in the rest of the lakes was lower and decreased with altitude. The water temperature on the surface of the lake Zgornje Kriško jezero, at an elevation of 2150 m, was 4 to 5 °C lower than in the lakes at around 1430 m (Krnsko Jezero and Jezero na Planini pri Jezeru). Late summer temperatures in all five lakes gave almost identical profiles up to the end of October, and differ only due to altitude, with a gradient of about 0.56 °C per 100 m of altitude. The situation changed after formation of ice and, in

Slika 1: Temperaturni profili v Jezeru v Ledvicah (Triglavski narodni park, Slovenija)
*Figure 1: Temperature profiles in the lake Jezero v Ledvicah (Triglav National Park, Slovenia)*

Slika 2: Temperaturni profili v Jezeru na Planini pri Jezeru (Triglavski narodni park, Slovenija)
*Figure 2: Temperature profiles in the lake Jezero na Planini pri Jezeru (Triglav National Park, Slovenia)*




smo v petih jezerih sledili temperaturo vode 1 m pod površino, kar nam je dalo dodatno informacijo o temperaturnih režimih (slika 3). Najtoplejši sta bili Krnsko jezero in Jezero na Planini pri Jezeru. Tu so temperature poleti na površini dosegle skoraj 20 °C. Temperatura vode v ostalih jezerih je bila nižja in je z višino padala. Temperatura vode na površini Zgornjega Kriškega jezera, ki leži 2150 m visoko, je bila 4 do 5 °C nižja kot v jezerih, ki ležijo okrog 1430 m visoko (Krnsko jezero in Jezero na Planini pri Jezeru). Temperaturni profili v obdobju med poznim poletjem in koncem oktobra so bili skoraj identični v vseh petih jezerih. Razlikovali so se le v absolutni temperaturi, kar je posledica različne višine. Temperaturni gradient je znašal 0,56 °C na 100 m višine. Razmere so se spremenile, ko se je pričel tvoriti led. Predvsem dolžina trajanja ledene plasti se je precej razlikovala. Ko se je led raztopil, je bil vzorec nihanj podpovršinske temperature vode v vseh jezerih zopet podoben. Absolutne vrednosti temperature vode pa so bile pogojene z nadmorsko višino.

*Debelina ledu*

Debeline ledu nismo sistematično merili, vendar smo med vzorčenji zbrali nekaj podatkov. Največja debelina ledu je bila verjetno na Jezeru pod Vršacem, ki je bilo pred 1992 celo leto popolnoma prekrito z ledom, plundro in snegom. Pokrov je bil debel nekaj metrov in je bil verjetno posledica snežnih plazov s strmih pobočij nad jezerom. Po letu 1994 je bilo jezero v poletnem času brez ledu.

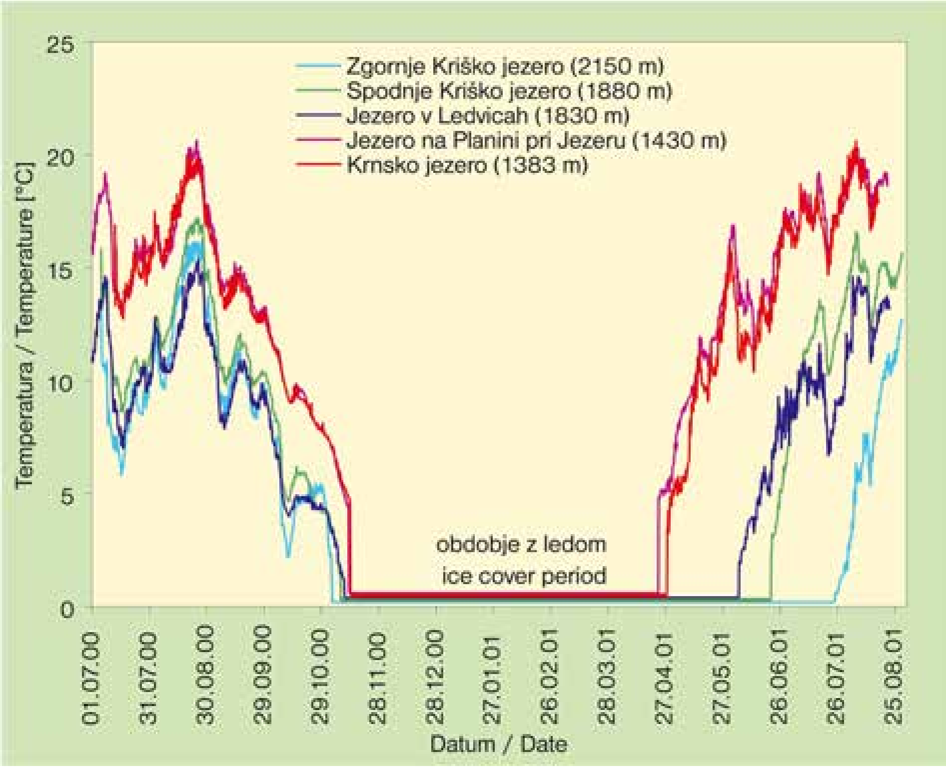
Med jezeri, ki so bila poleti redno brez ledu, smo največjo debelino ledu in plundre izmerili na Srednjem in Zgornjem Kriškem jezeru. Junija 1994 je bil led na Zgornjem Kriškem jezeru debel 2,5 m, medtem ko je bil konec junija 2001 led na Spodnjem Kriškem jezeru debel preko 3 m. Tako debele plasti ledu so bile posledica snežnih plazov in zametov. Med leti 1997 in 2001 je bila najdebelejša plast ledu (samo led) na Jezeru na Planini pri Jezeru 55 cm (20. februar 1997), na Jezeru v Ledvicah 80 cm (10. marec 1997) in na Krnskem jezeru 50 cm (11. februar 1998). Nadalje je bila na Jezeru

particular, the duration of ice-cover differed considerably. After ice-melt, all the lakes followed a similar pattern of sub-surface water temperature oscillations, the absolute water temperatures being influenced by the altitude.

*Ice cover*

Thickness of the ice was not measured systematically but some data were collected during the fieldwork. The maximum cover over the lake was probably on the lake Jezero pod Vršacem, which was completely covered by ice, slush and snow all the year round for several years until 1992. This was probably the result of snow avalanches from the steep slopes above the lake and was several meters deep. From 1994, the lake has been ice-free during summer.

On the lakes which regularly lost ice cover during the summer, the thickest cover, composed of slush and ice, was observed on Srednje and Zgornje Kriško jezero. In June 1994, the cover was 2.5 m thick on Zgornje Kriško jezero and more than 3 m at the end of June 2001 on Spodnje Kriško Jezero. On both lakes, the thick cover was the result of avalanches and snowdrifts. The thickest ice cover (ice only) recorded on Jezero na Planini pri Jezeru in the period from 1997–2001 was 55 cm (February 20, 1997), on Jezero v Ledvicah 80 cm (March 10,




Slika 3: Temperatura podpovršinske vode v Krnskem jezeru, Jezeru v Ledvicah, Jezeru na Planini pri Jezeru, Spodnjem in Zgornjem Kriškem jezeru (Triglavski narodni park, Slovenija)

*Figure 3: Sub-surface water temperatures in the lakes Krnsko jezero, Jezero v Ledvicah, Jezero na Planini pri Jezeru, Spodnje and Zgornje Kriško jezero (Triglav National Park, Slovenia)*

v Ledvicah 11. maja 1999 180 cm debela plast, ki je bila sestavljena iz 110 cm ledu in plundre ter 70 cm snega. 18. maja 2001 je bila plast ponovno debela 150 cm (led in sneg).

Čas trajanja ledu je bil odvisen od vremenskih razmer, vendar je v povprečju znašal okrog sedem mesecev. Običajno se je led pričel tvoriti novembra ali v prvi polovici decembra. Začetek topljenja ledu je bil ravno tako različen za vsako jezero, saj je odvisen od nadmorske višine, osvetljenosti jezera, količine snega. Na Jezeru na Planini pri Jezeru je bila 18. novembra 1997 2,5 cm debela plast ledu. 12. maja 1998 je bil led raztopljen. Na Jezeru v Ledvicah je bilo 25. maja 1997 še vedno nekaj kosov ledu, 19. novembra 1997 pa je bilo na jezeru 2 cm ledu. 13. maja 1998 je bilo na jezeru 70 cm ledu in snega, 22. oktobra 1998 pa se je led ponovno pričel tvoriti. 2. junija 1999 je bilo na jezeru še nekaj kosov ledu. Krnsko jezero je bilo 27. oktobra 1998 brez ledu, ravno tako 18. maja 1999. 11. decembra 2000 je bilo jezero še zmeraj brez ledu.

Minitermistorji so omogočali merjenje temperature podpovršinske vode ter določitev časa, v katerem je bilo jezero prekrito z ledom (slika 3). Led se je pričel tvoriti med 1. novembrom (Jezero v Ledvicah, Spodnje in Zgornje Kriško jezero) in sredino novembra leta 2000 (Krnsko jezero ter Jezero na Planini pri Jezeru). Zadnji dve jezeri sta izgubili

1997) and 50 cm on Krnsko jezero (February 11, 1998). In addition, on Jezero v Ledvicah, on May 11, 1999, there was 180 cm thick cover, consisting of 110 cm of ice and slush and 70 cm of snow. On May 18, 2001, the cover was still 150 cm thick (ice and snow combined).

The duration of ice cover depends on weather conditions, but on average, lasts about seven months. Normally ice formation starts in November or in the first part of December. The start of the ice free period is also specific for each lake and depends on altitude, exposure and sky line, snow precipitation. On Jezero na Planini pri Jezeru, on November 18, 1997 there was 2.5 cm ice cover and on May 12, 1998 the last ice melted. On Jezero v Ledvicah there were still a few floes on May 25, 1997, and, on November 19, 1997, it was covered with 2 cm of ice. The next year on May 13, there was 70 cm thick ice and snow and on October 22, 1998 the first ice was formed. On June 2, 1999, there were still floes on the lake. Krnsko jezero was ice-free on October 27, 1998 and again on May 18, 1999. On December 11, 2000, the lake was still ice-free.

Minithermistors enable us to measure sub-surface temperatures and also the duration of ice cover could be recognised (Figure 3). Ice formation started between November 1 (Jezero v Ledvicah, Spodnje and Zgornje Kriško Jezero) and mid-No-ledeni pokrov v drugem delu aprila leta 2001 (čas trajanja ledu 146 in 141 dni). Led na Jezeru v Ledvicah in Spodnjem Kriškem jezeru se je raztopil v začetku junija (čas trajanja ledu 213 in 209 dni). Na Zgornjem Kriškem jezeru je led vztrajal do druge polovice julija (263 dni). Februarja in marca 2001 je v gorah močno snežilo, zaradi česar je bilo nad 1600 m zelo veliko snega (več kot 6 m na Kredarici, 2514 m) (glej tudi 2. poglavje). Dolžina trajanja ledu je bila odvisna od nadmorske višine jezera. V povprečju se je podaljšala za 11 dni na vsakih 100 m višine. Zaradi lokalnih posebnosti jezer je podaljšanje dolžine trajanja ledu nihalo med 9,8 in 12,2 dnevi na 100 m višine.

*Koncentracija kisika*

Kisik je pomemben plin, ki je potreben za večino organizmov. Vir kisika v jezerih so fotosintetski procesi, ki večinoma potekajo v algah. Drugi pomemben vir je difuzija kisika iz zraka v površinsko plast vode, od koder se s tokovi prenaša v globlje plasti vodnega stolpca. Kisik v vodi se porablja za dihanja živali in alg (ponoči) ter pri razgradnji organske snovi, ki poteka v bakterijah in glivah (Schwoerbel, 1987).

Koncentracija kisika v vodnem stolpcu je bila tesno povezana s trofičnim stanjem jezera. Večina naših visokogorskih jezer je še vedno oligotrofnih ali mezotrofnih. V površinski plasti teh jezer smo izmerili koncentracije kisika med 9–12 mg $O_2\ l^{-1}$, vodni stolpec pa je bil popolnoma nasičen s kisikom vse do dna jezera v času, ko jezero ni bilo prekrito z ledom. Profil kisika po globini teh jezer je

vember 2000 (Krnsko Jezero and Jezero na Planini pri Jezeru). The latter lakes were ice-free by the second part of April 2001 (duration of ice cover was 146 and 141 days, respectively), while ice on Jezero v Ledvicah and Spodnje Kriško Jezero melted in the beginning of June (213 and 209 days of ice cover, respectively). On Zgornje Kriško Jezero, ice persisted to the second part of July (263 days of ice cover). In February/March 2001, there was intensive snowfalling, resulting in extreme snow cover above 1600 m (more than 6 m on Kredarica (altitude of 2514 m), see also Chapter 2). Ice cover duration on the lakes was altitude dependent and increased by about 11 days per 100 m of altitude. Due to local effects, ice cover duration varied from 9.8 days per 100 m of altitude to 12.2 days per 100 m of altitude.

*Oxygen concentration*

Oxygen is an important gas, needed by most organisms. The sources of oxygen in the lakes are photosynthetic processes, which take place mainly in algae. The second important source is diffusion of oxygen from the air to the surface water, from where it is transported by currents into the deeper layers. The oxygen in the water column is consumed

Količino kisika v vodnem stolpcu Jezera na Planini pri Jezeru lepo ponazarjajo vzorci, odvzeti po Winklerjevi metodi. Rjava barva pomeni veliko kisika, svetla oz. bela pa malo. (Foto: Anton Brancelj)
*The concentration of oxygen in the water column in Jezero na Planini pri Jezeru is well represented by samples collected according the Winkler's method. Brown colour means high oxygen concentration and pale / whitish colour low concentration. (Photo: Anton Brancelj)*

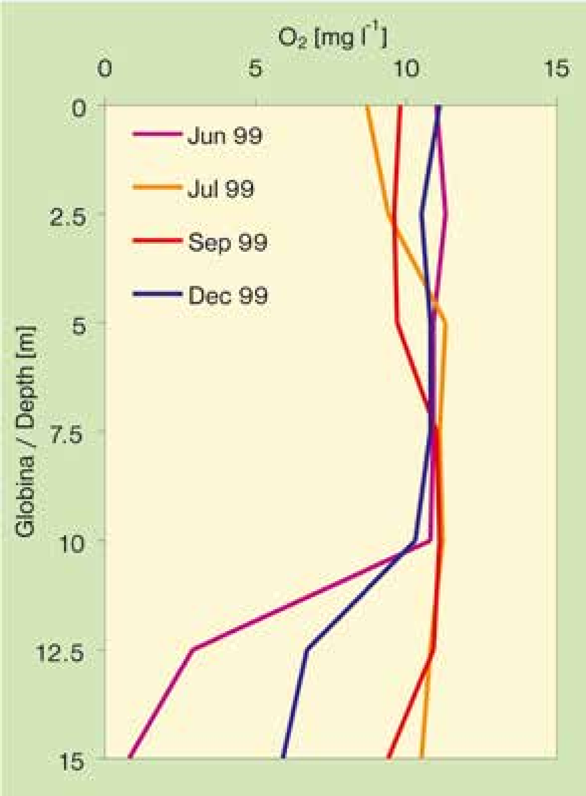
bil precej konstanten. Študirali smo tudi jezera z visoko primarno produkcijo (rezultat povišanih koncentracij hranil – evtrofikacija). Krnsko jezero ter Jezero na Planini pri Jezeru sta taki. V teh dveh jezerih smo zasledili visoke koncentracije kisika v površinski plasti vode, ki so podnevi dosegale celo 14 mg $O_2$ $l^{-1}$. Čeprav je bilo evfotično območje (približno dvakratna globina Secchijeve plošče = osvetljeni del vodnega stolpca) prenasičeno s kisikom, se je koncentracija kisika močno znižala v globljih plasteh vodnega stolpca, ki ga imenujemo tudi afotično območje (neosvetljnei del vodnega stolpca). Tega območja ne smemo enačiti s hipolimnijem, čeprav sta v evtrofnih jezerih hipolimnij, kot tudi del metalimnija, običajno vključena v afotično območje. Koncentracija kisika v hipolimniju je večinoma padla pod 1 mg $O_2$ $l^{-1}$. V nekaterih primerih smo opazili tudi popolnoma anoksične pogoje, ko je koncentracija kisika padla pod 0,2 mg $O_2$ $l^{-1}$.

Profila temperature in koncentracije kisika sta povezana. Z znižanjem temperature se koncentracija kisika poviša, saj je topnost plinov v vodi pri nižji temperaturi višja (Moore, 1990). To zvezo lahko vidimo, če primerjamo sliki 1 in 4. Vendar to velja le za oligotrofna jezera, kjer ne pride do znižanja koncentracije kisika zaradi biološke aktivnosti v vodnem stolpcu.

Podrobnejša profila koncentracije kisika v Jezeru v Ledvicah in Jezeru na Planini pri Jezeru sta prikazana na slikah 4 in 5. V oligotrofnem Jezeru v Ledvicah je bil večino leta celotni vodni stolpec nasičen s kisikom. Izjema je čas, ko je bilo jezero

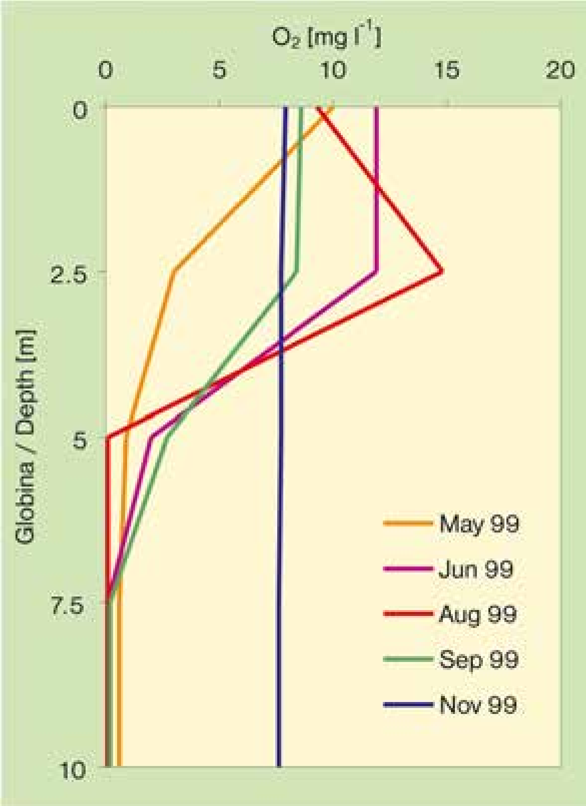
by respiration of animals and algae (during the night) and by decomposition processes effected by bacteria and fungi (Schwoerbel, 1987).

The oxygen concentration in the water column of the lakes was closely related to their trophic status. Most of the lakes are still oligotrophic or mesotrophic. Surface concentrations of oxygen of 9–12 mg $O_2$ $l^{-1}$ were observed in these lakes and the water columns were completely saturated with oxygen all the way down to the bottom during the ice-free period, resulting in fairly uniform oxygen profiles in these lakes. However, there are some lakes with higher primary production (a result of elevated concentration of nutrients – eutrophication). Krnsko jezero and Jezero na Planini pri Jezeru are such lakes. In these lakes, high oxygen concentrations were measured in the surface layers during the day, reaching as high as 14 mg $O_2$ $l^{-1}$. Although oxygen was over-saturated in the euphotic zone (approximately double Secchi disk depth = illuminated part of the water column), strong depletion of oxygen was observed in the deeper layers of the water column, also called the aphotic zone (dark part of the water column). This zone is not identical with the hypolimnion, but in eutrophic lakes the hypolimnion as well as part of the metalimnion is usually included in that zone. The oxygen con-




Slika 4: Profili raztopljenega kiska v Jezeru v Ledvicah (Triglavski narodni park, Slovenija)
*Figure 4: Dissolved oxygen profiles in the lake Jezero v Ledvicah (Triglav National Park, Slovenia)*

prekrito z ledom ter kratko obdobje po topljenju ledu, ko je organska snov, ki se je odlagala na sneg in led med zimo, vstopila v vodni stolpec. Ko je bilo jezero prekrito z ledom, je bila difuzija kisika iz zraka prekinjena in v globljih plasteh jezera smo za kratek čas zasledili pomanjkanje kisika (slika 4, jun. 99). To obdobje je trajalo do spomladanskega mešanja, ko se je voda v jezeru v celoti premešala. Popolnoma nasprotno stanje smo opazili v visoko produktivnem, evtrofnem Jezeru na Planini pri Jezeru. V epilimniju je bila koncentracija kisika visoka. Najvišje vrednosti, ki so dosegale 14 mg $O_2$ $l^{-1}$, smo izmerili pozno poleti. V tem času sta bila primarna produkcija in posledično sproščanje kisika podnevi med fotosintezo najbolj intenzivna (slika 5, avg. 99). Vendar je koncentracija kisika nato hitro upadla in v hipolimniju smo pogosto zasledili močno pomanjkanje kisika zaradi razgradnje organske snovi. Pozno poleti je občasno prihajalo celo do popolnih anoksičnih razmer (slika 5, jun., avg., sept. 99). Jezero je namreč poleti termično stratificirano. Zaradi različnih gostot epilimnijske in hipolimnijske vode se voda v jezeru ne more mešati in kisik se v spodnjih plasteh ne obnavlja. Koncentracija kisika v hipolimnijski vodi je bila zato nizka do jesenskega mešanja, ko se je voda v jezeru znova premešala (slika 5, nov. 99).




centration in the hypolimnion generally dropped below 1 mg $O_2$ $l^{-1}$. In some cases, complete anoxic conditions were observed, with oxygen concentration as low as 0.2 mg $O_2$ $l^{-1}$.

Temperature and oxygen concentration profiles were related. When temperature dropped, oxygen concentration increased, because the solubility of gases in water is higher at lower temperature (Moore, 1990), as can be seen when comparing Figures 1 and 4. However, this was true only for oligotrophic lakes, where oxygen depletion due to biological activity was not observed.

Detailed oxygen concentration profiles in Jezero v Ledvicah and Jezero na Planini pri Jezeru are shown in Figures 4 and 5. In the oligotrophic lake Jezero v Ledvicah, the whole water column was rich in oxygen for most of the year. The only exception was the ice cover period and a brief period after the melt, when most of the organic material which had accumulated on the snow and ice during the winter, sank to the bottom. During the ice cover, oxygen diffusion through the ice was limited and depletion of oxygen was for a brief period observed in the deeper layers of the water column (Figure 4, June 1999). This situation only lasted until the spring overturn, when the water column mixed completely. The completely opposite situation was observed in the highly productive, eutrophic lake Jezero na Planini pri Jezeru. In the epilimnion, the oxygen concentration was high. Peak values of up to 14 mg $O_2$ $l^{-1}$ were generally observed in the late summer months. Primary production and subsequent oxygen release in photosynthesis during the day was most intensive during that time (Figure 5, August 1999). However, the oxygen concentration decreased rapidly and, in the hypolimnion, strong oxygen depletion was frequently observed, as the result of the decomposition of organic matter. In the late summer, even complete anoxic conditions occurred occasionally (Figure 5, June, August, September 1999). The epilimnion and hypolimnion water did not mix due to thermal stratification of the lake water, which causes different water densities and hence, prevents water mixing. The hypolimnion water was therefore low in oxygen until the autumn overturn, when the whole water column was again mixed (Figure 5, November 1999).

Slika 5: Profili raztopljenega kiska v Jezeru na Planini pri Jezeru (Triglavski narodni park, Slovenija)
*Figure 5: Dissolved oxygen profiles in the lake Jezero na Planini pri Jezeru (Triglav National Park, Slovenia)*

*Prevodnost*

Z meritvijo prevodnosti ugotavljamo, kakšna je zmožnost vode, da prevaja električni tok. Uporablja se lahko za ocenitev celotne količine raztopljenih soli v vodi, saj je neposredno odvisna od celotne koncentracije raztopljenih ionov (Wetzel in Likens, 2000). Prevodnost vode v visokogorskih jezerih je najbolj odvisna od geološke sestave (tip kamnin) in velikosti pojezerja ter tudi od bioloških procesov v jezeru, predvsem v hipolimniju. Ti so zlasti pomembni v evtrofnih jezerih. Prevodnost je odvisna tudi od temperature merjenja. Z naraščajočo temperaturo se prevodnost povečuje (Moore, 1990). Zato so vse meritve prevodnosti izražene na referenčno temperaturo 25 °C, da se izničijo odstopanja, povezana s sezonskimi in globinskimi temperaturnimi spremembami vode.

Prevodnost vode na površini je znašala med 120 in 150 µS $cm^{-1}$. V jezerih z večjo produkcijo smo izmerili višje površinske prevodnosti, in sicer okrog 170 µS $cm^{-1}$. Profil prevodnosti po vodnem stolpcu je bil prav tako pogojen s trofičnim stanjem jezera. V oligotrofnem Jezeru v Ledvicah je bil profil prevodnosti precej enoten. Prevodnost je rahlo naraščala, od 150 µS $cm^{-1}$ na površini do 170 µS $cm^{-1}$ na dnu jezera. Nasprotno pa je prevodnost v evtrofnem Jezeru na Planini pri Jezeru močno naraščala z globino in je v poznem poletju na dnu dosegla celo 350 µS $cm^{-1}$. Tak potek prevodnosti je posledica biološke aktivnosti v hipolimniju, kar bo razloženo kasneje v tem poglavju. Profili prevodnosti med mešanjem so bili enolični v vseh jezerih.

*Conductivity*

Conductivity is a measure of the ability of water to support an electric current. It can be used to estimate the amount of total dissolved salts in the water, since it depends largely on the total concentration of dissolved ions (Wetzel & Likens, 2000). Conductivity in high-mountain lakes is controlled mainly by geology (rock types) and size of the lake catchment area as well as by biological processes, particularly in the hypolimnion. The latter are particularly important in eutrophic lakes. Conductivity is also dependent upon the temperature of measurement. It increases at higher temperatures (Moore, 1990). Consequently, all conductivity measurements quoted in the following are temperature compensated to 25 °C, to eliminate temperature differences associated with seasons and depth.

The surface water conductivity ranged between 120–150 µS $cm^{-1}$. Higher surface conductivity was observed in the more productive lakes (approximately 170 µS $cm^{-1}$). The conductivity profiles down the water column were once again affected by the trophic status of the lakes. In the oligotrophic lake Jezero v Ledvicah, the conductivity profile was quite uniform, ranging from 150 µS $cm^{-1}$ at the lake surface to 170 µS $cm^{-1}$ at the bottom of the lake. In contrast, conductivity in the eutrophic lake Jezero na Planini pri Jezeru increased with depth and reached 350 µS $cm^{-1}$ in the late summer at the bottom of the lake. This behaviour is caused by biological activity in the hypolimnion and will be discussed later in this chapter. Nevertheless, the conductivity profiles during the overturn period were uniform in all lakes.

## KEMIJSKI PARAMETRI

*pH*

pH izraža koncentracijo vodikovih ionov v vodi. Je eden od najpomembnejših parametrov vode, saj so mnoge reakcije odvisne od pH. Sprememba pH vpliva na ostale kemijske parametre, kot so alkaliteta, koncentracija kalcija in topnost hranil.

Ker ležijo naša visokogorska jezera na podlagi iz apnenca, je bil pH jezerskih vod ves čas šibko bazičen. Povprečna vrednost pH je znašala med 7,5 in 8,0, medtem ko smo v Jezeru na Planini pri Jezeru izmerili tudi višje vrednosti, do 8,5. V oligotrofnih jezerih se pH vrednost po globini praktično ni spreminjala. Nasprotno pa je v evtrofnih jezerih pH precej padel v hipolimniju in je v poletnih mesecih znašal celo manj kot 7 pri dnu jezera.

Profil pH iz Jezera v Ledvicah in Jezera na Plan-

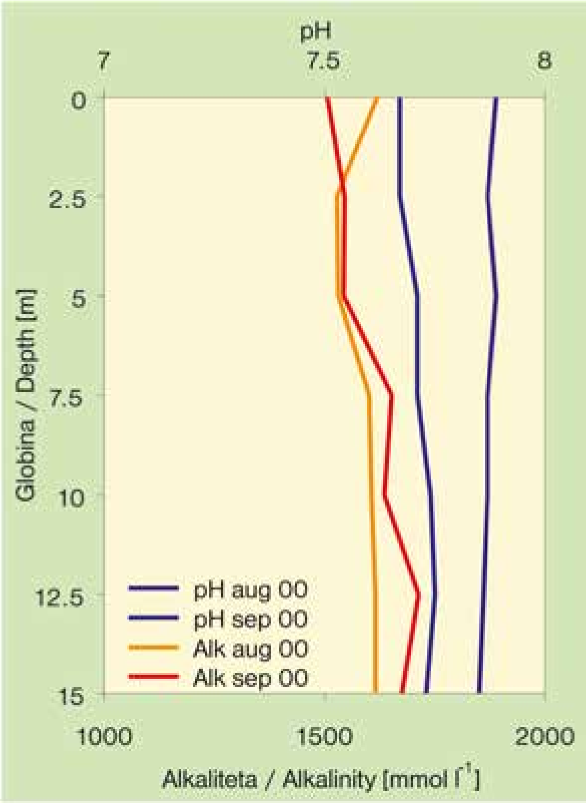
## CHEMICAL PARAMETERS

*pH*

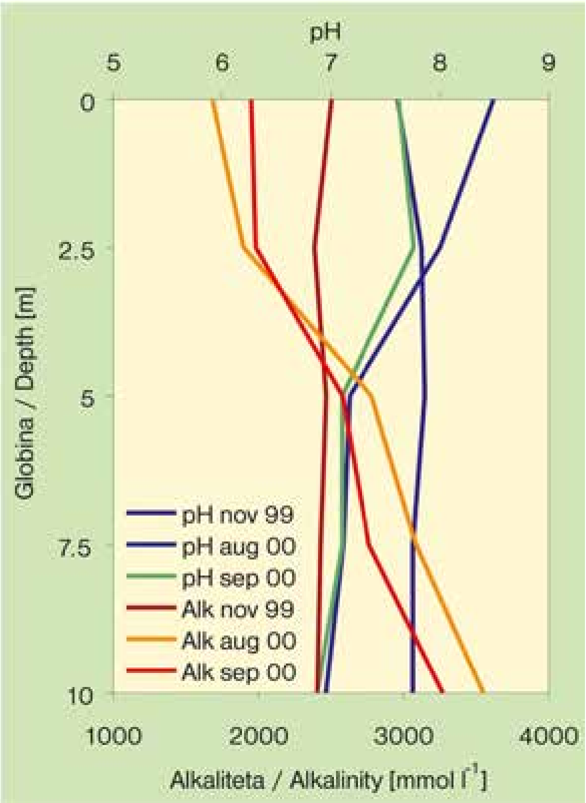
pH is a measure of the hydrogen ion concentration in water samples. It is one of the most important parameters in water, since many reactions are pH–dependent. A change of pH affects other chemical parameters such as alkalinity, calcium concentration and solubility of nutrients.

Because of the limestone bedrock, pH values were slightly basic at all times. The average surface pH values were 7.5–8.0 but a pH as high as 8.5 was measured in Jezero na Planini pri Jezeru. Almost uniform pH profiles were observed in oligotrophic lakes while, in eutrophic lakes, pH decreased remarkably in the hypolimnion, where pH values below 7 were observed in the summer months.

More detailed pH profiles from Jezero v Led-




Slika 6: Profili pH in alkalitete v Jezeru v Ledvicah (Triglavski narodni park, Slovenija)
*Figure 6: pH and alkalinity profiles in the lake Jezero v Ledvicah (Triglav National Park, Slovenia)*




Slika 7: Profili pH in alkalitete v Jezeru na Planini pri Jezeru (Triglavski narodni park, Slovenija)
*Figure 7: pH and alkalinity profiles in the lake Jezero na Planini pri Jezeru (Triglav National Park, Slovenia)*

ini pri Jezeru sta podrobneje predstavljena na sliki 6 in 7. Profil v Jezeru na Ledvicah je bil precej stalen, saj so se vrednosti gibale med 7,5 in 8,0. pH se je počasi zviševal z globino, vendar je ostal v območju 0,2 pH enote od površinske vrednosti pH. Poleg tega se je pH med letom le minimalno spreminjal. Profil pH iz Jezera na Planini pri Jezeru pa kaže čisto drugačno sliko. Med mešanjem je bil precej enoten in je znašal okrog 7,8 (slika 7, nov. 99). V času poletne stratifikacije je pH na površini občutno narasel. $CO_2$ se je porabljal v fotosintezi, zato je pH v epilimniju narasel do 8,5. Nato se je močno znižal z globino. Dihanje in razgradnja organske snovi v hipolimniju sta procesa, kjer se $CO_2$ sprošča. $CO_2$ se nato raztopi v vodi in tvori se šibka ogljikova kislina, zato se pH zniža. Pri dnu jezera, kjer so ti procesi najbolj intenzivni, smo izmerili pH vrednosti do 6,9.

vicah and Jezero na Planinni pri Jezeru are presented in Figures 6 and 7. Very uniform pH profiles have been noted in Jezero v Ledvicah, ranging from 7.5 to 8.0. The pH values increased moderately down the water column but they stayed within 0.2 pH unit of the surface pH. In addition, only slight seasonal variations were observed. In contrast, pH profiles in Jezero na Planini pri Jezeru showed very different behaviour. During the overturn periods, the pH profiles were quite uniform with average pH values of 7.8 (Figures 7, November 1999). During the summer stratification, however, the surface pH values increased markedly. $CO_2$ was consumed during photosynthesis and pH values in the epilimnion therefore increased up to a value of 8.5. However, a sharp decrease of pH was observed down the water column. Respiration and decomposition of organic matter in the hypolimnion are processes where $CO_2$ is released. $CO_2$ dissolves in water, forming a weak carbonic acid, and consequently, pH decreases. Values as low as 6.9 were observed at the bottom of the lake, where these processes were the most intensive.

*Alkaliteta*

Alkaliteta vode je njena zmogljivost za nevtralizacijo kislin. Je vsota vseh baz, ki jih lahko titriramo, in torej predstavlja zmožnost vode, da se upira spremembi pH zaradi dodatka kislin (Wetzel in Likens, 2000). Zaradi tega se alkaliteta uporablja kot glavni indikator občutljivosti na kisli dež. V jezerih, ki so na apnenčasti kamninski osnovi, je alkaliteta funkcija koncentracije karbonatnih ($CO_3^{2-}$), bikarbonatnih ($HCO_3^-$) in hidroksidnih ($OH^-$) ionov. Koncentracije karbonata, bikarbonata in $CO_2$ v vodi so povezane z enačbo karbonatnega ravnotežja (Stumm in Morgan, 1996). Glede na to, da je $CO_2$ plin, ki se porablja v fotosintezi in se sprošča med dihanjem in razgradnjo organske snovi, je alkaliteta močno povezana s spremembami pH zaradi biološke aktivnosti in posledično zaradi raztapljanja $CaCO_3$ v vodnem stolpcu. V epilimniju se $CO_2$ porablja v fotosintezi in pH se zviša. Skladno s karbonatnim ravnotežjem se poviša tudi koncentracija karbonata. Ker uravnava koncentracijo karbonata v vodi topnostni produkt $CaCO_3$, se presežni karbonat obori kot $CaCO_3$ in tone proti dnu jezera. V hipolimniju poteka nasprotna reakcija. $CO_2$ se sprošča med dihanjem in razgradnjo organske snovi in pH se zniža, zato se zniža tudi koncentracija karbonata, skladno s spremembo karbonatnega ravnotežja. $CaCO_3$, ki se je tvoril v epilimniju, in/ali $CaCO_3$ iz sedimenta se raztaplja in alkaliteta lah-

*Alkalinity*

Alkalinity of water is its acid–neutralising capacity. It is the sum of all the titratable bases and therefore, represents the ability of water to resist changes in pH caused by the addition of acids (Wetzel & Likens, 2000). Consequently, it is used as the main indicator of susceptibility to acid rain. In the lakes situated on limestone bedrock the alkalinity is primarily a function of carbonate ($CO_3^{2-}$), bicarbonate ($HCO_3^-$) and hydroxide ($OH^-$) content. The carbonate, bicarbonate and $CO_2$ concentrations in the water are controlled by the carbonate equilibrium (Stumm & Morgan, 1996). Since $CO_2$ is a gas, consumed in photosynthesis and released during respiration and decomposition processes, the alkalinity is greatly affected by the pH changes due to biological activity and subsequent dissolution of $CaCO_3$ in the water column. In the epilimnion, $CO_2$ is removed during photosynthesis and pH rises. In accordance with the carbonate equilibrium, the carbonate concentration also rises. Since the carbonate concentration in the water is regulated by the solubility product of $CaCO_3$, the excess carbonate precipitates as $CaCO_3$ and sinks toward the bottom of the lake. In the hypolimnion, the opposite reaction takes place. $CO_2$ is released during respiration and decomposition of organic matter and pH drops. Consequently, the carbonate concentration also drops, as ruled by the carbonate equilibrium. Subsequently, $CaCO_3$ formed in the epilimnion and/or $CaCO_3$ from the lake sediment re-dissolves and the alkalinity can increase significantly, since a higher concentration of carbonate/bicarbonate ions is present in this part of the water column. This behaviour also affects other parameters such as calcium concentration and conductivity.

Since all Slovenian high-mountain lakes are situated on limestone bedrock, the alkalinity is high.

| | | | pH | Alk [mmol $l^{-1}$] | $SO_4^{2-}$ [mg $l^{-1}$] | $NO_3$-N [mg $l^{-1}$] | $Ca^{2+}$ [mg $l^{-1}$] | $Mg^{2+}$ [mg $l^{-1}$] | $NH_4$-N [mg $l^{-1}$] | TN [mg N $l^{-1}$] | TP [µg P $l^{-1}$] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jezero v Ledvicah | Jun | *S* | 7.3 | 1.5 | 1.9 | 0.4 | 21.0 | 4.0 | < 0.04 | 1.5 | 8 |
| | | *B* | 7.6 | 1.6 | 2.0 | 0.4 | 24.0 | 4.3 | < 0.04 | 1.5 | 15 |
| | Sep | *S* | 7.7 | 1.5 | 1.4 | 0.2 | 16.3 | 3.3 | < 0.04 | 1.4 | 9 |
| | | *B* | 7.7 | 1.7 | 1.5 | 0.3 | 18.0 | 3.9 | < 0.04 | 1.8 | 19 |
| Jezero na Planini pri Jezeru | Jun | *S* | 8.0 | 1.7 | 2.1 | < 0.01 | 24.5 | 2.4 | < 0.04 | 1.3 | 41 |
| | | *B* | 6.9 | 3.3 | 1.2 | < 0.01 | 39.0 | 3.3 | 1.7 | 2.5 | 118 |
| | Sep | *S* | 7.6 | 1.9 | 0.9 | < 0.01 | 24.7 | 2.1 | < 0.04 | 1.6 | 64 |
| | | *B* | 6.9 | 3.3 | 0.8 | < 0.01 | 43.6 | 2.4 | 1.0 | 3.7 | 264 |

Preglednica 1: Sezonska nihanja nekaterih kemijskih parametrov v Jezeru v Ledvicah in Jezeru na Planini pri Jezeru v letu 2000 (Triglavski narodni park, Slovenija)
*Table 1: Seasonal variations of some chemical parameters in the lakes Jezero v Ledvicah and Jezero na Planini pri Jezeru in year 2000 (Triglav National Park, Slovenia)*
*S* – površinska plast / surface layer
*B* – spodnja plast / bottom layer
Alk: alkaliteta / alkalinity; TN: celokupni dušik / Total Nitrogen; TP: celokupni fosfor / Total Phosphorus

ko močno naraste, saj se poveča koncentracija karbonatnih/bikarbonatnih ionov v vodnem stolpcu. Ta mehanizem vpliva tudi na druge parametre, kot sta koncentracija kalcija in prevodnost.

Glede na to, da vsa slovenska visokogorska jezera ležijo na karbonatni podlagi, je alkaliteta visoka. Povprečna alkaliteta v oligotrofnih jezerih je znašala med 1000 in 1600 mmol $l^{-1}$. Alkaliteta je z globino rahlo naraščala. V jezerih z večjo primarno produkcijo je bila alkaliteta na površini višja in se je gibala med 1700 in 2400 mmol $l^{-1}$. Z globino je še naraščala in dosegla celo 3500 mmol $l^{-1}$ na dnu jezera.

Alkaliteta v vodnem stolpcu iz Jezera v Ledvicah in Jezera na Planini pri Jezeru bo obravnavana podrobneje. Njena profila sta prikazana na slikah 6 in 7. Alkaliteta v prvem jezeru je znašala okrog 1500 do 1600 mmol $l^{-1}$ na površini ter se je rahlo povečevala z globino. Na dnu jezera smo tako izmerili vrednosti do 1800 mmol $l^{-1}$. Tak profil alkalitete smo določili v celotnem obdobju, ko je bilo jezero brez ledu in se ujema z oligotrofnim stanjem tega jezera.

Profil alkalitete v Jezeru na Planini pri Jezeru je bil precej drugačen, kar je posledica evtrofnega stanja jezera. Najnižjo alkaliteto smo izmerili na površini, kjer se je gibala med 1800 in 2400 mmol $l^{-1}$. Tako široko koncentracijsko območje je bilo posledica sprememb v fotosintetski aktivnosti alg v evfotičnem območju. Poleti je bila fotosintetska aktivnost najbolj intenzivna, kar se je odražalo v višjih pH vrednostih in višji alkaliteti na površini. V času, ko je bilo jezero stratificirano, se je alkaliteta močno povečala v hipolimniju zaradi raztapljanja $CaCO_3$. Zaradi biološke aktivnosti se je $CO_2$ sproščal v hipolimniju. Karbonatno ravnotežje se je premaknilo in $CaCO_3$ se je raztapljal (s tem se je koncentracija $Ca^{2+}$ in $HCO_3^-$ povečala), zato se je povišala tudi alkaliteta. V poznem poletju je alkaliteta občasno presegla celo 3500 mmol $l^{-1}$. Edino obdobje, ko je bila alkaliteta v Jezeru na Planini pri Jezeru enotna po celotnem profilu, je bilo v času mešanja (slika 7, nov. 99).

*Anioni*

V vzorcih smo merili alkaliteto, klorid, nitrit, nitrat, ortofosfat in sulfat. Rezultati so povzeti v preglednici 1.

Karbonati so bili najbolj pogosti anioni in so predstavljali do 95 % celotne koncentracije anionov. Njihova porazdelitev v vodnem stolpcu je bila opisana v razdelku alkalitete. Kot smo tam že omenili, predstavljajo alkaliteto karbonatni, bikarbonatni in hidroksidni ioni. pH v naših jezerih se giblje med 7 in 8. V tem območju je koncentracija hidroksidnih ionov zelo majhna, zato jo lahko zanemari-

The average alkalinity of oligotrophic lakes ranged between 1000 and 1600 mmol $l^{-1}$. A slight increase toward the bottom of the lake was generally observed. In contrast, the alkalinity in more productive lakes was higher at the surface and ranged from 1700 to 2400 mmol $l^{-1}$, but increased remarkably with depth. At the bottom, alkalinity as high as 3500 mmol $l^{-1}$ was observed.

Alkalinity in the water column will be discussed in more detail for Jezero v Ledvicah and Jezero na Planini pri Jezeru. Their profiles are presented in Figures 6 and 7. The alkalinity in the former was 1500–1600 mmol $l^{-1}$ at the surface. A slight increase down the water column was observed and concentrations up to 1800 mmol $l^{-1}$ were measured at the bottom of the lake. Alkalinity followed that distribution throughout the ice free period. This profile is in a good agreement with the oligotrophic status of the lake.

Alkalinity profiles for Jezero na Planini pri Jezeru show a different response, in accordance with the eutrophic status of the lake. The lowest alkalinity was noted at the surface and ranged between 1800 and 2400 mmol $l^{-1}$. This wide concentration range was caused by different photosynthetic activities of algae in the euphotic zone. In the high summer, photosynthesis was at its most intensive, reflected in higher surface pH values and thus, in higher surface alkalinity. During the lake stratification, a remarkable increase of alkalinity was observed in the hypolimnion, caused by dissolution of $CaCO_3$. $CO_2$ was released in the hypolimnion due to biological activity. Subsequently, the carbonate equilibrium shifted and $CaCO_3$ dissolved (thus increasing $Ca^{2+}$ and $HCO_3^-$ concentrations). Therefore, the alkalinity also increased. In the late summer months, the alkalinity occasionally exceeded 3500 mmol $l^{-1}$. The only time when uniform alkalinity profiles were observed in Jezero na Planini pri Jezeru was during the overturn period (Figure 7, November 1999).

*Anion compounds*

The alkalinity, chloride, nitrate, nitrite, orthophosphate and sulphate concentrations were measured in the water samples. Results are summarised in Table 1.

Carbonates were the most abundant anions, constituting up to 95 % of the total anion concentration. Their distribution in the water column was described in the alkalinity section. As mentioned there, the alkalinity is composed of carbonate, bicarbonate and hydroxide ions. In the pH range 7–8, which was observed in all the lakes, hydroxide mo. Alkaliteta torej predstavlja porazdelitev karbonatov v vodnem stolpcu.

Ostali anioni so bili občutno manj pogosti. V povprečju so predstavljali 10 % ali celo manj od celotne koncentracije anionov. Njihova pogostnost je padala od nitrata proti sulfatu in kloridu, profili pa so bili precej konstantni. Nitrita in ortofosfata večinoma nismo zasledili. Koncentraciji nitrata in sulfata sta se povečali v zgodnji pomladi, po topljenju snega, ter sta znašali do 0,4 mg $NO_3^-$–N $l^{-1}$ in 2 mg $SO_4^{2-}$ $l^{-1}$. Ta dva aniona sta najpomembnejša sestavna dela kislega dežja, ki zaradi onesnaževanja nastaja v ozračju (Mosello in Marchetto, 1996). Iz ozračja se izpereta z dežjem in snegom ter se nalagata na snegu. V času topljenja snega vstopata v vodni stolpec, zato njune koncentracije v vodi narastejo (Johannessen in Henriksen, 1978). V preostalem obdobju sta koncentraciji nitrata in sulfata znašali med 0,2 in 0,4 mg $NO_3^-$–N $l^{-1}$ ter 1,0–1,8 mg $SO_4^{2-}$ $l^{-1}$.

Koncentracija sulfata se med sezono skoraj ni spreminjala, medtem ko je koncentracija nitrata v evtrofnih jezerih precej nihala. Najvišja je bila spomladi, nato pa je padala. Nitrat v epilimniju je pomemben vir dušika v fotosintezi, zato se je porabljal v tem procesu. V anoksičnih razmerah pa je prišlo do redukcije nitrata v amonij v hipolimniju, kar se je ponovno odražalo v nižji koncentraciji nitrata (Schwoerbel, 1987). V času najbolj intenzivne primarne produkcije je koncentracija nitrata v Jezeru na Planini pri Jezeru padla pod 0,1 mg $NO_3^-$–N $l^{-1}$, v določenih obdobjih pa nitrata sploh nismo zasledili. V oligotrofnih jezerih tako skrajnih primerov nismo zasledili. Koncentracija nitrata je bila precej konstantna celo leto. Koncentracija klorida se je gibala med 0,3 in 0,6 mg $Cl^-$ $l^{-1}$ v vseh jezerih, in ni kazala posebnih sezonskih nihanj.

Koncentracija nitrita je bila v vseh jezerih celo leto povečini pod mejo detekcije, ki je znašala 0,01 mg $NO_2^-$–N $l^{-1}$. Nitrit se je v epilimniju takoj oksidiral v nitrat. V času močno anoksičnih razmer v Jezeru na Planini pri Jezeru smo izmerili koncentracije nitrita do 0,02 mg $NO_2^-$–N $l^{-1}$.

Tudi ortofosfat smo redko zasledili v jezerih. V splošnem je bila njegova koncentracija ves čas pod mejo detekcije 0,02 mg $PO_4^{3-}$–P $l^{-1}$. Edina izjema je bilo ponovno Jezero na Planini pri Jezeru, kjer smo v času poletne stratifikacije določili vrednosti do 0,2 mg $PO_4^{3-}$–P $l^{-1}$ v globljih plasteh vodnega stolpca.

concentration is very low and was, hence, neglected. The alkalinity thus reflects the distribution of carbonates in the water column.

Other anions were considerably less abundant. On average, they comprised approximately 10 % or even less of the total anion concentration. Their abundance decreased successively from nitrate, through sulphate to chloride. Rather constant depth profiles were observed. Nitrite and ortho-phosphate were generally not detected. The nitrate and sulphate concentrations increased in the early spring after snowmelt up to 0.4 mg $NO_3^-$–N $l^{-1}$ and 2 mg $SO_4^{2-}$ $l^{-1}$, respectively. These anions are major atmospheric acid rain constituents, originating from pollution sources (Mosello & Marchetto, 1996). They are washed out of the atmosphere by rain and snow and accumulate in the snowpack. During snowmelt, they enter the water column and result in increased lake water concentrations (Johannessen & Henriksen, 1978). For the rest of the year, the nitrate and sulphate concentrations ranged from 0.2 to 0.4 mg $NO_3^-$–N $l^{-1}$ and 1.0–1.8 mg $SO_4^{2-}$ $l^{-1}$, respectively.

The sulphate distributions showed almost no seasonal variations. In contrast, the nitrate concentration varied remarkably in eutrophic lakes. The concentration was highest in the spring and then decreased. Nitrate in the epilimnion was an important source of nitrogen in photosynthesis and was therefore taken up in these reactions. As a result of anoxic conditions, bacterial reduction of nitrate to ammonium occurred in the hypolimnion, resulting in nitrate depletion (Schwoerbel, 1987). During the most intensive primary production, the nitrate concentration in Jezero na Planini pri Jezeru was below 0.1 mg $NO_3^-$–N $l^{-1}$, with some periods when it was not even detected. In oligotrophic lakes, no such extreme seasonal behaviour was observed and fairly constant nitrate concentrations were noted throughout the year. The chloride concentration ranged from 0.3 to 0.6 mg $Cl^-$ $l^{-1}$ in all lakes, with no particular seasonal changes.

Nitrite was generally below the detection limit of 0.01 mg $NO_2^-$–N $l^{-1}$ in all the lakes throughout the year. It was immediately oxidized to nitrate in the epilimnion. However, in the hypolimnion, where strongly anoxic conditions prevailed (Jezero na Planini pri Jezeru), nitrite concentrations of up to 0.02 mg $NO_2^-$–N $l^{-1}$ were detected.

Ortho-phosphate was also seldom detected in the lakes. In general, its concentration was below the detection limit of 0.02 mg $PO_4^{3-}$–P $l^{-1}$ throughout the year. The only exception was the eutrophic lake Jezero na Planini pri Jezeru, where concentra-

*Kationi*

V vzorcih smo analizirali amonij, kalcij, kalij, magnezij, natrij in pH. Nekateri rezultati so prikazani v tabeli 1.

Zaradi apnenca, kot osnovne kamnine, je bil kalcij najbolj pogost kation. Predstavljal je do 85 % celotne koncentracije kationov. Koncentracijsko območje kalcija v jezerih je bilo široko. Povprečne vrednosti so se gibale med 17 in 22 mg $Ca^{2+}$ $l^{-1}$. Najnižja vrednost je znašala 12 mg $Ca^{2+}$ $l^{-1}$, medtem ko je najvišja dosegla 45 mg $Ca^{2+}$ $l^{-1}$. Koncentracija kalcija je bila v oligotrofnih jezerih nižja kot v evtrofnih. V prvih se koncentracija tudi ni bistveno spreminjala z globino. V evtrofnih jezerih je koncentracijski profil kalcija sledil profilu alkalitete, saj je porast obeh parametrov posledica raztapljanja $CaCO_3$ (glej razdelek alkalitete). $CaCO_3$ se skladno s karbonatnim ravnotežjem raztaplja v hipolimniju, zaradi česar se koncentracija kalcija občutno poveča, kar lahko vidimo iz tabele 1.

Pogostnost ostalih kationov je redko presegla 15 % celotne koncentracije kationov in je padala od magnezija proti natriju in kaliju. Njihovi koncentracijski profili so bili ves čas bolj ali manj konstantni.

Vsebnost magnezija se je gibala med 2 in 5 mg $Mg^{2+}$ $l^{-1}$. Koncentracije natrija in kalija so bile pod 1 mg $Na^+$ $l^{-1}$ in 0,8 mg $K^+$ $l^{-1}$. Koncentracija natrija je bila spomladi nekoliko višja, a je nato upadla, česar v primeru kalija nismo zasledili.

V jezerih, kjer je bilo dovolj kisika v vodnem stolpcu, je bila koncentracija amonija celo leto pod mejo detekcije 0,04 mg $NH_4^+$–N $l^{-1}$. Amonij se je oksidiral v nitrat. Nasprotno smo v evtrofnih jezerih zasledili močno povišanje koncentracije amonija z globino. V hipolimniju se je amonij sproščal med razgradnjo organske snovi, poleg tega pa se je nitrat bakterijsko reduciral v amonij. Zaradi tega se je koncentracija amonija v globljih plasteh vodnega stolpca Jezera na Planini pri Jezeru, kjer so ti procesi najbolj intenzivni, močno zvišala in znašala celo 1,5 mg $NH_4^+$–N $l^{-1}$.

tions as high as 0.2 mg $PO_4^{3-}$–P $l^{-1}$ were observed in the deepest water layers during the high summer stratification.

*Cation compounds*

Water samples were analysed for ammonium, calcium, magnesium, pH, potassium and sodium ions. Some results are shown in Table 1.

Due to the limestone bedrock, calcium was the most abundant cation. It constituted as much as 85 % of the total cation concentration. Nevertheless, a wide range of calcium concentrations was observed in the lakes. The average concentrations were 17 to 22 mg $Ca^{2+}$ $l^{-1}$ but values as low as 12 mg $Ca^{2+}$ $l^{-1}$ and as high as 45 mg $Ca^{2+}$ $l^{-1}$ were observed. Calcium concentrations were lower in oligotrophic than in eutrophic lakes, and no obvious variations down the water column were observed in the former. In eutrophic lakes, the calcium distribution closely followed the alkalinity profile in the water column, since the increase of both parameters is caused by the dissolution of $CaCO_3$ (see the alkalinity section). $CaCO_3$ dissolves in the hypolimnion, as directed by the carbonate equilibrium and, in consequence, the calcium concentration increased remarkably, as seen in Table 1.

The abundance of other cations rarely exceeded 15 % of the total cation concentration, and decreased from magnesium to sodium and potassium. Their depth profiles remained quite constant at all times.

The magnesium content ranged from 2 to 5 mg $Mg^{2+}$ $l^{-1}$. Sodium and potassium concentrations were below 1 mg $Na^+$ $l^{-1}$ and 0.8 mg $K^+$ $l^{-1}$, respectively. The sodium content was slightly higher in the spring and decreased afterwards whereas in the case of potassium, no such behaviour was observed.

In the lakes rich in oxygen, the ammonium concentration was below the detection limit of 0.04 mg $NH_4^+$–N $l^{-1}$ all the year round. It was oxidised to nitrate. However, in eutrophic lakes, a remarkable increase of ammonium was observed with depth. In the hypolimnion, ammonium was liberated by the decomposition of organic matter. Additionally, nitrate was reduced by bacteria to ammonium. For these reasons, concentrations as high as 1.5 mg $NH_4^+$–N $l^{-1}$ were observed in the deeper layers of Jezero na Planini pri Jezeru, because these processes are most intensive at the bottom.

*Celotni fosfor*

Koncentracija celotnega fosforja določa trofični status jezera. Fosfor je omejujoče hranilo v jezeru in določa stopnjo tvorjenja organske snovi pri fotosintezi. Običajno je bila koncentracija ortofosfata, edine oblike fosforja, ki ga zelene rastline lahko uporabljajo pri fotosintezi, pod mejo detekcije 0,02 mg $PO_4^{3-}$–P $l^{-1}$. Celotni fosfor je potencialna količina ortofosfatov, ki se večinoma sprostijo pri razgradnji organske snovi in tako postanejo dosegljivi rastlinam. Organske spojine običajno potonejo na dno jezera, še preden jih bakterije v vodnem stolpcu popolnoma razgradijo. Oligotrofna jezera imajo nizke koncentracije hranil, to je dušika in fosforja. Posledično je tudi produkcija organske snovi majhna. Nasprotno je vsebnost hranil v evtrofnih jezerih velika, zato poleti prihaja do intenzivne primarne produkcije v teh jezerih.

Koncentracija celotnega fosforja je bila v večini jezer nizka. V splošnem se je gibala med 10 in 20 µg P $l^{-1}$. Ta jezera smo obravnavali kot oligotrofna. V Krnskem jezeru in Jezeru na Planini pri Jezeru smo zasledili precej višje koncentracije celotnega fosforja na površini, in sicer med 20 do 60 µg P $l^{-1}$. Z globino je koncentracija močno naraščala in v evtrofnem Jezeru na Planini pri Jezeru smo v poletnem času v nižjih plasteh vodnega stolpca izmerili celo 350 µg P $l^{-1}$. V mezotrofnem Krnskem jezeru je koncentracija redko presegla 100 µg P $l^{-1}$. Visoke koncentracije fosforja so odražale razgradnjo organske snovi v nižjih plasteh vodnega stolpca. Poleg tega tudi sediment lahko služi kot pomemben vir fosforja. V sedimentu namreč prihaja do kemisorpcije fosfatov na železove(III) okside. V anoksičnih pogojih se železo(III) reducira v železo(II), zaradi česar se fosfati sprostijo v vodni stolpec. V obeh primerih se zato koncentracija celotnega fosforja v vodi poveča. Njegova koncentracija se je v letih precej spreminjala, saj je močno odvisna od intenzivnosti primarne produkcije, ki se je prav tako spreminjala. Občasno smo povišane koncentracije celotnega fosforja do 50 µg P $l^{-1}$ zasledili celo v oligotrofnih jezerih.

*Total phosphorus*

The phosphorus concentration determines the trophic status of the lakes. Phosphorus is a limiting nutrient in the lakes and therefore, determines the rate of organic matter production during photosynthesis. Normally, ortho-phosphate, the only form of phosphorus, which can be taken up by green plants, was below the detection limit of 0.02 mg $PO_4^{3-}$–P $l^{-1}$. Total phosphorus is a potential amount of ortho-phosphate, most of it released during mineralization of organic matter and thus becoming available for plants. Organic compounds usually sink to the bottom before being completely mineralised by bacteria in the water column. Oligotrophic lakes have low concentrations of nutrients i.e., nitrogen and phosphorus. And consequently, production of organic matter is low. In contrast, eutrophic lakes have high nutrient contents and intensive primary production take place during the summer in these lakes.

The total phosphorus concentration was low in most lakes. In general, it ranged from 10 to 20 µg P $l^{-1}$. These lakes have therefore been defined as oligotrophic. In two lakes, Krnsko jezero and Jezero na Planini pri Jezeru, much higher total phosphorus concentrations 20 – 60 µg P $l^{-1}$ were observed in the upper layers of the water column but increasing with depth. A total phosphorus concentration as high as 350 µg P $l^{-1}$ was found in the summer time at the bottom of the eutrophic lake Jezero na Planini pri Jezeru. In the mesotrophic lake Krnsko jezero, its concentration rarely exceeded 100 µg P $l^{-1}$. High phosphorus concentrations reflected decomposition of sedimentary organic matter in the bottom layers of the water column. Additionally, sediments could serve as an important source of phosphorus. Phosphates are chemisorbed on iron (III) oxides. In anoxic sediments, iron (III) is reduced to iron (II) and consequently, phosphates are liberated to the water column. Both cases, therefore, are reflected in increased phosphorus concentrations in the lake water. However, the total phosphorus concentrations varied seasonally, relating to the intensity of primary production, which changed from year to year. Occasionally, higher total phosphorus concentrations of up to 50 µg P $l^{-1}$ were observed, even in oligotrophic lakes.

## ZAKLJUČKI

Ena od značilnosti visokogorskih jezer v Julijskih Alpah je, da so pogosto več kot pol leta pokrita z ledom, pri čemer je pomembna predvsem nadmorska višina. Zaradi svoje lege na apnenčasti podlagi imajo nekaj značilnosti, ki jih ločijo od drugih jezer v Alpah. Najbolj izraziti sta visoka koncentracija kalcija v vodi in posledično visoke vrednosti pH. Oboje zmanjšuje problem zakisovanja jezer, ki je sicer velik problem drugje po Evropi. Po drugi strani pa je največji problem jezer v Julijcih evtrofizacija, bodisi naravna ali tista, ki jo povzroča človek.

Na podlagi kemijskih in fizikalnih lastnosti vode lahko jezera v Julijskih Alpah razdelimo v tri skupine. V prvi so tista, kjer je človekov vpliv minimalen. Sem spada večina jezer nad gozdno mejo, pri čemer sta najvidnejši Jezero v Ledvicah ter Zgornje Kriško jezero. V teh je v vodnem stolpcu dovolj kisika, kar omogoča normalne življenjske procese. V drugi skupini jezer so tista, kjer je vpliv človeka že opazen. Ležijo pod gozdno mejo, pogosto v bližini pomembnih gorskih poti oziroma planinskih koč. Med temi so Dvojno jezero, Črno jezero, Dupeljsko jezero, pa tudi Spodnje in Srednje Kriško jezero. Po večini fizikalnih in kemijskih parametrov so sicer še v kategoriji razmeroma neonesnaženih jezer, vendar pa so vrednosti posameznih parametrov vsaj občasno višje oziroma nižje kot normalno. Pokazatelj neugodnega stanja je predvsem znižana koncentracija kisika v spodnjih plasteh, ki lahko traja dlje časa. Zaradi obiskovalcev in nepremišljenih dejanj, npr. naseljevanje rib, se stanje v teh jezerih hitro slabša. V tretji skupini jezer, kjer vrednosti nekaterih parametrov močno odstopajo od povprečja, sta Krnsko jezero in Jezero na Planini pri Jezeru. Obe jezeri sta že dolgo časa pod močnim vplivom človeka. Njuno slabo stanje se kaže v povečani količini hranil v vodnem stolpcu, ki omogoča bujno rast alg, s čimer pa se zmanjša prosojnost vode. Po drugi strani pa je v globjih delih jezera redno znižanje ali celo pomanjkanje kisika.

## CONCLUSIONS

Long lasting ice cover is characteristic of high-mountain lakes in the Julian Alps. It lasts usually more than six months, its duration being determined by altitude. The lakes are on the limestone area, which makes them distinct from other lakes in the Alps. The most characteristic features of the lakes are high content of calcium in the water and consequently high pH values. Both reduce the effects of acidification of the lakes, which is a serious problem in the rest of Europe. In contrast, the most important problem in the lakes in the Julian Alps is eutrophication, induced either by natural processes or by human activities.

On the basis of chemical and physical properties of the lake water, the lakes from the Julian Alps can be separated into three groups. In the first one are lakes with least human influence. They are usually above the tree line and Jezero v Ledvicah and Zgornje Kriško Jezero are the most important. The water column in these lakes contains enough oxygen to support normal life processes. In the second group are lakes already affected by human activities. They are below the tree line and close to the main mountain routes or mountain cottages. Dvojno jezero, Črno jezero, Dupeljsko jezero and Spodnje and Srednje Kriško jezero belong to this group. Most of chemical and physical parameters are still in a range characteristic of non-polluted lakes, but some values, at least from time to time, deviate from the normal. Low oxygen concentration in the near-the-bottom layers indicate unfavourable conditions, and can last for some time. Visitors, and certain activities like introduction of fish, accelerate the worsening status of the lakes. In the third group are the lakes heavily affected by humans. Krnsko jezero and Jezero na Planini pri Jezeru belong to this group. The bad condition of these lakes is indicated by the high concentration of nutrients in the water column, which support intensive growth of algae and consequently reduce the water transparency. In addition, there is a permanent deficiency or even depletion of oxygen in deeper layers of the lakes.

*Poglavje* 7 *Chapter*

# *Alge Algae*

Milijan ŠIŠKO* & Gorazd KOSI*

## UVOD

Alge naseljujejo različne ekosisteme v morskem, kopenskem in sladkovodnem okolju. Nekatere najdemo v tako skrajnih habitatih, kot so termalne vode, površina snega in podobno. Ker večinoma nastopajo kot pionirske in kozmopolitske vrste, so bile in so še predmet intenzivnih raziskav. Kot indkatorji so pomembne pri ocenjevanju ekoloških odnosov in stanja okolja. Prisotnost ali odsotnost določenih vrst in njihova številčna prisotnost opredeljujejo stopnjo obremenitve ekosistema. Za razliko od drugih rastlinskih in živalskih vrst, ki so ogrožene, alge niso, saj večinoma živijo kozmopolitsko, vendar v značilnih vodnih habitatih. Z obremenjevanjem ekosistemov povzročamo tako kakovostne kot količinske spremembe tudi v združbi alg.

Alge so v planktonu in bentosu, ki naseljujeta dva različna življenjska prostora v jezerih. Planktonsko okolje opredeljujejo lastnosti vodnega stolpca oziroma odprtega vodnega okolja, medtem ko bentoško (perifitonsko) zaznamuje izmenjava med vodo in dnom. Glede na tip dna, ki ga naseljuje, delimo perifiton v tri različne tipe. Epiliton imenujemo združbo, ki prerašča kamnito podlago litoralnega pasu, epifiton pa tisto, ki prerašča na dnu živeče rastline. Na drobnem sedimentu, kjer je svetlobe še dovolj, da lahko poteka pozitivna neto fotosinteza, pa najdemo združbo, ki jo označujemo kot epipelon.

Visokogorska jezera Julijskih Alp so zaradi svoje nadmorske višine in s tem vremenskih razmer

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## INTRODUCTION

Algae frequent different ecosystems in marine, terrestrial and freshwater environments. Some of them are found in extreme habitats such as thermal waters or the snow surface. Due to their pioneering and cosmopolitan occurrence they were, and are, the subject of intensive research. From ecological and environmental points of view, algae are a useful indicator of impacted ecosystems. Presence or absence of particular species and their quantitative representation indicate the degree of disturbance. Unlike some other plant and animal species that can be regarded as endangered, algae can not, because most of them are cosmopolitan but living in specific water habitats. Quantitative and qualitative changes occur in the community of algae in most ecosystems, which are under human influence.

Algae are present in the plankton and benthos, the two main environments in lake ecosystems. The planktonic environment is characterised by the water column, the open water of the lake, and the benthic one (periphyton) by the interface of substratum with water. The periphyton can be divided into three different habitat types depending on the origin of the substratum. Epilithon denotes associations growing on rocks in the littoral zone of the lake. Epiphyton represents associations living on other plants growing on the bottom of the lake. Associations on fine sediments at the bottom of the lake, where the light is still intensive enough to maintain positive net photosynthesis, are known as epipelon.

Because of their altitude and weather condi-

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skrajni biotop za alge v Sloveniji. Zaradi karbonatne podlage (večina evropskih visokogorskih jezer leži na kristalinični podlagi) pa so skrajni biotop tudi v evropskem merilu. Ne glede na njihovo oddaljenost že zaznavamo vpliv človekove dejavnosti. Slednja se odraža tudi v trofičnem stanju nekaterih jezer.

tions, high-mountain lakes in the Julian Alps represent an extreme biotope for algae in Slovenia. Due to their carbonate bedrock (most European high-mountain lakes lie on the crystalline bedrock) they also represent an extreme biotope in Europe. However, despite their remoteness, Man has already influenced them. This can be seen in the trophic state of some lakes.

## ZGODOVINSKI PREGLED RAZISKAV ALG V JULIJSKIH ALPAH

V preteklosti so bile združbe alg visokogorskih jezer Julijskih Alp le redko predmet raziskav. Svoja opažanja o prisotnosti alg v Jezeru na Planini pri Jezeru je 1925 objavil Pevalek, ki pa je raziskovanja usmeril v bolj v močvirne kopne habitate. Omenja nekatere vrste modrozelenih in zelenih alg, ki so tam živele.

Lazar (1960, 1969, 1975) je preučeval to in še nekatera druga jezera v Julijskih Alpah. Njegov poglavitni namen je bil oceniti floro alg Julijskih Alp kot del slovenske flore. V Jezeru na Planini pri Jezeru, Jezeru pod Vršacem, Zelenem jezeru in Dvojnem Petem jezeru je z izjemo kremenastih alg določil ostale vrste alg, ki jih je tam našel sredi prejšnjega stoletja.

## HISTORICAL OVERVIEW OF ALGAL STUDIES IN THE JULIAN ALPS

Algal communities living in high-mountain lakes of the Julian Alps were scarcely investigated until recent times. Pevalek (1925) published some data on algae from Jezero na Planini pri Jezeru. His main research was more orientated to moors and wetland habitats than to lakes. He mentioned some species of blue-green and green algae living there.

Lazar (1960, 1969, 1975) studied these and some other lakes in the Julian Alps. His main intention was to evaluate flora of the algae of the Julian Alps as a part of the Slovenian flora. Species of algae, with the exception of diatoms, were determined in the lakes Jezero na Planini pri Jezeru, Jezero pod Vršacem, Zeleno jezero and Dvojno jezero (the north basin only).

In these works some species with a classical location in the Julian Alps can be found. Three species, one blue-green alga *Holopedia dednensis* Peva-

Posnetki alg s svetlobnim mikroskopom. Tri vrste kremenastih alg – skrajno levo zgoraj: *Navicula* sp. Bory, nekoliko proti sredini: *Cymbella microcephala* Grunow, pod njima: *Amphora ovalis* Kützing, desno zgoraj: modrozelena alga *Chroococcus minutus* (Kützing) Nägeli, levo spodaj: dezmida *Staurastrum polymorphum* Brébisson, desno spodaj: zelena alga *Willea irregularis* (Wille) Schmidle slikana v faznem kontrastu (Foto: Milijan Šiško)

*Light microscope micrographs of some algae are shown. Three diatom species – upper left corner:* Navicula *sp. Bory, a little to the center:* Cymbella microcephala *Grunow, under them:* Amphora ovalis *Kützing, upper right corner: the blue-green alga* Chroococcus minutus *(Kützing) Nägeli, lower left corner: a desmid* Staurastrum polymorphum *Brébisson, lower right corner: the green alga* Willea irregularis *(Wille) Schmidle taken in phase contrast mode (Photo: Milijan Šiško)*

V teh delih najdemo nekatere vrste s klasično lokacijo v Julijskih Alpah. Pevalek je opisal tri vrste: modrozeleno algo *Holopedia dednensis* Pevalek, dezmidi *Staurastrum julicum* Pevalek in *Staurastrum pokljukense* Pevalek s Pokljuke ter dve varieteti med dezmidami *Cosmarium formosulum* Hoff. var. *poljanae* Pevalek in *Cosmarium speciosum* Lund var. *slovenicum* Pevalek, obe s Poljane pri Dednem polju.

Oba avtorja navajata večinoma alge, ki so obraščale kamenje in višje vodne rastline v priobalnem pasu ali so plavale na jezerski površini. Pevalek opisuje tudi vzorce, pobrane z vodoravnim potegom planktonske mrežice, v katerih je našel le dve vrsti. Navajata tudi alge, ki sta jih nabrala v drugih habitatih visokogorskega okolja, kot so napajalna zajetja, mlake, potoki, slapovi in mokre skale.

V okviru preglednega monitoringa dvanajstih od štirinajstih jezer Julijskih Alp, s katerim smo začeli v devetdesetih letih prejšnjega stoletja, smo vsaj enkrat letno vzorčevali tako fitoplankton kot perifiton. V prispevku Brancelj in sod. (1997) so obravnavane alge vertikalnega profila planktona s 144 vrstami in v priobalnem pasu nabranega perifitona s 190 vrstami. V Jezeru na Planini pri Jezeru in Krnskem jezeru smo opazili vodni cvet. Upadanje celotnega števila perifitonskih algnih vrst smo povezali z naraščajočo nadmorsko višino.

Leta 1993 smo začeli z delom na projektu Limnoflora in limnofavna Slovenije, v katerem smo poskusili zajeti vse objavljene podatke o organizmih, ki živijo oziroma so živeli v Triglavskem narodnem parku (Brancelj in sod., 1995).

V kratkem pregledu alg obrasti dna visokogorskih jezer v Julijskih Alpah smo opisovali razmerje med epilitskimi, epifitskimi in epipeličnimi združbami (Šiško, 2000). Visokogorska jezera Julijskih Alp smo primerjali na osnovi podatkov o vrstah alg, prisotnih v perifitonskih združbah leta 1994.

lek from Poljana pri Dednem Polju and Jezero na Planini pri Jezeru, two desmids *Staurastrum julicum* Pevalek and *Staurastrum pokljukense* Pevalek from Pokljuka and two varieties of desmids *Cosmarium formosulum* Hoff. var. *poljanae* Pevalek and *Cosmarium speciosum* Lund var. *slovenicum* Pevalek both from Poljana pri Dednem Polju were described.

Both authors listed the species found on the shore covering stones and higher plants or floating on the surface of the studied lakes. Pevalek took a horizontal net sample of phytoplankton too, but he found just two species there. They focused their attention on algal inhabitants of some other habitats like watering-ponds, pools, brooks, waterfalls and wet rocks.

As a part of a monitoring survey started in the 1990s, periphyton and phytoplankton were sampled at least once per year in twelve of fourteen lakes in the Julian Alps (Brancelj *et. al.*, 1997). Open water phytoplankton and near-shore periphyton samples were analised and 144 planktonic and 190 periphytic species were reported. Algae blooms were detected in two lakes, Krnsko jezero and Jezero na Planini pri Jezeru. A decrease in the total number of species of periphyton with increasing altitude of lakes was observed.

In 1993 a project "Limnoflora and limnofauna Sloveniae" started, with a special work-package which attempted to make a list of all published organisms found in the Triglav National Park up to 1993 (Brancelj *et al.*, 1995).

A relationship between epilithic, epiphytic and epipelic associations was described in a brief overview of periphyton associations in high-mountain lakes of the Julian Alps (Šiško, 2000). A comparison between high-mountain lakes in the Julian Alps, based on data of periphyton associations as sampled in 1994, was also presented.

## KAKOVOSTNI PREGLED FITOPLANKTONA IN PERIFITONA

V obdobju od leta 1991 do 2000 smo z namenom, da bi določili tamkajšnje alge, vzorčili planktonske (preglednica 1) in perifitonske (preglednica 2) združbe v visokogorskih jezerih Julijskih Alp (preglednica 3). Fitoplanktonske vzorce smo pobirali s 30 mikrometrsko (μm) mrežico. V priobalnem pasu smo s pol metra globoko potopljenega kamenja postrgali večino vzorcev perifitonske združbe. V dveh jezerih smo slednje združbe vzorčili tudi na globinskih prerezih od obale do dna jezera.

## QUALITATIVE DATA ON PHYTOPLANKTON AND PERIPHYTON

During the period from 1991 to 2000 phytoplankton (Table 1) and periphyton (Table 2) associations were sampled for species analysed in the high-mountain lakes of the Julian Alps (Table 3). Phytoplankton samples were taken with a 30 μm net. Periphyton communities were mostly sampled on near-shore stones at a half metre depth in all fourteen lakes. In addition to these samples, profiles of periphyton communities were taken from the shore to the bottom of two lakes.

Preglednica 1: Število vrst alg iz posameznih skupin, prisotnih v fitoplanktonskih združbah visokogorskih jezer v Julijskih Alpah (Triglavski narodni park, Slovenija) v obdobju 1991–2000
*Table 1: Number of species of algae from particular groups, present in phytoplankton communities of high-mountain lakes in the Julian Alps (Triglav National Park, Slovenia) from 1991 to 2000*

| Jezero / Lake \ Skupina / Group | Cyanophyta | Chrysophyceae | Bacillarophyceae | Pyrrophyta | Euglenophyta | Conjugatae | Chlorophyceae | Skupaj / Together |
|---|---|---|---|---|---|---|---|---|
| Jezero pod Vršakom | 15 | 1 | 9 | 2 | 0 | 5 | 8 | 40 |
| Rjavo jezero | 13 | 1 | 7 | 2 | 0 | 1 | 10 | 34 |
| Zeleno jezero | 22 | 1 | 9 | 2 | 0 | 13 | 18 | 65 |
| Jezero v Ledvicah | 10 | 1 | 2 | 1 | 0 | 2 | 11 | 27 |
| Dvojno Peto jezero | 18 | 1 | 11 | 2 | 2 | 10 | 10 | 54 |
| Dvojno Šesto jezero | 19 | 1 | 8 | 4 | 3 | 9 | 11 | 55 |
| Črno jezero | 10 | 2 | 9 | 4 | 0 | 6 | 10 | 41 |
| Krnsko jezero | 10 | 3 | 6 | 3 | 3 | 12 | 16 | 53 |
| Dupeljsko jezero | 15 | 1 | 11 | 3 | 0 | 14 | 18 | 62 |
| Jezero na Planini pri Jezeru | 8 | 0 | 8 | 4 | 4 | 9 | 15 | 48 |
| Jezero v Lužnici | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 4 |
| Zgornje Kriško jezero | 2 | 0 | 0 | 0 | 0 | 2 | 3 | 7 |
| Srednje Kriško jezero | 1 | 0 | 0 | 0 | 1 | 1 | 7 | 10 |
| Spodnje Kriško jezero | 2 | 0 | 0 | 0 | 0 | 2 | 5 | 9 |

Preglednica 2: Število vrst alg iz posameznih skupin, prisotnih v perifitonskih združbah visokogorskih jezer v Julijskih Alpah (Triglavski narodni park, Slovenija) v obdobju 1991–2000
*Table 2: Number of species of algae from particular groups, present in periphyton communities of high-mountain lakes in the Julian Alps (Triglav National Park, Slovenia) from 1991 to 2000*

| Jezero / Lake \ Skupina / Group | Cyanophyta | Bacillarophyceae | Pyrrophyta | Euglenophyta | Conjugatae | Chlorophyceae | Rhodophyta | Skupaj / Together |
|---|---|---|---|---|---|---|---|---|
| Jezero pod Vršakom | 11 | 36 | 0 | 0 | 2 | 0 | 0 | 49 |
| Rjavo jezero | 20 | 32 | 0 | 0 | 2 | 2 | 0 | 56 |
| Zeleno jezero | 25 | 56 | 0 | 0 | 13 | 4 | 0 | 98 |
| Jezero v Ledvicah | 23 | 36 | 0 | 1 | 3 | 4 | 0 | 67 |
| Dvojno Peto jezero | 19 | 45 | 0 | 0 | 4 | 1 | 0 | 69 |
| Dvojno Šesto jezero | 23 | 45 | 1 | 0 | 3 | 1 | 0 | 73 |
| Črno jezero | 19 | 57 | 0 | 0 | 4 | 3 | 0 | 83 |
| Krnsko jezero | 29 | 31 | 0 | 1 | 18 | 10 | 0 | 89 |
| Dupeljsko jezero | 22 | 51 | 0 | 0 | 18 | 17 | 0 | 108 |
| Jezero na Planini pri Jezeru | 11 | 52 | 1 | 2 | 14 | 7 | 1 | 88 |
| Jezero v Lužnici | 0 | 42 | 0 | 0 | 0 | 0 | 0 | 42 |
| Zgornje Kriško jezero | 12 | 30 | 0 | 0 | 4 | 3 | 0 | 49 |
| Srednje Kriško jezero | 9 | 30 | 0 | 0 | 2 | 2 | 0 | 43 |
| Spodnje Kriško jezero | 16 | 33 | 1 | 0 | 10 | 4 | 0 | 64 |

V septembru 1991 smo prvič vzorčevali fitoplankton v devetih jezerih. S Secchijevo ploščo smo merili prosojnost vodnega stolpca (glej poglavje 6). Jezero na Planini pri Jezeru je bilo prosojno do globine 2 m, Krnsko jezero pa do 4,5 m. Ostala jezera, z izjemo Jezera pod Vršacem, ki je bilo še pod ledom, so bila prosojna do dna. V vzorcih iz teh jezer smo našli 90 planktonskih vrst alg, med katerimi smo 27 vrst določili kot Cyanophyta, 21 kot Chrysophyta, 4 kot Pyrrophyta, 1 kot Euglenophyta in 37 kot Chlorophyta. V večini jezer je bila pogostost

In September 1991 phytoplankton samples were taken for the first time in the nine lakes. By means of Secchi disk we measured transparency of the water column (see Chapter 6). In Jezero na Planini pri Jezeru the Secchi disk depth was 2 m and in Krnsko jezero 4.5 m. In the other seven lakes the water was transparent to the bottom with the exception of Jezero pod Vršacem still covered with ice. In samples from these lakes 90 planktonic species were found, of which 27 species belonged to Cyanophyta, 21 to Chrysophyta, 4 to Pyrrophyta, 1

| Leto / Year | Združba / Community \ Jezero / Lake | Jezero pod Vršakom | Rjavo jezero | Zeleno jezero | Jezero v Ledvicah | Dvojno Peto jezero | Dvojno Šesto jezero | Črno jezero | Krnsko jezero | Dupeljsko jezero | Jezero na Planini pri Jezeru | Jezero v Lužnici | Zgornje Kriško jezero | Srednje Kriško jezero | Spodnje Kriško jezero |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1991 | plankton | X | X | X | X | X | X | X | X | | X | | | | |
| | periphyton | | X | X | X | X | X | X | X | X | X | | | | |
| Jul. 1992 | plankton | | X | X | X | X | X | X | X | X | X | | | | |
| | periphyton | X | X | X | X | X | X | X | X | X | X | X | | | |
| Sep. 1992 | plankton | X | X | X | X | X | X | X | X | X | X | | X | X | X |
| | periphyton | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 1993 | plankton | X | X | X | X | X | X | X | X | X | X | | | | |
| | periphyton | X | X | X | X | X | X | X | X | X | X | | X | X | X |
| 1994 | plankton | | | | | | | | | | | | | | |
| | periphyton | X | X | X | X | X | X | X | X | X | X | | X | X | X |
| 1996 | plankton | | | | | | | | | | | | | | |
| | periphyton | X | | X | X | X | X | X | X | X | X | X | X | X | X |
| 1997 | plankton | | | | | | | | | | | | | | |
| | periphyton | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 1998 | plankton | | | | | | | | | | | | | | |
| | periphyton | X | | | X | | | | X | X | X | X | | | X |
| 1999 | plankton | | | | | | | | | | | | | | |
| | periphyton | X | X | X | X | X | X | X | X | | X | X | X | X | X |
| 2000 | plankton | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| | periphyton | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

Preglednica 3: Visokogorska jezera v Julijskih Alpah (Triglavski narodni park, Slovenija) v katerih smo vzorčili fitoplanktonske oziroma perifitonske združbe v obdobju 1991–2000
*Table 3: High-mountain lakes in the Julian Alps (Triglav National Park, Slovenia) sampled for phytoplankton and periphyton communities from 1991 to 2000*

vrst ocenjena kot redke. V planktonu iz Jezera na Planini pri Jezeru je bila dezmida vrste *Staurastrum cuspidatum* Brébisson ocenjena kot zelo pogosta, modrozelena alga vrste *Microcystis pulverea* (Wood) Forti, kremenasti algi *Nitzschia acicularis* W. Smith in *Fragilaria ulna* v. *ulna* (Nitzsch) Lange – Bertalot pa kot pogoste. Modrozeleno algo vrste *Pseudanabaena constricta* Lauterb., rumeno algo *Dinobryon acuminatum* Ruttner ter kremenasti algi *Stephanodiscus dubius* (Fricke) Hustedt in *Fragilaria ulna* v. *acus* (Kützing) Lange – Bertalot smo ovrednotili kot pogoste v planktonu Krnskega jezera. Obe jezeri smo ocenili kot evtrofni.

Pri vrstni analizi perifitonskih združb iz istih jezerih smo v tem obdobju določili 121 vrst, med katerimi je bilo 36 vrst določenih kot Cyanophyta, 41 kot Chrysophyta, 1 kot Pyrrophyta, 3 kot Euglenophyta in 40 kot Chlorophyta. V vzorcih iz Dvojnega Šestega jezera in iz Krnskega jezera so bile vse vrste ocenjene kot redke. Tudi v vzorcih iz drugih jezer so bile posamezne vrste redke, nekaj vrst pa je bilo ocenjenih kot pogoste.

V letu 1992 smo opravili dve vzorčenji, prvo v

to Euglenophyta and 37 to Chlorophyta. In most of the lakes the species were rare. A desmid species *Staurastrum cuspidatum* Brébisson was prevalent, while the blue-green alga *Microcystis pulverea* (Wood) Forti and two diatoms *Nitzschia acicularis* W. Smith and *Fragilaria ulna* v. *ulna* (Nitzsch) Lange – Bertalot were denoted as common in Jezero na Planini pri Jezeru. One blue-green alga *Pseudanabaena constricta* Lauterb., one chrysophycea *Dinobryon acuminatum* Ruttner and two diatoms *Stephanodiscus dubius* (Fricke) Hustedt and *Fragilaria ulna* v. *acus* (Kützing) Lange – Bertalot were evaluated as common in Krnsko jezero. Both lakes were recognised as eutrophic.

Samples of near-shore periphyton community were also taken for species analysis from the same lakes. There were 121 species present, with 36 identified as Cyanophyta, 41 as Chrysophyta, 1 as Pyrrophyta, 3 as Euglenophyta and 40 as Chlorophyta. In Dvojno jezero (the south basin) and Krnsko jezero all species present were evaluated as rare. Even in other lakes species were not abundant, but some of them were denoted as common.

In 1992 there were two surveys, one in July and juliju in drugo v septembru. Za analizo fitoplanktonskih združb smo julija vzorčili v devetih jezerih. Vsa jezera so bila prosojna do dna, le Jezero na Planini pri Jezeru je bilo prosojno do globine 2 m in Krnsko jezero do globine 3,5 m. V vzorcih smo določili 56 vrst planktonskih alg, od tega 24 kot Cyanophyta, 4 kot Chrysophyta, 2 kot Pyrrophyta, 2 kot Euglenophyta in 24 kot Chlorophyta. Kot zelo pogoste so bile ocenjene sledeče vrste alg: v Črnem jezeru rumena alga *Dinobryon divergens* Imhof in zelena alga *Planctosphaeria gelatinosa* G. M. Smith, v Krnskem: rumena alga *Dinobryon divergens* Imhof in kremenasta alga *Fragilaria ulna* v. *acus* (Kützing) Lange – Bertalot, v Jezeru na Planini pri Jezeru modrozelena alga *Microcystis pulverea* (Wood) Forti in kremenasta alga *Fragilaria ulna* v. *acus* (Kützing) Lange – Bertalot. Nekatere vrste smo v planktonu vseh jezer ocenili kot pogoste, le v planktonu Rjavega jezera smo vse vrste ovrednotili kot redke.

V junijskih vzorcih smo v priobalnih perifitonskih združbah enajstih jezer določili 92 vrst. Med njimi je bilo 28 vrst prepoznanih kot Cyanophyta, 36 kot Chrysophyta, 1 kot Euglenophyta, 26 kot Chlorophyta in 1 kot Rhodophyta. Vse vrste v Jezeru pod Vršacem in Dvojnem Šestem jezeru smo ovrednotili kot redke. V ostalih jezerih smo nekaj vrst ocenili kot pogoste. Le v Dupeljskem jezeru je bila nedoločena vrsta iz rodu zelenih alg *Zygnema* Agardh ovrednotena kot zelo pogosta.

V septembru istega leta smo vzorčili planktonske združbe trinajstih jezer. Nekatera so bila prosojna do dna, le Krnsko jezero do globine 5 m, Jezero na Planini pri Jezeru do globine 2,2 m in Dvojno Šesto jezero do globine 3,5 m. V vzorcih smo določili 77 planktonskih vrst, od tega 31 kot Cyanophyta, 7 kot Chrysophyta, 2 kot Pyrrophyta, 1 kot Euglenophyta in 36 kot Chlorophyta. Kot zelo pogosti smo ocenili zeleni algi *Planctosphaeria gelatinosa* G. M. Smith in nedoločeno vrsto rodu *Spirogyra* Link iz Jezera pod Vršakom, nedoločeni vrsti zelenih alg rodov *Spirogyra* Link in *Zygnema* Agardh iz Črnega jezera, modrozeleno algo *Microcystis pulverea* (Wood) Forti in kremenasto algo *Fragilaria ulna* v. *acus* (Kützing) Lange – Bertalot iz Jezera na Planini pri Jezeru ter modrozeleno algo *Chroococcus minutus* (Kützing) Nägeli iz Spodnjega Kriškega jezera. V treh jezerih, Rjavo jezero, Jezero v Ledvicah in Zgornje Kriško jezero, smo vse vrste ovrednotili kot redke, v ostalih pa nekatere kot pogoste.

V septembru smo v perifitonskih združbah v vseh štirinajstih jezerih določili 105 vrst alg. Med njimi je bilo 34 vrst določenih kot Cyanophyta, 44 kot Chrysophyta, 1 kot Pyrrophyta, 1 kot Euglenop-

one in September. In summer nine lakes were sampled for phytoplankton analysis. All the lakes were transparent to the bottom with the exception of Jezero na Planini pri Jezeru with 2 m and Krnsko jezero with a 3.5 m Secchi disk depth. 56 planktonic species were determined, with 24 identified as Cyanophyta, 4 as Chrysophyta, 2 as Pyrrophyta, 2 as Euglenophyta and 24 as Chlorophyta. In Črno jezero a chrysophycea *Dinobryon divergens* Imhof and green alga *Planctosphaeria gelatinosa* G. M. Smith, in Krnsko jezero a chrysophycea *Dinobryon divergens* Imhof and a diatom *Fragilaria ulna* v. *acus* (Kützing) Lange – Bertalot and in Jezero na Planini pri Jezeru a blue-green alga *Microcystis pulverea* (Wood) Forti and a diatom *Fragilaria ulna* v. *acus* (Kützing) Lange – Bertalot were abundant. The abundance of some of other species was evaluated as common in all the lakes sampled except Rjavo jezero.

In the same sampling period 92 species were determined in the near-shore periphyon samples of 11 lakes. 28 of them belonged to Cyanophyta, 36 to Chrysophyta, 1 to Euglenophyta, 26 to Chlorophyta and 1 to Rhodophyta. All species present in Jezero pod Vršacem and Dvojno jezero (south basin) were denoted as rare. In other lakes some species were evaluated as common. Only one undetermined species of green algae genus *Zygnema* Agardh in Dupeljsko jezero was abundant.

In autumn the phytoplankton communities were sampled in thirteen lakes. Not all lakes were transparent to the bottom. Krnsko jezero had a Secchi disk depth of 5 m, Jezero na Planini pri Jezeru of 2.2 m, and Dvojno jezero (south basin) of 3.5 m. 77 planktonic species were found there, with 31 species identified as Cyanophyta, 7 as Chrysophyta, 2 as Pyrrophyta, 1 as Euglenophyta and 36 as Chlorophyta. In Jezero pod Vršakom one green alga *Planctosphaeria gelatinosa* G. M. Smith and one unidentified species of green algae genus *Spirogyra* Link, in Črno jezero two unidentified species of the green algae genera *Spirogyra* Link and *Zygnema* Agardh, in Jezero na Planini pri Jezeru one blue-green alga *Microcystis pulverea* (Wood) Forti and one diatom *Fragilaria ulna* v. *acus* (Kützing) Lange – Bertalot and in Spodnje Kriško jezero one blue-green alga *Chroococcus minutus* (Kützing) Nägeli, were abundant. In most lakes sampled the abundance of some of other species were evaluated as common. In three lakes, Rjavo jezero, Jezero v Ledvicah and Zgornje Kriško jezero, all species were evaluated as rare.

The periphyton communities of fourteen lakes were sampled during the same period and 105 species were found. 34 were determined as Cyanophyhyta in 25 kot Chlorophyta. Le v Srednjem Kriškem jezeru smo ocenili vse vrste kot redke. V ostalih jezerih smo nekatere vrste ocenili kot pogoste, v Zelenem jezeru in v Dupeljskem jezeru pa nedoločeno vrsto zelenih alg iz rodu *Spirogyra* Link kot zelo pogosto.

Septembra 1993 smo vzorčili fitoplanktonske združbe v desetih jezerih in določili le njihovo kvalitativno zgradbo. Nekatera jezera so bila prosojna do dna, Jezero pod Vršakom do globine 3,8 m, Dvojno Peto jezero do 6 m, Dvojno Šesto jezero do 4 m, Jezero na Planini pri Jezeru do 1,5 m in Krnsko jezero do globine 3,5 m. V fitoplanktonskih vzorcih smo določili 96 vrst alg, med katerimi je bilo 25 vrst določenih kot Cyanophyta, 19 kot Chrysophyta, 5 kot Pyrrophyta, 5 kot Euglenophyta in 42 kot Chlorophyta.

V istem obdobju smo vzorčili tudi perifitonske združbe v trinajstih jezerih. V vzorcih smo določili 48 vrst kremenastih alg. Ostalih skupin nismo določali. V Zelenem jezeru, Jezeru v Ledvicah, Dvojnem Petem jezeru, Dupeljskem jezeru in Jezeru na Planini pri Jezeru smo nekatere vrste ocenili kot pogoste, druge vrste pa tako kot vse vrste v ostalih jezerih kot redke.

V letu 1994 smo nabrali vzorce priobalnih perifitonskih združb v trinajstih jezerih. V njih smo prepoznali 131 vrst alg. Med njimi je bilo 41 vrst iz skupine Cyanophyta, 49 iz skupine Chrysophyta, 1 iz skupine Pyrrophyta, 2 iz skupine Euglenophyta in 38 iz skupine Chlorophyta. Nobena vrsta ni bila ovrdnotena kot zelo pogosta. V Jezeru na Planini pri Jezeru so bile vse vrste ocenjene kot redke.

V obdobju od 1996 do 1999 smo vzorčevali le perifitonske združbe in določili le kremenaste alge. Leta 1996 smo nabrali vzorce v vseh jezerih, razen v Rjavem jezeru, in določili 75 vrst kremenastih alg. 1997 smo vzorčili vsa jezera in našli 72 vrst kremenastih alg. V letu 1998 smo nabrali vzorce le v sedemih jezerih in v njih ugotovili 56 vrst kremenastih alg. Vsa, razen Dupeljskega jezera, smo vzorčili v letu 1999 in v njih prepoznali 67 vrst kremenastih alg.

Konec avgusta in začetek septembra 2000 smo vzorčili fitoplanktonske združbe v vseh štirinajstih jezerih. Večina jezer je bila prosojna do dna, le Jezero na Planini pri Jezeru do globine 1,1 m in Krnsko jezero do globine 2,5 m. V fitoplanktonskih vzorcih smo našli 53 vrst alg, 10 iz skupine Cyanophyta, 9 iz skupine Chrysophyta, 1 iz skupine Pyrrophyta, 2 iz skupine Euglenophyta in 31 iz skupine Chlorophyta. Zeleno algo *Planctosphaeria gelatinosa* G. M. Smith iz Krnskega jezera, dve nedoločeni vrsti med

ta, 44 as Chrysophyta, 1 as Pyrrophyta, 1 as Euglenophyta and 25 as Chlorophyta. Only in Srednje Kriško jezero were all species rare. In all other lakes some species were denoted as common and one unknown species of green algae genus *Spirogyra* Link was abundant in Zeleno jezero and Dupeljsko jezero.

In September 1993 phytoplankton samples were collected in ten lakes and analysed only for qualitative data. Some lakes were transparent to the bottom. Jezero pod Vršakom had a 3.8 m Secchi disk depth, Dvojno jezero in the north basin 6 m and in the south basin 4 m, Jezero na Planini pri Jezeru 1.5 m and Krnsko jezero 3.5 m. 96 species were found in the phytoplankton samples, 25 were identified as Cyanophyta, 19 as Chrysophyta, 5 as Pyrrophyta, 5 as Euglenophyta and 42 as Chlorophyta.

In the same period thirteen lakes with the exception of Jezero v Lužnici were sampled for periphyton community analysis. Only diatoms were determined and 48 species were recognised. In Zeleno jezero, Jezero v Ledvicah, Dvojno jezero (north basin), Dupeljsko jezero and Jezero na Planini pri Jezeru some species were evaluated as common. Other species were denoted as rare as were all species of diatoms in all other lakes.

In 1994 thirteen lakes were sampled for periphyton community analysis. 131 species were determined, 41 as Cyanophyta, 49 as Chrysophyta, 1 as Pyrrophyta, 2 as Euglenophyta and 38 as Chlorophyta. There were no species evaluated as abundant. In Jezero na Planini pri Jezeru all present species were denoted as rare.

In the period from 1996 to 1999 only periphyton samples were collected and only diatom species were determined. In 1996, Rjavo jezero was not sampled. 75 diatom species were recognised in the sampled lakes. In 1997, all lakes were sampled and 72 diatom species were found. In 1998, just seven lakes were sampled and 56 diatom species were determined. With the exception of Dupeljsko jezero, all the lakes ware sampled in 1999 and 67 diatom species were identified.

All fourteen lakes were sampled for phytoplankton analysis at the end of August and beginning of September 2000. Most of these lakes were transparent to the bottom and only Jezero na Planini pri Jezeru had a Secchi disk depth of 1.1 m and Krnsko jezero of 2.5 m. 53 planktonic species were found in these lakes, with 10 species recognised as Cyanophyta, 9 as Chrysophyta, 1 as Pyrrophyta, 2 as Euglenophyta and 31 as Chlorophyta. A green alga *Planctosphaeria gelatinosa* G. M. Smith in Krnsko jezero, two unidentified species of green algae genera *Mougeo-*

zelenimi algami iz rodov *Mougeotia* sp. Agardh in *Spirogyra* sp. Link in zeleno algo *Scenedesmus ecornis* (Balfs) Chodat iz Dupeljskega jezera, modrozeleno algo *Microcystis pulverea* (Wood) Forti iz Jezera na Planini pri Jezeru, nedoločeno zeleno algo iz rodu *Chlamydomonas* sp. Ehrenberg iz Srednjega Kriškega jezera in zeleno algo *Willea irregularis* (Wille) Schmidle iz Spodnjega Kriškega jezera smo ocenili kot pogoste. V istem letu smo v vseh jezerih poleg fitoplanktonskih združb vzorčili tudi priobalne perifitonske združbe. V vzorcih smo določili le kremenaste alge in prepoznali 41 vrst.

*tia sp.* Agardh and *Spirogyra sp.* Link and another green alga *Scenedesmus ecornis* (Balfs) Chodat in Dupeljsko jezero, a blue-green alga *Microcystis pulverea* (Wood) Forti in Jezero na Planini pri Jezeru, an unidentified green alga of the genus *Chlamydomonas sp.* Ehrenberg in Srednje Kriško jezero and a green alga *Willea irregularis* (Wille) Schmidle in Spodnje Kriško jezero were denoted as common.

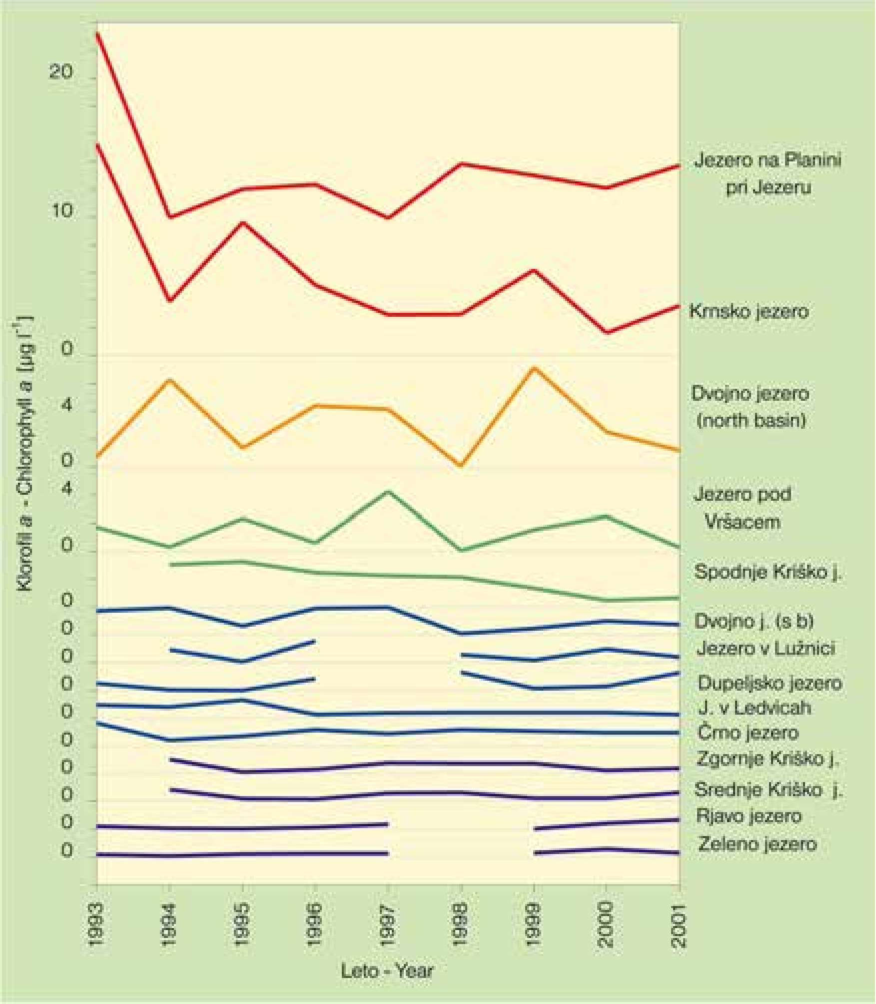
In addition to phytoplankton all lakes were sampled for periphyton analysis during this year. Only diatoms were determined and there were 71 species found.

## KOLIČINSKE MERITVE FITOPLANKTONSKIH ZDRUŽB

Da bi lahko ocenili množino fitoplanktonske združbe, smo precedili skozi 1 µm filter točno določeno količino vode in kasneje s pomočjo spektrofotometra izmerili koncentracijo klorofila *a*.

## QUANTITATIVE DATA ON PHYTOPLANKTON

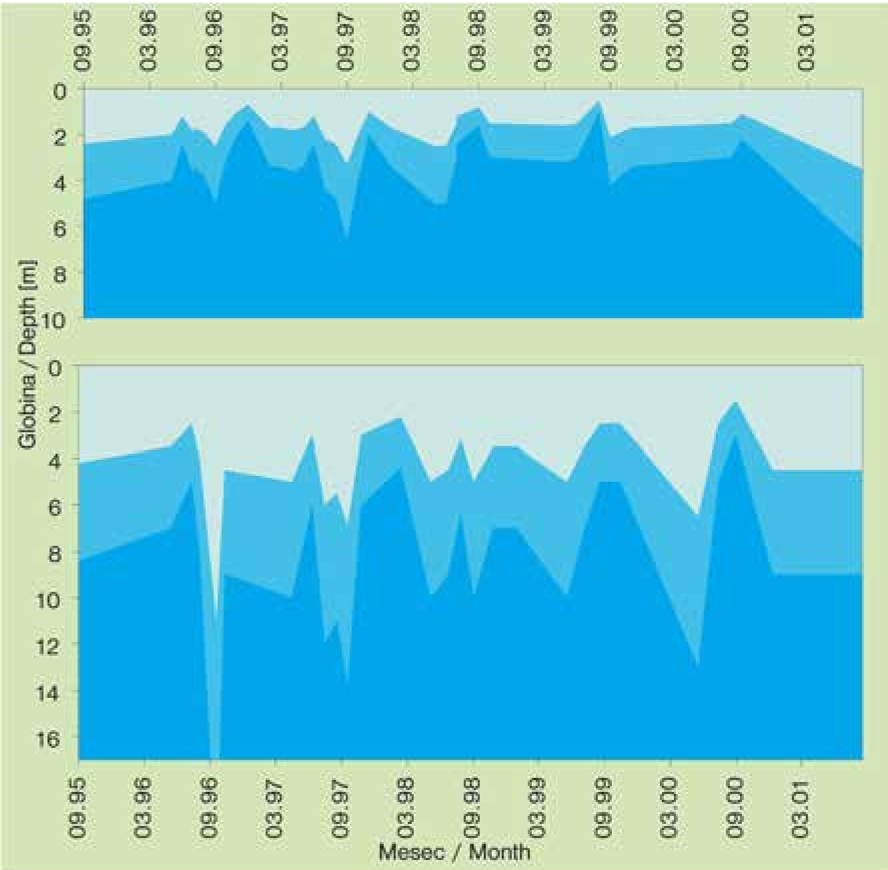
For quantitative analysis a known volume of water was filtered through a 1 µm pore filter and afterwards chlorophyll *a* concentrations were measured by means of a spectrophotometer.




Slika 1: Dinamika jesenskih koncentracij klorofila *a*, izračunanih iz koncentracij v vodnem stolpcu, na celotni volumen posameznih visokogorskih jezer v Julijskih Alpah (Slovenija) v obdobju 1993–2000 (pikasta črta predstavlja 0 µg chl *a* $l^{-1}$).
*Figure 1: Dynamics of autumn concentrations of chlorophyll a calculated from water column profile to whole volume of particular lake of the Julian Alps (Slovenia) during the period 1993 to 2000 (dashed line represents 0 µg chl a* $l^{-1}$*).*

V obdobju od 1993 do 2001 smo na različnih globinah v vodnem stolpcu vseh štirinajstih jezer v Julijskih Alpah izmerili vsebnost klorofila *a*. Te koncentracije smo s pomočjo modela, ki smo ga glede na prostornine posameznih plasti priredili za vsako jezero posebej, preračunali na volumen celotnega jezera. Dinamika povprečnih jesenskih koncentracij klorofila *a* je prikazana na sliki 1. V štirih jezerih, Zeleno jezero, Rjavo jezero, Srednje Kriško jezero in Zgornje Kriško jezero, so se koncentracije klorofila *a* gibale med mejno vrednostjo zaznave uporabljene metode in 1 µg $l^{-1}$ (mikrogram na liter) jezerske vode. Po OECD-jevi razporeditvi jezer glede na povprečne koncentracije klorofila *a* (Harper, 1992) ta jezera lahko uvrstimo med ultraoligotrofna. V naslednjih treh jezerih, Jezero v Ledvicah, Dupeljsko jezero in Jezero v Lužnici, koncentracije klorofila *a* niso presegale 1,5 µg $l^{-1}$ jezerske vode, v Črnem jezeru in Dvojnem Šestem jezeru pa ne več kot 2 µg $l^{-1}$. S stališča vsebnosti klorofila *a* lahko zadnjih pet jezer uvrstimo med oligotrofna, a moramo pri tem upoštevati, da v nekaterih jezerih temelji primarna produkcija na makrofitih. Koncentracija klorofila *a* v Spodnjem Kriškem jezeru je od 1995 s

During the period 1993 to 2001 phytoplankton was quantitatively evaluated by measuring concentrations of chlorophyll *a* in the water column of all fourteen lakes from the Julian Alps. The water column concentrations were recalculated to the whole lake volume using a lake-specific model with the volume of layers at different depths to obtain an average chlorophyll *a* concentration for each lake. The dynamics of autumn chlorophyll *a* concentrations for all lakes are illustrated in Figure 1. Concentrations of chlorophyll *a* in the four lakes, Zeleno jezero, Rjavo jezero, Srednje Kriško jezero and Zgornje Kriško jezero oscillate between the limit of detection and 1 µg $l^{-1}$ of lake water. Following the OECD classification on the basis of chlorophyll *a* concentrations (Harper, 1992) these lakes could be classified as ultraoligotrophic. In the other three lakes, Jezero v Ledvicah, Dupeljsko jezero and Jezero v Lužnici, concentrations do not exceed 1.5 µg $l^{-1}$ of lake water and in Črno jezero and Dvojno jezero (south basin) are less than 2 µg $l^{-1}$ of chlorophyll *a*. From the point of view of chlorophyll *a* conditions the last five lakes can be denoted as oligotrophic, but it must be considered that in some




Slika 2: Prosojnost v Jezeru na Planini pri Jezeru (zgoraj), Krnskem jezeru (spodaj) v obdobju 1996–2001 (svetlo modro – globina Secchijevaga diska, temno modra – kompenzacijska točka fotosinteze, izražena kot dvojna globina Secchijevega diska; Triglavski narodni park, Slovenija)

*Figure 2: Transparency in the lakes Jezero na Planini pri Jezeru (top) and Krnsko jezero (bottom) during the period 1996 to 2001 (light cyan – Secchi disk depth, cyan – photosynthetic compensation point expressed as double Secchi disk depth; Triglav National park, Slovenia).*

3,3 μg l$^{-1}$ do 2001 leta z 0,7 μg l$^{-1}$ nenehno upadala. Produktivnost jezera upada in se približuje oligotrofnemu stanju. V Jezeru pod Vršacem in Dvojnem Petem jezeru opažamo večja nihanja v koncentraciji klorofila *a*, ki dosegajo 4,2 oziroma 7,2 μg l$^{-1}$. Ti jezeri uvrščamo med mezotrofna. Koncentracije klorofila *a* v Dvojnem Petem jezeru občasno dosegajo tiste, ki predstavljajo mejo evtrofnega stanja (8 μg l$^{-1}$). Še večje spremembe v koncentracijah klorofila *a* pa smo izmerili v Krnskem jezeru (do 15 μg l$^{-1}$) in v Jezeru na Planini pri Jezeru (do 23 μg l$^{-1}$). Obe jezeri uvrščamo med evtrofna jezera, Jezero na Planini pri Jezeru pa je blizu vrednosti, značilnih za hipereutrofna jezera (25 μg l$^{-1}$).

S prosojnostjo jezerske vode, ocenjene s pomočjo Secchijeve plošče, prav tako posredno prikazujemo produktivnost jezer. Približno dvojna globina Secchijeve plošče predstavlja fotosintetsko kompenzacijsko točko, to je globino, do katere imajo fitoplanktonske alge večjo fotosintetsko proizvodnjo, kot je poraba pri dihanju. Med jesenskimi vzorčenji izmerjene globine Secchijeve plošče so podane v preglednici 4. Večina jezer je bila prosojna do dna. V tem obdobju je bilo nekaj nihanj v prosojnosti vode v Dvojnem Petem in Dvojnem Šestem jezeru. V Spodnjem Kriškem jezeru pa so se svetlobne razmere v zadnjem obdobju izboljšale.

Sezonska dinamika prosojnosti obeh evtrofnih jezer, Jezera na Planini pri Jezeru in Krnskega jeze-

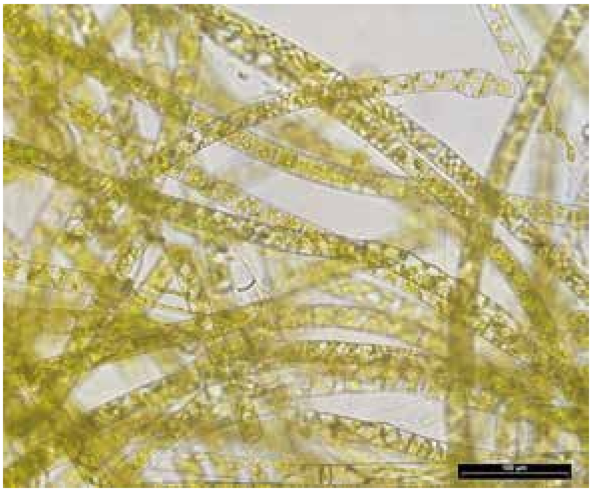
lakes the main primary production is from macrophytes. The concentrations of chlorophyll *a* in Spodnje Kriško jezero decreased steadily from 3.3 μg l$^{-1}$ in 1995 to 0.7 μg l$^{-1}$ in 2001. The productivity of the lake is diminishing and from the point of view of chlorophyll *a* conditions the lake is changing to an oligotrophic state. Jezero pod Vršacem and Dvojno jezero (the north basin) demonstrate bigger changes in chlorophyll *a* concentrations, reaching 4.2 and 7.2 μg l$^{-1}$ respectively. They can be classified as mesotrophic. Dvojno jezero (the north basin) was near the boundary of eutrophic lakes (8 μg l$^{-1}$). Even bigger changes can be observed in Krnsko jezero (to 15 μg l$^{-1}$) and Jezero na Planini pri Jezeru (to 23 μg l$^{-1}$). Both are eutrophic lakes. Jezero na Planini pri Jezeru is approaching 25 μg l$^{-1}$, which is a lower limit for hypereutrophic lakes.

The transparency of lake water measured with a Secchi disk is another measure describing lake productivity. Approximately double the Secchi disk depth represents the photosynthetic compensation point, the depth up to which algae living in the water column have a greater photosynthetic production then respiration consumption. Secchi disk depths measured in the lakes during the autumn surveys for the period 1991 to 2001 are presented in Table 4. Most of the lakes had transparent water right to the bottom. There have been some oscillations in transparency in both basins of the Dvojno jezero.

| Lake / Jezero \ Leto / Year | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jezero pod Vršacem | | B | 3.8 | B | B | B | 3.3 | B | B | B | B |
| Rjavo jezero | B | B | B | B | B | B | B | | B | B | B |
| Zeleno jezero | B | B | B | B | B | B | B | | B | B | B |
| Jezero v Ledvici | B | B | B | B | B | B | B | B | B | B | B |
| Dvojno Peto jezero | 3.0 | B | 6.0 | 4.0 | B | 4.5 | 6.5 | B | 6.5 | B | B |
| Dvojno Šesto jezero | B | 3.5 | 4.0 | 3.5 | B | 5.0 | 4.0 | B | 4.0 | B | B |
| Črno jezero | B | B | B | B | B | B | B | | B | B | B |
| Jezero na Planini pri Jezeru | 2.0 | 2.2 | 1.5 | 2.5 | 2.4 | 2.5 | 3.3 | 0.8 | 2.1 | 1.1 | 3.5 |
| Krnsko jezero | 4.5 | 5.0 | 3.5 | 4.5 | 4.2 | 4.0 | 6.9 | 5.0 | 2.5 | 1.5 | 4.5 |
| Dupeljsko jezero | B | B | B | B | B | B | B | B | B | B | B |
| Jezero v Lužnici | | B | | B | B | B | B | B | B | B | B |
| Zgornje Kriško jezero | | | | B | B | B | B | B | B | B | B |
| Srednje Kriško jezero | | | | B | B | B | B | B | B | B | B |
| Spodnje Kriško jezero | | | | 6.0 | B | 7.5 | 6.8 | 6.0 | B | B | B |

Preglednica 4: Prosojnost, izmerjena s Secchijevim diskom [m] med jesenskimi vzorčevanji v visokogorskih jezerih Julijskih Alp (Slovenija), v obdobju 1991–2001 (B – prosojno do dna, prazno – ni bilo izmerjeno).

*Table 4: Transparency measured with Secchi disk [m] in autumn samplings in the lakes in the Julian Alps (Slovenia) during the period 1991 to 2001 (B – transparent to bottom, empty – not measured).*



Preplet nitk jarmovke *Spirogyra* sp. Link, slikane s svetlobnim mikroskopom (Foto: Milijan Šiško)
*Light microscope micrographs of filamentous green alga* Spirogyra *sp. Link (Photo: Milijan Šiško)*

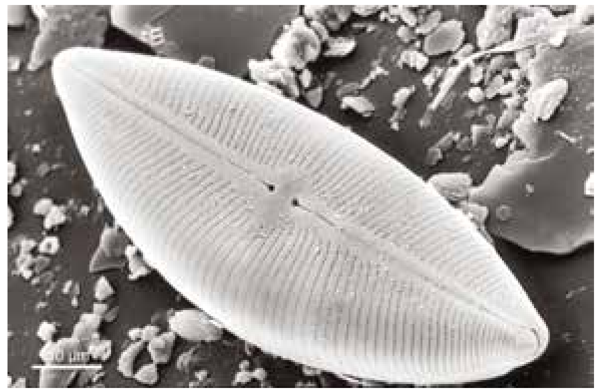
ra, v obdobju od 1996 do 2001 je prikazana na sliki 2. V Jezeru na Planini pri Jezeru je bila prosojnost vodnega stolpca tako majhna, da je bila več kot polovica vodnega stolpca skoraj vedno pretemna za pozitivno neto fotosintezo. Vodni stolpec v Krnskem jezeru je bil nekoliko prosojnejši.

## RAZMERJE MED ALGNIMI ZDRUŽBAMI IN OKOLJSKIMI DEJAVNIKI

Nekateri okoljski dejavniki kažejo močan vpliv na algne združbe. Poleg svetlobe so najpomembnejša hraniva. Med primernejšimi metodami, ki opisujejo razmerje med združbo in okoljskimi dejavniki, je tudi kanonična korespondenčna analiza (ter Braak in Verdonscot, 1995). Razporeditev vrst okoli dveh glavnih razporeditvenih osi kanonične korespondenčne analize smo primerjali s tremi glavnimi hranili: celokupnim fosforjem, nitratom in silicijevim dioksidom. Njihove koncentracije so bile merjene sočasno s fitoplanktonskimi združbami (slika 3). Le zelo pogoste in nekatere pogoste vrste so skupaj z jezeri označene na razporeditvenem grafu (glej legendo). Hraniva so ponazorjena z vektorji v sorazmerju z razporeditvenimi osmi. Pravokotna projekcija posamezne vrste na izbran okoljski vektor opisuje njeno odvisnost od izbranega okoljskega faktorja. Na primer: dezmida *Staurastrum cuspidatum* Brébisson, modrozelena alga *Microcystis pulverea* (Wood) Forti, zelo pogosti v Jezeru na Planini

The situation in Spodnje Kriško jezero improved during this period.

The transparency of two eutrophic lakes, Jezero na Planini pri Jezeru and Krnsko jezero, with seasonal changes during the period 1996 to 2001 is presented in Figure 2. The transparency in Jezero na Planini pri Jezeru was so low that more then half of the water column was almost always too dark for positive net photosynthesis. In Krnsko jezero the situation was somewhat better.

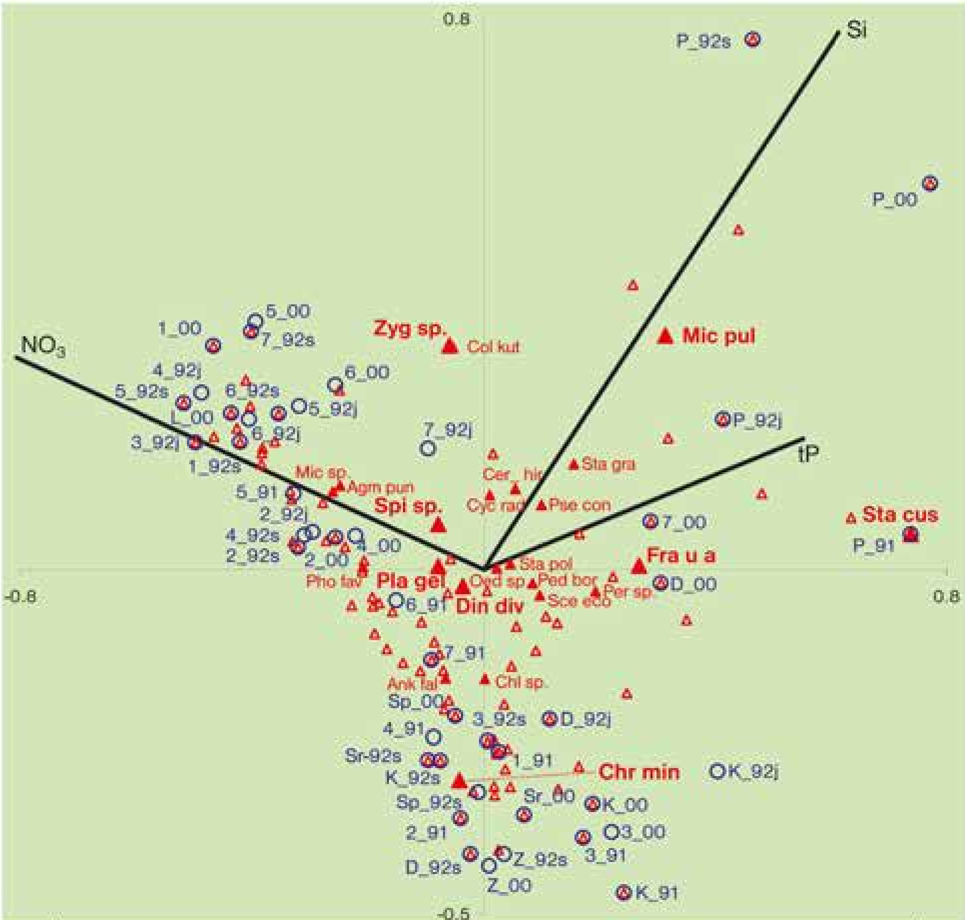


Kremenasta alga *Cymbella ehrenbergii* Kützing, posneta z vrstičnim elektronskim mikroskopom (Foto: Kazimir Drašlar)
*Scaning electron microscope micrograph of a diatom* Cymbella ehrenbergii *Kützing (Photo: Kazimir Drašlar)*

## RELATIONS BETWEEN ALGAE COMMUNITIES AND ENVIRONMENTAL PARAMETERS

Some environmental parameters are very important in determining algal communities. Apart from light, the most important are nutrient concentrations. One of most suitable methods to describe the relation between community and environment parameters is canonical correspondence analysis (ter Braak & Verdonscot, 1995).

Ordination of species composition around two main axes by canonical correspondence analysis was related to three main nutrients, total phosphorus, nitrate and silica. Their concentrations in the water column were measured at the same time as sampling of the phytoplankton communities (Figure 3). Only the prevalent and most common species present, together with sampling sites, are marked in the ordination diagram (see legend). Nutrients are represented as vectors in correlation with the ordination axes. Perpendicular projections of species to the chosen environmental vector describe their dependence on the represented ecological




Legenda: Legend:

| Pogoste vrste<br>Common species | | Najpogostejše vrste<br>Most common species | | | |
|---|---|---|---|---|---|
| Oznaka<br>Sign | Ime vrste<br>Species name | Oznaka<br>Sign | Ime vrste<br>Species name | Oznaka<br>Sign | Jezero<br>Lake |
| Agm pun | Agmenellum punctata | Chr min | Chroococcus minutus | 1 | Jezero pod Vršakom |
| Col kut | Coelosphaerium kutzingianum | Mic pul | Microcystis pulvera | 2 | Rjavo jezero |
| Mic sp. | Microcystis sp. | Din div | Dinobryon divergens | 3 | Zeleno jezero |
| Pho fav | Phormidium favosum | Fra u a | Fragilaria ulna v. acus | 4 | Jezero v Ledvicah |
| Pse con | Pseudanabaena constricta | Pla gel | Planctosphaeria gelatinosa | 5 | Dvojno Peto jezero |
| Cyc rad | Cyclotella radiosa | Spi sp. | Spirogyra sp. | 6 | Dvojno Šesto jezero |
| Cer hir | Ceratium hirudinella | Sta cus | Staurastrum cuspidatum | 7 | Črno jezero |
| Per sp. | Peridinium sp. | Zyg sp. | Zygnema sp. | K | Krnsko jezero |
| Ank fal | Ankistrodesmus falcatus | | | D | Dupeljsko jezero |
| Chl sp. | Chlamydomonas sp. | Oznaka | Čas vzorčevanja | L | Jezero v Lužnici |
| Oed sp. | Oedogonium sp. | Sign | Sampling time | Z | Zgornje Kriško jezero |
| Ped bor | Pediastrum boryanum | _91 | September 1991 | Sr | Srednje Kriško jezero |
| Sce eco | Scenedesmus ecornis | _92j | July 1992 | Sp | Spodnje Kriško jezero |
| Sta gra | Staurastrum gracile | _92s | September 1992 | P | Jezero na Planini pri |
| Sta pol | Staurastrum polymorphum | _00 | September 2000 | | Jezeru |

Slika 3: Ordinacijski diagram prve (kanonična vrednost 0,44) in druge (kanonična vrednost 0,37) osi kanonične korespondenčne analize na osnovi podatkov o relativni pogostosti alg v fitoplanktonskih združbah jezer v Julijskih Alpah (Slovenija), ki smo jih vzorčevali v septembru 1991, 1992 in 2000 ter v juliju 1992 v odnosu s hranivi: celokupni fosfor (tP), nitrat ($NO_3$) in silicijev dioksid (Si). Kumulativni odstotek variance odnosa vrste–okoljski dejavniki s prvima dvema osema je 74,4 %.

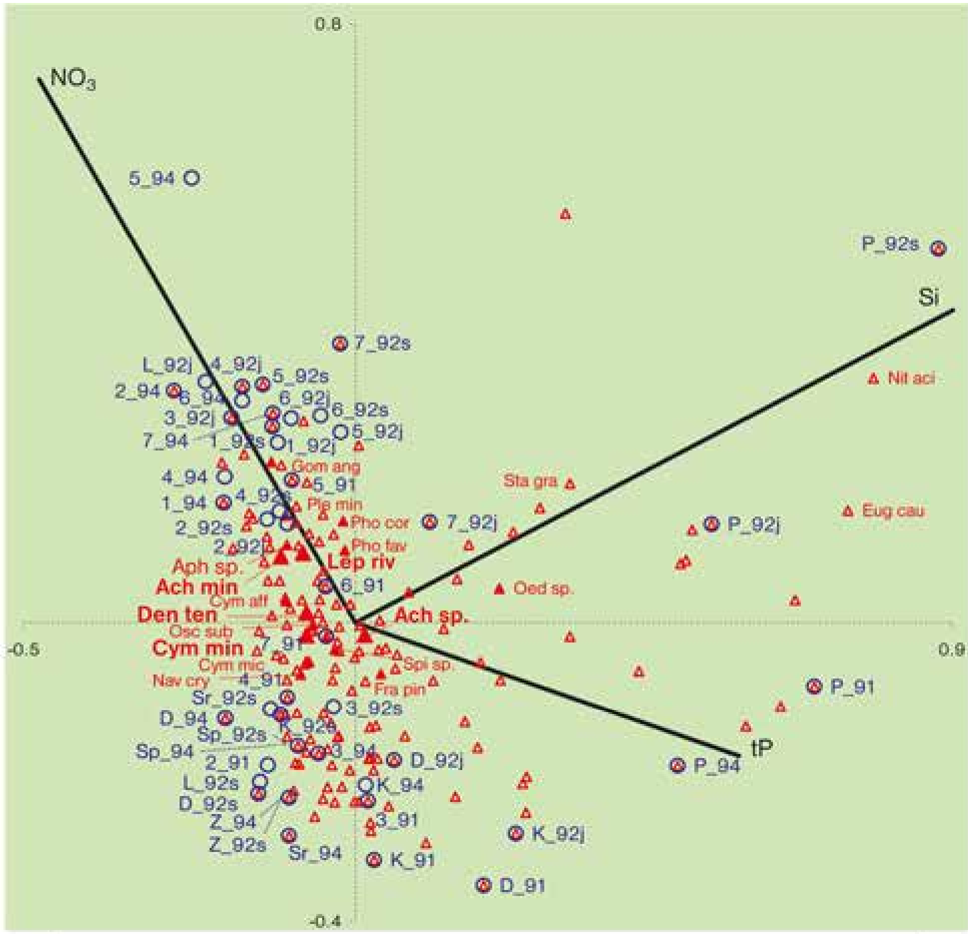
*Figure 3: Ordination diagram of first (canonical eigenvalue 0.44) and second (canonical eigenvalue 0.37) axes of canonical correspondence analysis on relative abundance data of phytoplankton communities sampled in September 1991, July 1992, September 1992 and September 2000 in 14 lakes from the Julian Alps (Slovenia) in relation to nutrients: total phosphorus (tP), nitrate ($NO_3$) and silica (Si). Cumulative percentage of variance of species–environment relation with first two axes is 74.7 %.*

pri Jezeru, ter kremenasta alga *Fragilaria ulna* v. *acus* (Kützing) Lange – Bertalot v Jezeru na Planini pri Jezeru in v Krnskem jezeru potrebujejo višje koncentracije fosforja kot rumena alga *Dinobryon divergens* Imhof v Krnskem in Črnem jezeru, ali zelena alga *Planctosphaeria gelatinosa* G. M. Smith v Krnskem jezeru, ali modrozelena alga *Chroococcus minutus* (Kützing) Nägeli v Spodnjem Kriškem jezeru. Vektor, ki ponazarja celokupni fosfor, je v izrazitejšem razmerju s fitoplanktonsko združbo iz Jezera na Planini pri Jezeru, nekoliko manj z združbami iz Črnega, Dupeljskega, Krnskega in Zelenega jezera iz nekaterih obdobij in najmanj s tistimi iz ostalih obdobij slednjih ter onih iz preostalih jezer. Vektor, ki predstavlja silicijev dioksid, je v še izrazitejšem sorazmerju z osema razporeditve fitoplanktonskih združb in ima nekoliko drugačen kot. Vektor, ki ponazarja nitrat, ima nekoliko močnejše sorazmerje z razporeditvenima osema kot celokupni fosfor, a popolnoma drugačen kot (~140°). To pomeni, da nitrat manj vpliva na združbe iz Jezera na Planini pri Jezeru, Krnskem jezeru in nekaterih drugih kot na združbe iz Dvojnega Petega jezera, Jezera pod Vršacem in preostalih jezer.

Z isto metodo smo primerjali perifitonske združbe s prisotnimi hranivi. V razporeditvenem grafu (slika 4) primerjamo glavni razporeditveni osi, ki opisujeta perifitonske združbe, s celokupnim fosforjem, nitratom in silicijevim dioksidom v obdobju od 1991 do 1994. Razporeditev vzorčnih mest posameznega obdobja jasno loči vzorce iz Jezera na Planini pri Jezeru od ostalih jezer. Slednji so močneje opredeljeni z relativno višjimi koncentracijami celokupnega fosforja in silicijevega dioksida. Tudi nekatere alge, kot sta kremenasta alga *Nitzschia acicularis* W. Smith in evglena *Euglena caudata* Hübner, so v močnejšem sorazmerju s celotnim fosforjem. Teh alg nismo našli v drugih jezerih. Kremenasta alga *Nitzschia acicularis* W. Smith je sicer bolj značilna za fitoplanktonske združbe, a jo najdemo tudi v perifitonskih. Najbolj pogoste vrste, prisotne v mnogih jezerih v Julijskih Alpah, kot so modrozelena alga *Leptochaete rivularis* Hansgirg in kremenaste alge *Achnanthes minutissima* Kützing, *Cymbella minuta* Hilse in *Denticula tenuis* Kützing, niso tako izrazito odvisne od kateregakoli od primerjanih hraniv. Celokupni fosfor ima nekaj vpliva na perifitonsko združbo iz Krnskega jezera, nekoliko manj na združbo iz Dupeljskega jezera kakor tudi na posamezne dezmide, kot *Cosmarium constrictum* Delp., *Cosmarium elipsoideum* Elfv. in *Staurastrum cristatum* (Nägeli) Arch., ki so prisotne v teh dveh jezerih.

factor. For example, a desmid species *Staurastrum cuspidatum* Brébisson, a blue-green alga *Microcystis pulverea* (Wood) Forti prevalent in Jezero na Planini pri Jezeru and a diatom *Fragilaria ulna* v. *acus* (Kützing) Lange – Bertalot in Jezero na Planini pri Jezeru and Krnsko jezero, need higher concentrations of phosphorus than do the chrysophycea *Dinobryon divergens* Imhof in Krnsko jezero and Črno jezero or green alga *Planctosphaeria gelatinosa* G. M. Smith in Krnsko jezero, or the blue-green alga *Chroococcus minutus* (Kützing) Nägeli in Spodnje Kriško jezero. The vector describing total phosphorus is most closely related to the phytoplankton community from Jezero na Planini pri Jezeru, a little less to the communities from Črno jezero, Dupeljsko jezero, Krnsko jezero and Zeleno jezero in some periods and least of all to that in other periods and communities from the remaining analysed lakes. The vector denoting silica explains even more strongly the ordination of species and has a slightly different angle. The vector denoting nitrate has a somewhat higher correlation coefficient than the one describing total phosphorus and quite a different angle (~140°). This means that nitrate has less influence on communities from Jezero na Planini pri Jezeru, Krnsko jezero and some others lakes than on communities from Dvojno jezero (the north basin), Jezero pod Vršacem and others.

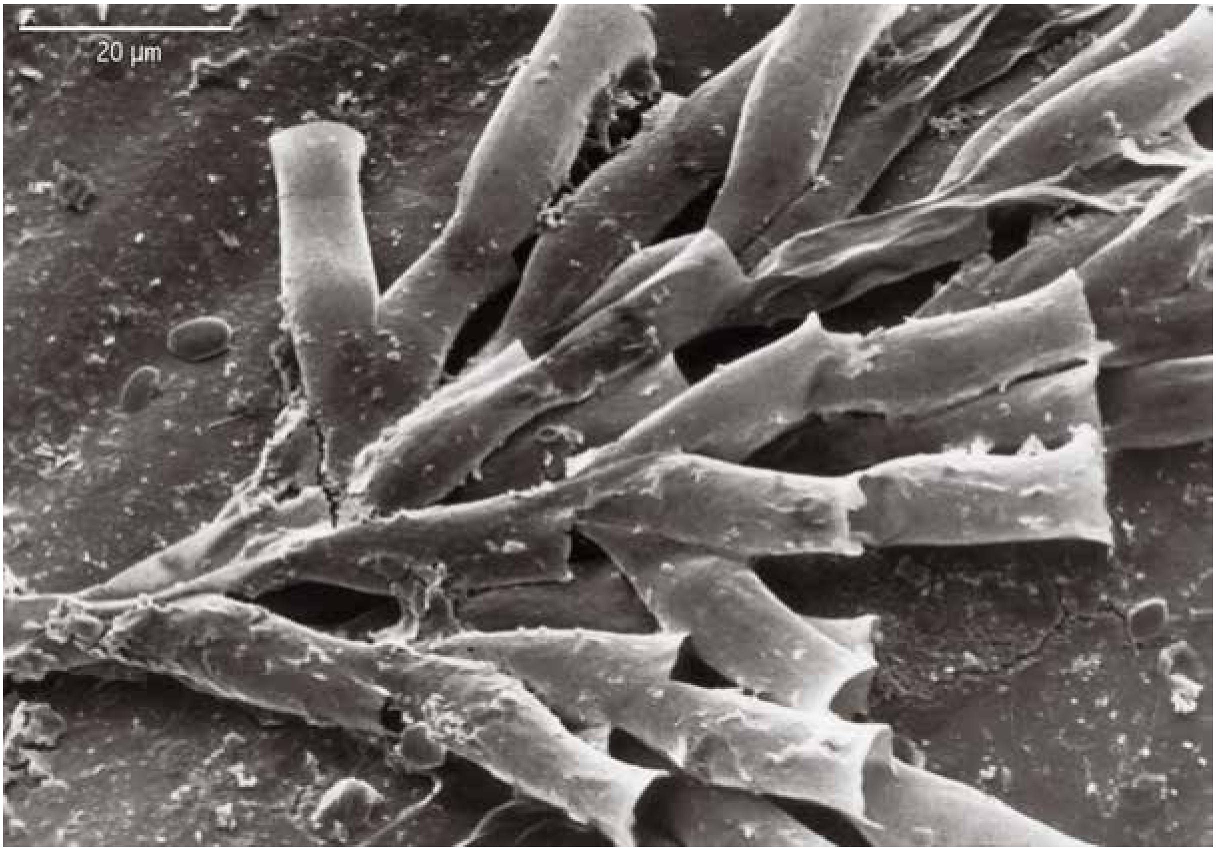
The same method was used to relate the periphyton communities to nutrients present in the lakes. In the ordination diagram (Figure 4) the first two canonical axes describing the distribution of periphyton species are related to total phosphorus, nitrate and silica during the period from 1991 to 1994. The distribution of overlaid locations clearly separates samples from Jezero na Planini pri Jezeru from other lakes. They were strongly defined with relatively high concentrations of total phosphorus and silica. Also, some species like the diatom *Nitzschia acicularis* W. Smith and the euglenophyta species *Euglena caudata* Hübner were highly related to total phosphorus. They were not found in other lakes. The diatom *Nitzschia acicularis* W. Smith is more characteristic for phytoplankton communities but can also be found in the periphyton. The most common species present in many of the lakes in the Julian Alps, like the blue-green alga *Leptochaete rivularis* Hansgirg, and the diatoms *Achnanthes minutissima* Kützing, *Cymbella minuta* Hilse and *Denticula tenuis* Kützing, were not so dependent on either of the described nutrients. Total phosphorus had some influence on the periphyton communities from Krnsko jezero and a little less on that from Dupeljsko jezero as well as on




| Legenda: | | | | | Legend: |
|---|---|---|---|---|---|
| Pogoste vrste<br>Common species | | Najbolj pogoste vrste<br>Species present in mass | | | |
| Oznaka<br>Sign | Ime vrste<br>Species name | Oznaka<br>Sign | Ime vrste<br>Species name | Oznaka<br>Sign | Jezero<br>Lake |
| Aph sp. | Aphanocapsa sp. | Lep riv | Leptochaete rivularis | 1 | Jezero pod Vršakom |
| Osc sub | Oscillatoria subtilissima | Ach min | Achnanthes minutissima | 2 | Rjavo Jezero |
| Ple min | Pleurocapsa minor | Ach sp. | Achnanthes sp. | 3 | Zeleno Jezero |
| Pho cor | Phormidium corium | Cym min | Cymbella minuta | 4 | Jezero v Ledvicah |
| Pho fav | Phormidium favosum | Den ten | Denticula tenuis | 5 | Dvojno Peto Jezero |
| Cym aff | Cymbella affinis | | | 6 | Dvojno Šesto Jezero |
| Cym mic | Cymbella microcephala | | | 7 | Črno jezero |
| Fra pin | Fragilaria pinnata | | | K | Krnsko Jezero |
| Gom anu | Gomphonema angustum | | | D | Dupeljsko Jezero |
| Nav cry | Navicula cryptotenella | Oznaka | Čas vzorčenja | L | Jezero v Lužnici |
| Nit aci | Nitzschia acicularis | Sign | Sampling time | Z | Zgornje Kriško jezero |
| Eug cau | Euglena caudata | _91 | September 1991 | Sr | Srednje Kriško jezero |
| Spi sp. | Spirogyra sp. | _92j | July 1992 | Sp | Spodnje Kriško jezero |
| Sta gra | Staurastrum gracile | _92s | September 1992 | P | Jezero na Planini pri |
| Oed sp. | Oedogonium sp. | _94 | September 1994 | | Jezeru |

Slika 4: Ordinacijski diagram prve (kanonična vrednost 0,44) in druge (kanonična vrednost 0,25) osi kanonične korespondenčne analize na osnovi podatkov o relativni pogostosti alg v perifitonskih združbah jezer v Julijskih Alpah (Slovenija), ki smo jih vzorčevali v septembru 1991, 1992 in 1994 ter v juliju 1992, v odnosu s hranili: celokupni fosfor (tP), nitrat ($NO_3$) in silicijev dioksid (Si). Kumulativni odstotek variance odnosa vrste–okoljski dejavniki s prvima dvema osema je 77,2 %.

*Figure 4: Ordination diagram of first (canonical eigenvalue 0.44) and second (canonical eigenvalue 0.25) axes of canonical correspondence analysis on relative abundance data of periphyton communities sampled in September 1991, July 1992, September 1992 and September 1994 in 14 lakes from the Julian Alps (Slovenia) in relation to nutrients: total phosphorus (tP), dissolved nitrate ($NO_3$) and silica (Si). Cumulative percentage variance of species-environment relation with first two axes is 77.2 %.*




Rumena alga *Dinobryon* sp. Ehrenberg, posneta z vrstičnim elektronskim mikroskopom (Foto: Kazimir Drašlar)
*Scaning electron microscope micrograph of chrysophycea* Dinobryon *sp. Ehrenberg (Photo: Kazimir Drašlar)*

Le kremenaste alge, kot pomembnejši del perifitonske združbe, smo primerjali s hranivi (celokupni fosfor, celokupni dušik in silicijev dioksid) v obdobju od 1996 do 2000. Vzorci iz Jezera na Planini pri Jezeru, ponovno izrazito odstopajo od ostalih. Vzorca iz 1996 leta iz Dvojnega Petega jezera in tisti iz 2000 leta iz Črnega jezera sta tudi ločena od osnovne skupine. Tudi nekatere vrste kremenasti alg kot so *Gomphonema clavatum* Ehrenberg, *Stephanodiscus parvus* Stoermer & Håkansson, *Fragilaria construens construens* (Ehrenberg) Grunow and *Achnanthes lanceolata* (Brébison) Grunow so močneje odvisne od celokupnega fosforja. Zadnje tri vrste so kar močno odvisne tudi od silicijevega dioksida in celokupnega dušika. Druge dokaj pogoste vrste kot *Achnanthes minutissima* Kützing, *Cymbella microcephala* Grunow, *Cymbella minuta* Hilse, *Denticula tenuis* Kützing and *Fragilaria pinnata* Ehrenberg pa so bile manj odvisne od teh treh hraniv.

some desmid species like *Cosmarium constrictum* Delp., *Cosmarium elipsoideum* Elfv. and *Staurastrum cristatum* (Nägeli) Arch. present there.

Just the diatom parts of the periphyton associations are related to nutrients (total phosphorus, total nitrogen and silica) present in lakes during the period from 1996 to 2000. The overlaid samples from Jezero na Planini pri Jezeru are once more clearly separated from the others. The sample taken in 1996 from Dvojno jezero (the north basin) and that taken in 2000 from Črno jezero are also separated from the main group. The diatom parts of the periphyton communities from the lakes mentioned in these sampling periods were strongly influenced by total phosphorus, especially species like *Gomphonema clavatum* Ehrenberg, *Stephanodiscus parvus* Stoermer & Håkansson, *Fragilaria construens construens* (Ehrenberg) Grunow and *Achnanthes lanceolata* (Brébison) Grunow. The last three species were quite strongly conditioned by silica as well as nitrogen. Other species like the most common ones *Achnanthes minutissima* Kützing, *Cymbella microcephala* Grunow, *Cymbella minuta* Hilse, *Denticula tenuis* Kützing and *Fragilaria pinnata* Ehrenberg were less dependent on these three nutrients.

## VERTIKALNA RAZPOREDITEV PERIFITONSKIH ZDRUŽB

Da bi ovrednotili perifitonske združbe, ki živijo globlje od prej opisanih priobalnih, smo nabrali vzorce na prerezu od obale jezera pa vse do njegovega dna. Vzorce iz prvega prereza smo nabrali v septembru 1997 v oligotrofnem Jezeru v Ledvicah. Določili smo le kremenaste alge. Na vzorcih, nabranih na različnih globinah, vidimo, da pogostost najpogostejše vrste *Achnanthes minutissima* Kützing z globino narašča, medtem ko dokaj pogosti vrsti *Cymbella microcephala* Grunow in *Denticula tenuis* Kützing upadata. Le v najglobljі plasti, kjer združba preide iz epilitične v epipelično, pogostost vrste *Denticula tenuis* Kützing naraste, medtem ko pogostost vrste *Achnanthes minutissima* Kützing upade.

V letu 1998 smo nabrali vzorce na treh globinskih profilih Krnskega jezera. Vzorce iz prvega profila smo nabrali na severni obali jezera. V nasprotju z dnom, kjer smo vzorčili ostala dva profila, je na tem območju dno nagosto preraščeno z makrofiti. Druga dva profila sta na skalnem dnu večinoma brez makrofitske obrasti. V vzorcih, pobranih na teh profilih, smo našli 50 vrst kremenastih alg, med 14 in 34 na posamezni globini. Epifitske kremenaste alge, kot sta *Cymbella caespitosa* (Kützing) Brun in *Cymbella affinis* Kützing, so bile najpogostejše na 2 m globine na prvem profilu. Na petem metru istega profila se je združba kremenastih alg spremenila, saj je tu pogostost makrofitov precej upadla in skoraj polovico populacije kremenastih alg predstavlja alga *Cymbella microcephala* Grunow. Na tretjem in četrtem profilu tvorita večino prisotnih kremenastih alg vrsti *Cymbella microcephala* Grunow in *Achnanthes minutissima* Kützing. Prva je pogostejša v plitvejši vodi, medtem ko je slednja pogostejša v globlji. Izjema je najgloblja plast na drugem profilu, kjer se začenjajo drobnejše usedline in so močneje zastopane epipelične vrste, kot npr. *Amphora ovalis* (Kützing) Kützing.

## VERTICAL DISTRIBUTION OF THE PERYPHITON

To evaluate the periphyton communities occurring deeper than those already described from nearshore samples, profiles were taken from the shore to the bottom of the lake. The first profile was taken in September 1997 in the oligotrophic lake Jezero v Ledvicah. Only diatom species were analysed. It is apparent that the abundance of the most common species *Achnanthes minutissima* Kützing increased with depth, while the fairly abundant species *Cymbella microcephala* Grunow and *Denticula tenuis* Kützing decreased. Just within the deepest layer where the community changed to an epipelic one, *Denticula tenuis* Kützing increased while *Achnanthes minutissima* Kützing decreased in abundance.

In 1998 three profiles were taken from Krnsko jezero. The first profile was taken near the north part of the lake shore. In contrast with the littoral zone of the other two profiles, this area has an abundant population of macrophytes. Other profiles were mainly on bare rocks. In total, 50 taxa of benthic diatoms were determined and between 14 to 34 per sample. Epiphytic diatom species such as *Cymbella caespitosa* (Kützing) Brun and *Cymbella affinis* Kützing were most abundant at a depth of two meters on the first profile. At the fifth metre of the same profile the diatom community changes because of less abundant macrophytes and *Cymbella microcephala* Grunow represents by number, nearly half of the community. The second and third profiles were almost without macrophytes. Species like *Cymbella microcephala* Grunow and *Achnanthes minutissima* Kützing formed the main part of the diatom community of these profiles. The former was more abundant at lower depths, the latter at deeper ones. The exception was the deepest layer of the second profile where fine sediments begin, where were more common epipelic species like *Amphora ovalis* (Kützing) Kützing.

## ZAKLJUČKI

V štirinajstih jezerih Julijskih Alp smo v obdobju zadnjih deset let določili 380 vrst in podvrst alg, predstavnic perifitonskih in fitoplanktonskih združb. Planktonskih je bilo 197 vrst, vendar je potrebno poudariti, da mnoge med njimi niso tipično planktonske. Zaradi majhne globine in premikanja vodnih mas se perifitonske vrste pogosto dvigujejo s tal in se pomešajo med evplanktonske vrste.

## CONCLUSIONS

In the last ten years 380 algal species were determined in phytoplankton and periphiton communities of the fourteen lakes of the Julian Alps. There were 197 planktonic species, but it should be remembered that many of these species are not typical planktonic. The lakes described are mainly shallow and some of them have strong water flows. Because of this, many periphytic species can be found in the

Predstavnic perifitona je bilo 279 vrst in podvrst, prevladovale so kremenaste alge s 137 vrstami in le 44 zignematoficej. Med vsemi vrstami (380) so zastopane kremenaste s 146 in zignematoficeje s 57 vrstami. Lazar (1969) poroča, da ob neupoštevanju kremenastih alg prevladujejo v jezerih Julijskih Alp zignematoficeje. Naše raziskave kažejo, da prevladujejo kremenaste alge, zelene alge in zignematoficeje pa so zastopane s podobnih številom predstavnikov (60 oz. 57 vrstami in podvrstami). Podobno poroča Messikommer (1942), ko zaključuje, da so kremenaste alge pogoste na karbonatni, zignematoficeje pa na kristalinični, to je zakisani podlagi.

Razlike v vertikalni razporeditvi perifitonske združbe so pogojene s svetlobnimi razmerami, predvsem v UV-spektru (Vinebrooke in sod., 1996, Franncoeur in sod., 1998). Drugi, prav tako pomemben dejavnik je tip podlage, npr. makrofitska vegetacija.

Na trofično stanje posameznih jezer v Julijskih Alpah pogosto vpliva človekova dejavnost. Vrednosti klorofila *a*, prosojnosti in vrstni sestav alg kažejo na evtrofno stanje Jezera na Planini pri Jezeru in Krn-

water column and the number of euplanktonic species is considerably lower. 279 periphytic species were found, of which 137 were diatoms and just 44 Zygnematophyceae. Considering planktonic and periphytic species together, from 380 species there were 146 diatoms and 57 Zygnematophyceae. Lazar (1969) mentioned that with exception of diatoms in high-mountain lakes in the Julian Alps zygnematophycean species prevail, but even the chlorophycean species (60) are as common as zygnematophycean ones. In his observations on species living in calcareous environment Messikommer (1942) concluded that diatoms are more frequent in such habitats and zygnematophyceae in more acid ones.

The differences in vertical distribution of periphyton communities are mainly driven by light conditions, especial the UV part (Vinebrooke et al., 1996; Franncoeur et al., 1998). Another factor with a strong influence on such communities is the type of substratum, e.g. macrophyte cover.

The trophic state of lakes in the Julian Alps is in many cases influenced by man. From chlorophyll *a* and transparency determinations, as well as spe-

V globljih delih jezer so vzorce alg nabirali potapljači (Milijan Šiško – levo – pred potopom v Jezero v Ledvicah) (Foto: Jurij Dobravec)

*Samples of algae in the deeper part of the lakes were collected by scuba divers (Milijan Šiško – on the left – before the dive in Jezero v Ledvicah) (Photo: Jurij Dobravec)* skega jezera. Za prvega lahko trdimo, da je že na meji hiperevtrofnosti. Nekatera druga, npr. Dvojno jezero, uvrščamo v mezotrofna, opazen pa je trend povečane produkcije kot posledice turizma in naseljevanja rib. Le Spodnje Kriško jezero kaže izboljšano trofično stanje. Nekatera jezera, Jezero v Ledvicah, Zgornje Kriško jezero in Jezero v Lužnici, ostajajo še naprej oligotrofna.

cies analyses, two lakes, Jezero na Planini pri Jezeru and Krnsko jezero, can be described as eutrophic. The first one lies at the boundary of hypereutrophic lakes. Many of the lakes like Dvojno jezero (both basins), considered as mesotrophic, are getting more productive due to human influence (tourism and fish introduction). Only Spodnje Kriško jezero is improving in its trophic state. There are still some oligotrophic lakes, like Jezero v Ledvicah, Zgornje Kriško jezero and Jezero v Lužnici.

# *Poglavje* 8 *Chapter*

# *Vodni makrofiti* *Aquatic Macrophytes*

Olga URBANC-BERČIČ* & Alenka GABERŠČIK*

## UVOD

Rastline, ki se pojavljajo v visokogorskih jezerih, so enake tistim, ki jih poznamo z nižinskih jezer, le da je seznam vrst mnogo krajši. Glede na njihov filogenetski razvoj so to taksonomsko različne skupine rastlin, ki jih uvrščamo med alge, mahove in višje rastline. Izraz vodni makrofiti je torej ekološka kategorija, ki jo opredeljujejo predvsem skupne življenjske okoliščine, v katerih te rastline živijo. Prvi dve skupini, alge in mahovi, sta evolucijsko starejši. Vanju spadajo vrste, ki so pionirske, saj se prve naselijo v jezero. Zaradi enostavne zgradbe prenesejo višji hidrostatski pritisk vode in lahko dosežejo znatne globine. Mah sicer večinoma obrašča kamenje v plitvini ali na obrežju, kamor še seže vpliv nihanja vodne gladine, najdemo pa ga tudi v globoki vodi, do nekaj 10 metrov pod vodno gladino. Prevladujoča skupina v visokogorskih jezerih so alge, med katere spadajo parožnice in nitaste bentoške alge. Obe skupini se pogosto pojavljata v zlahka opaznih prevlekah v litoralu. Ker je predvsem pojav nitastih zelenih alg v jezerih povezan s povečano količino hranil v vodi, je to znak pospeševanja evtrofikacijskih procesov v ekosistemu.

Organizmi se v jezero naseljujejo postopoma, v odvisnosti od več dejavnikov. Tako se v določenem ontogenetskem razvoju jezera pojavijo tudi vodni makrofiti. Kot primarni proizvajalci potrebujejo za svoj razvoj določene razmere. Eden od pomembnih je vrsta sedimenta, ki omogoča njihovo zakoreninjenje. Druga dva pomembna dejavnika sta svetloba in temperatura. Za visokogorska jezera je

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## INTRODUCTION

Plant species in high-mountain lakes are the same as those from lowland lakes, but number of species living there is minor. Phylogenetically, the plants belong to three taxonomic groups, algae, mosses and higher plants. The term "aquatic macrophyte" is therefore an ecological category defined in terms of the circumstances in which these plants happen to be living. The first two groups, algae and mosses are evolutionarily older than the higher plants. Certain species of algae and mosses are pioneers in aquatic ecosystems. Their anatomy is simple, so that they can stand higher hydrological pressure and are able to thrive in deep water. Generally, mosses cover stones in shallow water or on banks where the influence of the fluctuation of the water table is seen, but they are also found in deeper water down to depths of some 10 metres. The dominating groups in high-mountain lakes are algae, mainly Charophytes and filamentous benthic algae. Both taxa frequently appear in readily observed mats in the lake littoral. The appearance of filamentous green algae in lakes is closely related to the increase of nutrients in the water, and is therefore an indication of accelerated eutrophication.

Colonisation of lakes by different organisms is a gradual process and depends on many factors. Aquatic macrophytes, as primary producers, appear at a certain stage of development of a lake, when special conditions are established. The type of sediment, which allows rooting of plants, is an important factor. Erosion in this extreme environment,

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V plitvini Dupeljskega jezera so bentoške alge pogost pojav. (Foto: Olga Urbanc – Berčič)
*Benthic algae are a frequent feature in a shoal in Dupeljsko jezero. (Photo: Olga Urbanc – Berčič)*

značilno veliko nihanje teh dejavnikov. V poletnih mesecih, ko je vode v jezerih običajno najmanj, ima visoka intenziteta svetlobe v litoralu močan vpliv na makrofite, enako velja tudi za temperaturo, saj se voda v plitvinah zelo segreje. Vrednost obeh dejavnikov močno pade v hladnejšem delu leta, ko zaradi nizkih temperatur jezera kar za nekaj mesecev prekrije ledeni pokrov. Vendar so se rastline na te omejitve prilagodile tako po delovanju kot po zgradbi (Wetzel, 1990).

with high daily and seasonal fluctuations of temperature, is continual as is the production of fine sediment. In addition to sediment, two other environmental factors, light and temperature, are significant for macrophytes. In high-mountain lakes, fluctuation of these factors is high. In summers, when the water table in lakes is usually low, intensive insolation and temperature strongly influence macrophytes. Both factors show quite a different picture in colder periods, when low air temperatures lead to ice cover, which can last for many months. As a response to these conditions, macrophytes develop functional and structural adaptations to overcome the limitations they elicit (Wetzel, 1990).

## ZGODOVINSKI PREGLED

Pred letom 1988 je bilo o vodnih makrofitih v jezerih Triglavskega narodnega parka malo znanega (Blaženčić in sod., 1990; Brancelj in sod., 1995). V avgustu 1988 izvedena raziskava pa je pokazala, da so zakoreninjeni makrofiti prisotni v petih od 14 preiskanih jezer. V kasnejših raziskavah smo ugotovili, da so bentoške alge občasno ali stalno prisot-

## HISTORICAL OVERVIEW

Few data were available on aquatic macrophytes in the high-mountain lakes of the Triglav National Park before 1988 (Blaženčić *et al.*, 1990; Brancelj *et al.*, 1995). In August 1988, a survey showed that submerged macrophytes were present in five lakes. Later, it was discovered that benthic algae were present periodically or permanently in other lakes, ne še v drugih jezerih. Razlike v vrstni sestavi in številčnosti makrofitov so med jezeri kar precejšnje. Večina teh razlik je prepoznavnih že iz značaja pojezerja. Z večletnim opazovanjem smo ugotovili, da se stanje makrofitov v jezerih opazno spreminja, predvsem kot posledica povečane človekove aktivnosti v pojezerju pa tudi zaradi globalnih sprememb v okolju. Povečuje se obseg planinarjenja, spreminjata se način pašništva in razporejenost padavin, povečuje se onesnaženje zraka, ki doseže tudi visokogorski svet (Brancelj in sod., 2000). Vse omenjene spremembe se še posebno močno odražajo prav v jezerskem litoralu, potencialnem biotopu makrofitov, kjer se prepletajo in seštevajo vplivi s kopnega in z jezera (Gaberščik in Urbanc – Berčič, 1996).

too. Differences in species composition and abundance between the lakes are substantial and can be predicted from the characteristics of the watershed. Recently, the status of macrophytes in the lakes changed noticeably as a consequence of intensified human activity in the watershed, as well as of the changing global environment. Besides increasing mountaineering, there is a change in pasturing habits, a changing distribution of precipitation and increased air-borne pollution reaching the remote mountain areas (Brancelj *et al.*, 2000). All these processes are reflected in the lake littoral, a potential biotope of macrophytes, where influences from land and water are inter-related and integrated (Gaberščik & Urbanc – Berčič, 1996).

## SEDANJE STANJE

Prvemu pregledu stanja makrofitov v letu 1988 je sledilo spremljanje stanja enkrat do dvakrat letno. Pokazale so se podobnosti in razlike med jezeri z makrofiti (Urbanc – Berčič, 1999). Z makrofiti bogato porasla sta Zeleno in Dupeljsko jezero, ki

## PRESENT SITUATION

Monitoring, which followed the first assessment in 1988, has been performed once or twice a year, revealing similarities and differences among the high-mountain lakes with respect to macrophytes (Urbanc – Berčič, 1999). Macrophytes are very

V močvirju ob Jezeru na Planini pri Jezeru prevladuje togi šaš (*Carex elata* L.), preraslolistni dristavec (*Potamogeton perfoliatus* L.) pa uspeva v vodi v plitvem delu jezera. (Foto: Olga Urbanc – Berčič)
*In the wetland flat along Jezero na Planini pri Jezeru a sedge* (Carex elata *L.*) *prevails, while a submersed species* Potamogeton perfoliatus *L.thrives in a shoal. (Photo: Olga Urbanc – Berčič)*

sta si po zunanjosti precej podobna, glede na geografsko lego pa pripadata dvema različnima skupinama jezer. Plitva jezerska kotanja je skoraj povsem porasla z zeleno preprogo. V obeh jezerih sta že nekaj deset let prisotni dve podvodni vrsti makrofitov. Globlji del kotanje porašča zelena alga parožnica *Chara contraria f. capillacea* Mig., na obrobju pa je lasastolistna vodna zlatica *Batrachium trichophyllum* Chaix. Za razliko od Zelenega jezera se v Dupeljskem jezeru zadnja leta redno pojavljajo tudi nitaste alge, znak povečanega spiranja hranil iz zaledja, česar v Zelenem jezeru nismo opazili. Jezeri dobivata vodo s taljenjem snega in z dežjem. Če je zimskih zalog malo, lahko v sušnem letu ostane vode le še za dobra 2 metra, kar vpliva tudi na stanje makrofitov. V najplitvejšem delu kotanje se lahko voda povsem umakne. Rastline ali propadejo (bentoške alge) ali pa razvijejo nova tkiva, prilagojena življenju na kopnem, kot je to v primeru lasastolistne vodne zlatice. Skupna obema jezeroma je močvirska vegetacija na obrobju kotanje. Ob Zelenem jezeru prevladuje ozkolistni munec (*Eriophorum angustifolium* Honck.), ob Dupeljskem jezeru pa zaščitena vrsta Scheuchzerjev munec *(E. scheuchzeri* Hopp*)* ter pisana preslica (*Equisetum variegatum* Schleich.). Podobnostim pa sledijo razlike v zaledju obeh jezer. Območje ob Dupeljskem jezeru pokriva planinski pašnik, Zeleno jezero pa obdaja skalnato zaledje, kjer je mogoče najti le krpe travne ruše. Nosilna kapaciteta teh okolij je različna, kar se odraža tudi na jezerih.

V dolini Triglavskih jezer je edino Zeleno jezero tisto, kjer so makrofiti stalno prisotni. Občasno se pojavljajo manjše ali večje krpe nitastih zelenih alg še v Dvojnem in Črnem jezeru. V letu 2000 pa smo v Dvojnem jezeru prvič opazili tudi lasastolistno vodno zlatico, ki se je pojavila v plitvini Petega jezera kot majhna zelena krpa.

Jezero na Planini pri Jezeru je posebnež med visokogorskimi jezeri v Julijskih Alpah. Izstopa po obsežnem močvirju, ki nastaja ob njem. Vzrok temu pojavu je povečan vnos snovi v jezero, ki omogoča tudi povečano produkcijo v samem jezeru. Območje je zaradi primerne lege že stoletja privlačno za pašništvo in druge dejavnosti ljudi iz bližnjega Bohinjskega kota, kar je pospešilo staranje jezera in zasipavanje kotanje (Brancelj in sod., 2000). Na ravnici ob jezeru uspevata dve vrsti šašev: togi *Carex elata* All. in črni šaš *Carex nigra* (L.) Reichart, najdemo pa še nekatere druge, manj očitne močvirske vrste (preglednica 1). Kljub slabim svetlobnim razmeram v jezeru, ki so posledica pospešene evtrofizacije, uspeva do globine 1,5 metra podvodna vrsta

abundant in Zeleno jezero and Dupeljsko jezero, which are similar in outward appearance but, in terms of their geographical position, belong to two different groups of lakes. Both are shallow, with the bottom almost completely overgrown with macrophytes. Two species of aquatic macrophyte were found in this zone, a stonewort *Chara contraria f. capillacea* Mig. which colonised the deeper parts of the lakes, and a buttercup *Batrachium trichophyllum* (Chaix) Van den Bosch which found favourable conditions in the littoral. In recent years, Dupeljsko jezero, unlike Zeleno jezero, is often colonised with filamentous algae. The lake water originates from melting snow and precipitation events affect both lakes. In the years with mild winters, when the accumulation of snow is modest, the water level in the lakes drops to depths of about 2 metres only. The shallowest parts of the lakes dry out and the new conditions affect macrophytes. Filamentous algae decay while buttercups develop new assimilation areas that are adapted to the terrestrial environment. Helophytic vegetation on their fringe is common to both lakes. At Zeleno jezero a cottongrass *Eriophorum angustifolium* Honck. prevails, while at Dupeljsko jezero, another species, *E. scheuchzeri* Hopp from the Red list of protected plants, grows vigorously, accompanied by horsetail *Equisetum variegatum* Schleich.. Despite these similarities, the lakes differ in their catchment characteristics. The grassy slopes above Dupeljsko jezero serve as a pasture while a rocky area with tufts of grass surround the lake Zeleno jezero. This difference is primarily reflected in the lakes' buffering capacity.

Besides Zeleno jezero in the Triglav Lakes Valley, in which macrophytes are constantly present, only some mats of filamentous green algae of varying size appear occasionally in two other lakes, Dvojno jezero and in Črno jezero.

In summer 2000, a small patch of buttercups was noticed for the first time in the littoral of the north basin of Dvojno jezero.

Jezero na Planini pri Jezeru is an exception within high-mountain lakes in the Julian Alps. It is characterised by an extended wetland area surrounding the lake. The wetland is the result of increased run-off from the watershed into the lake as well as increased production in the lake itself. The reason for such a high input is the activity of local people who have been using the slopes around the lake as pastures for centuries (Brancelj *et al.*, 2000). In the wetland flat alongside the lake two species of sedges are found, *Carex elata* All. and *Carex nigra* (L.) Reichart, along with some other, less conspic-

| | | Jezero / Lake — Vrsta / Species | Zeleno jezero | Dupeljsko jezero | Krnsko jezero | Jezero na Planini pri Jezeru | Spodnje Kriško jezero |
|---|---|---|---|---|---|---|---|
| Emergentne vrste / Emergent species | | *Carex elata* All. | | | | 5 (0) | |
| | | *Carex nigra* (L.) Reichart | | | | 2 (0) | |
| | | *Juncus filiformis* L. | | 2 (0) | | | |
| | | *Eriophorum angustifolium* Honck. | 3 (0) | | | | |
| | | *Eriophorum scheuchzeri* Hoppe | | 3 (0) | | | |
| | | *Equisetum variegatum* Schleich. | | 2 (0) | | | |
| | | *Caltha palustris* L. | | 1 (0) | | 1 (0) | |
| | | *Cardamine amara* L. | | | | 3 (0) | |
| Submerzne vrste / Submerged species | Cvetnice / Anthophyta | *Batrachium trichophyllum* (Chaix) Van den Bosch | 3 (1) | 3(0.5) | | | 5 (3) |
| | | *Potamogeton alpinus* Balbis | | | 2 (1.5) | | |
| | | *Potamogeton pusillus* L. | | | 2 (1.5) | | |
| | | *Potamogeton perfoliatus* L. | | | | 5 (1.5) | |
| | Alge / Algae | *Chara contraria* f. *capillacea* Mig. | 5 (2.5) | 5 (2.5) | 5 (5.5) | | |
| | | *Chara delicatula* Ag. | | | 5 (7.5) | | |

Preglednica 1: Vrstna sestava zakoreninjenih vodnih makrofitov v gorskih jezerih v Triglavskem narodnem parku (Slovenija) v letu 2001. Označena je številčnost vrste in največja globina uspevanja (v metrih). Relativna ocena številčnosti posamezne vrste (abundanca): 1 – posamična; 2 – redka; 3 – običajna; 4 – pogosta; 5 – prevladujoča ali številna vrsta.

*Table 1: Species composition of rooted aquatic macrophytes in alpine lakes of the Triglav National Park (Slovenia) in 2001. The values indicate the abundance of species and maximum depth (in brackets). Relative abundance of species: 1 – rare, 2 – sparse, 3 – common, 4 – frequent, 5 – dominant.*

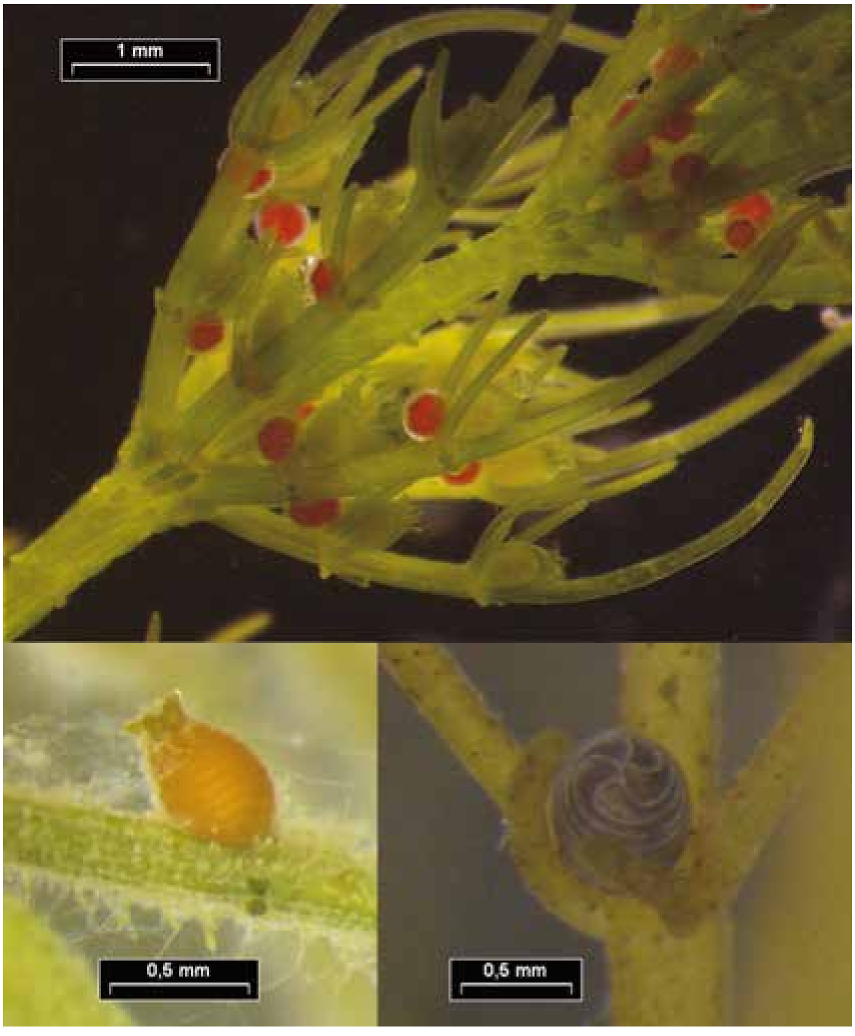
preraslolistni dristavec (*Potamogeton perfoliatus* L.). Rastlina s svojo strategijo še kljubuje hitremu slabšanju razmer v jezeru, saj čvrsti poganjki v začetku vegetacijske sezone hitro rastejo proti gladini jezera, preden planktonske alge, ki se namnožijo s segrevanjem vode, zmanjšajo prosojnost vode.

S stališča makrofitov je daleč najbolj zanimivo Krnsko jezero. Podvodni travniki makrofitov, ki skoraj v strnjenem pasu poraščajo litoral, segajo danes do globine 7,5 metrov in pokrivajo približno 40 % površine. Ob prvem pregledu leta 1988 so parožnice segale še do globine 10 metrov (Blaženčić in sod., 1990), v zadnjih letih pa rastline zaradi slabšanja svetlobnih razmer v jezeru v globljih območjih propadajo. V jezeru sta dve vrsti parožnice: *Chara contraria* f. *capillacea* in *Chara delicatula* Ag. Bogata poraslost z makrofiti je posebnost jezera, zato smo v letu 1998 s potapljači pregledali litoral in ocenili biomaso podvodnih makrofitov (Gaberščik in sod., 2000). Največja biomasa, 5,8 kg suhe mase m$^{-2}$, je bila požeta v pasu med 2. in 3. m. Izračunana skupna biomasa parožnic v jezeru pa je kar 17.537 kg suhe mase. Tako visoka produkcija je nedvomno presenetljiva za visokogorsko jezero. Tako visoke vrednosti so poznane le iz umetno hranjenih vod-

uous wetland species (see Table 1). In spite of modest light conditions due to accelerated eutrophication of the lake, one submerged species *Potamogeton perfoliatus* L. thrives, but only to a depth of 1.5 m. Vigorous shoots spring up to the water surface in the early summer, before algal blooms worsen light conditions in the lake, which seems to be the successful life strategy of the plants.

Krnsko jezero hosts the most abundant and diverse population of macrophytes. Submerged macrophytes colonise nearly the whole littoral, which constitutes approximately 40 % of the lake area. They spread down to a depth of 7.5 m. In the first survey in 1988 charophytes thrived to a depth of 10 m (Blaženčić *et al.*, 1990). In recent years, modest light conditions have prevented macrophyte growth. Two stoneworts, *Chara contraria* f. *capillacea* and *Chara delicatula* Ag., dominate in the lake. Luxurious vegetation enables efficient use of solar energy and therefore high primary production. In 1998 the littoral was examined by scuba diving and the biomass of macrophytes sampled over the depth profile (Gaberščik *et al.*, 2000). The biomass harvested at depths of 2–3 m was 5.8 kg dry mass m$^{-2}$, constituting the greatest contribution to the entire nih teles. Ostali dve makrofitski vrsti sta po biomasi mnogo skromnejši, saj je delež alpskega dristavca *Potamogeton alpinus* Balbis in pritlikavega dristavca *P. pusillus* L. le 0,6 % (okoli 100 kg suhe mase). Rasteta v manjših sestojih in jih je moč opaziti na več mestih na obrobju litorala. Razlike v življenjski strategiji teh štirih vrst so očitne. Parožnice se z rizoidi pričvrstijo v mehka tla, sposobnost vegetativnega in spolnega razmnoževanja pa jim omogoči, da mehak in rahel organski sediment hitro prekrijejo in ga tako stabilizirajo. S tem se zmanjša izmenjava snovi med vodo in sedimentom, kar je ugodno tudi za celotni ekosistem. V plitvejši vodi pa se bolje znajdejo dristavci, ki poženejo korenine globlje v sediment in se tako lažje prilagodijo manj stabilni podlagi. V plitvini se pogosto pojavijo tudi nitaste zelene alge, ki jim spiranje hranil iz zaledja omogoči hitro razmnoževanje. Razvijejo se lahko tudi v večjih globinah, odvisno od spleta okoliščin. Prav v primeru Krnskega jezera ima povečana potresna

production of charophytes, estimated at 17,500 kg of dry mass. Such production in a high-mountain lake is extraordinary, similar values only being obtained in fertilised fish ponds. Two other macrophyte species, *Potamogeton alpinus* Balbis and *P. pusillus* L., formed small patches in the shallow part of the littoral. They were sparse and their biomass was estimated to be 0.6 % (about 100 kg of dry mass). The life strategy of the present submerged species differs considerably. Stoneworts are able to colonise the soft sediment and form extensive meadows from the littoral towards the deep water. They stabilise the loose organic sediment which they root with tiny rhizoids. Their thick cover prevents the release of nutrients back into the water column. On the other hand, pondweeds are found only in shallow littoral, rooting in small patches of unstable rough sediment. They often compete with filamentous algae. Every now and then, filamentous algae can be found also in the deeper littoral. Their abun-




Del steljke alge parožnice *Chara contraria* var. *capillacea* Mig. z razmnoževalnimi organi (oranžni anteridiji in zeleni oogoniji) iz Zelenega jezera. Spodaj levo: oogonij, desno: oospora. (Foto: Olga Urbanc – Berčič)

*Green alga* Chara contraria *var.* capillacea *Mig.with the gametangia (orange antheridia and green oogonia) from Zeleno jezero. Below: oogonium on the left and oospora on the right. (Photo: Olga Urbanc – Berčič)* dinamika na širšem območju velik vpliv na jezerski ekosistem. Posledica močnih potresnih sunkov v letih 1997 in 1998 je bil povečan vnos snovi v jezero, kar je povzročilo vidne spremembe v jezeru (Brancelj in sod., 2000).

Preostala tri jezera so iz skupine Kriških jezer. V Spodnjem Kriškem jezeru raste pionirska vrsta lasastolistna vodna zlatica (*Batrachium trichophyllum*). Mehak sediment, ki se useda med kamenje iz meliščnega zaledja, ji povsem ustreza. V času vegetacijske sezone se pojavijo na samem robu kotanje drobne cvetoče rastlinice, ki so razširjene tudi v globljih delih kotanje, vse do globine 3 metrov. Ker je jezero kar nekaj mesecev na leto pod ledenim pokrovom, ki se mu pridružijo tudi snežni plazovi (glej poglavje 6), imajo rastline skrajšano vegetacijsko sezono, kar premostijo s kombinacijo spolnega in vegetativnega razmnoževanja. V Srednjem in Zgornjem Kriškem jezeru najdemo le nitaste zelene alge. V prvem jezeru občasno gosto poraščajo plitvino in se širijo v globino. V prosojnem Zgornjem Krišken jezeru so bentoške alge redkejši pojav, saj je izvir hranil, potrebnih za primarno produkcijo, v tem oddaljenem območju pičel. Pa vendar so tudi tu dogajanja, ki v sicer čistem, oligotrofnem jezeru omogočajo razvoj nitastih alg. Neenakomerna razporeditev padavin vpliva na mineralizacijo in na spiranje snovi iz pojezerja. Prav tako so potresi s spremljajočimi zemeljskimi plazovi ogromen vir snovi in bremen za ekosistem (Brancelj in sod., 2000). Manj očitno pa vendar učinkovito je tudi onesnaževanje zraka, ki ima s suhim in mokrim odlaganjem onesnažil velik vpliv na majhna visokogorska jezera (glej poglavje 10).

dance depends on the run-off from the watershed. In the case of Krnsko jezero, other sources in addition to pasturing and mountaineering, contribute to the availability of nutrients. A sequence of earthquakes in 1997 and 1998 triggered soil avalanches, which were flushed into the lake. The increased nutrient input affected the dynamic equilibrium of this ecosystem (Brancelj *et al.*, 2000).

The last three lakes with macrophytes belong to the lakes Kriška jezera. In Spodnje Kriško jezero, a buttercup *Batrachium trichophyllum* colonises the soft sediment which accumulates among stones from the nearby scree. Plants appear from the littoral to a depth of 3 m. In the peak season, tiny white flowers appear on the surface of shallow water. In addition to the vegetative mode, sexual reproduction with seeds is an important adaptation under conditions of the short vegetative period resulting from thick ice cover, which is present for several months a year (see Chapter 6). In Srednje Kriško jezero and Zgornje Kriško jezero, filamentous algae are the only macrophytes present. In the former they frequently cover the slopes from the littoral toward the bottom. Benthic algae are occasionally present in the highest and clear lake Zgornje Kriško jezero. In such a remote environment the nutrients needed for primary production are rather scarce. The appearance of filamentous algae in otherwise oligotrophic lakes is enabled by different events. Irregular distribution of precipitation can affect the mineralisation and run-off of matter from the watershed. Earthquakes, followed by soil avalanches, result in an increase of organic matter input and loading of the ecosystem (Brancelj *et al.*, 2000). Less obvious but important is air pollution with dry and wet deposition, readily affecting small lakes (see Chapter 10).

## ZAKLJUČEK

Vodni makrofiti se pojavljajo v 6 od 14 visokogorskih jezer Triglavskega narodnega parka.V oligotrofnih jezerih vodnih makrofitov ni, saj se zanje še niso ustvarili ustrezni pogoji. Nadaljnja stopnja v razvoju makrofitov je vidna v Dvojnem, Črnem, Zgornjem in Srednjem Kriškem jezeru. Občasno se lahko v njih pojavijo posamične zakoreninjene rastline. Pogost pojav so številne nitaste bentoške alge, ki ga običajno omogoči povečan vnos hranil iz pojezerja. V Dupeljskem, Zelenem in Spodnjem Kriškem jezeru so že stalno prisotne zakoreninjene podvodne vrste, katerih gostota se v zadnjih letih

## CONCLUSIONS

Aquatic macrophytes are present in 6 out of 14 high-mountain lakes in Triglav National Park. The absence of macrophytes in oligotrophic lakes is due to unfavourable conditions for their growth. The macrophyte vegetation in an early state of development can be observed in the lakes Dvojno jezero, Črno jezero and Zgornje and Srednje Kriško jezero. Every now and than a single rooted plant can be found while filamentous green algae frequently develop in great abundance. Their luxurious growth is enabled by the run-off of nutrients from the watershed. In the recent years in the lakes bistveno ne spreminja. Drugačno pa je stanje v Krnskem jezeru in v Jezeru na Planini pri Jezeru, kjer se kaže težnja k zmanjševanju gostote sestojev, krči pa se tudi globinski pas uspevanja zaradi slabšanja svetlobnih razmer. Razvoj makrofitov v zadnjih letih kaže na pospešeno dinamiko procesov v pojezerju kot tudi v jezerih.

Dupeljsko jezero, Zeleno jezero and Spodnje Kriško jezero rooted submerged macrophytes have formed stable populations. Conversely macrophytes in the lakes Krnsko jezero and Jezero na Planini pri Jezeru show a tendency to reduced abundance and depth distribution due to diminished light conditions. The status of macrophytes in the lakes of Triglav National Park reflects the accelerated dynamics in both the watershed and in the lakes.

*Poglavje* 9 *Chapter*

# *Živalstvo: zooplankton, bentos, ribe* / *Fauna: Zooplankton, Benthos and Fish*

Anton BRANCELJ*

## UVOD

Visokogorska jezera niso prazna in brez življenja. Celo tista na velikih višinah, ki so pokrita z ledom več mesecev na leto, so domovanje vsaj nekaj živalskih vrst, predvsem drobnih kotačnikov (Rotifera), majhnih rakcev iz skupin ceponožcev in vodnih bolh (Crustacea: Copepoda, Cladocera) ter žuželk (Insecta). Te živali so sposobne preživeti v težkih pogojih, ki jih določajo nizke temperature vode, kratka obdobja brez ledu na površini, močno sončno obsevanje (vključno z intenzivnim UV-žarčenjem) ter majhne količine hrane. Gledano z geološkimi merili so jezera v Alpah mlada. Prva jezera so se pojavila šele po umiku ledenikov, t. j. pred 8000–10.000 leti. Nekatera jezera so še mlajša, saj se je na nekaterih led stalil šele pred kratkim, potem ko so bila dolgo časa povsem zamrznjena ali vsaj pokrita z ledom. Visokogorska jezera na apnencu so zaradi kraških pojavov razmeroma redka, ne samo v evropskem, temveč tudi v svetovnem merilu. Predstavljajo zanimivo okolje, ki ga določajo specifičen vodni režim ter fizikalne in kemijske lastnosti vode.

Jezera v vzhodnem delu Julijskih Alp so sicer majhna in čeprav ležijo na kraškem območju, dolgo časa niso pritegnila pozornosti raziskovalcev. Eden prvih podatkov o živalstvu v teh jezerih izvira iz leta 1935, ko sta Seliškar in Pehani opisala neotenično obliko alpskega pupka – *Triturus alpestris lacustris* iz Jezera na Planini pri Jezeru in novo podvrsto *Triturus alpestris lacus-nigri* iz Črnega jezera. Ne ene ne druge oblike kasneje niso več našli (Sket,

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## INTRODUCTION

High-mountain lakes are not empty and lifeless ecosystems. Even those at high altitudes, covered with ice for several months, have a few inhabitants at least, mainly tiny rotifers (Rotifera), crabs (Crustacea: Copepoda, Cladocera) and insects (Insecta). They are able to survive in the harsh environment characterised by low water temperature, short ice-free periods, intensive solar radiation (including high UV radiation) and scarcity of food. On the geological time-scale, the lakes in the Alps are young. The first were formed after the glaciers retreated between 8000 and10,000 years ago. Some of them are much younger, having lost their permanent or long-lasting ice and snow cover quite recently. Mountain lakes on limestone bedrock are, because of karstic phenomena, relatively rare even on the world scale, not just in Europe. They are unique ecosystems, determined by a specific hydrological regime and the physical and chemical properties of water.

Lakes in the eastern part of the Julian Alps are small, and the result of a karstified area, and they did not attract any specific attention from scientists for a long time. One of the earliest records of biota from these lakes is dated 1935, when Seliškar and Pehani found and described a neotenic form of alpine newt – *Triturus alpestris lacustris* from Jezero na Planini pri Jezeru and a new subspecies *Triturus alpestris lacus-nigri* from Črno jezero. Neither taxa has ever been found again (Sket, 1992). Pehani and Seliškar mentioned in their work several represent-

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1992). Seliškar in Pehani sta v svojem delu naštela nekaj planktonskih vrst rakov iz obeh jezer. Za Jezero na Planini pri Jezeru tako navajata vrste: *Diaphanosoma brachyurum* (Lievin, 1848), *Heterocope saliens* (Lilljeborg, 1863), *Daphnia longispina* O. F. Müller, 1785 in *Bosmina coregoni* Baird, 1857, za Črno jezero pa *Heterocope saliens* and *Daphnia longispina.* Rejic (1960 a, 1960 b, 1962) je naredil prvi natančnejši popis zooplanktonskih in bentoških vrst ceponožcev (Copepoda) in vodnih bolh (Cladocera) iz večine visokogorskih jezer. Petkovski (1983) je njegov seznam dopolnil še z nekaj vrstami. Edini predstavnik primitivnih rakov iz skupine Anostraca, *Chirocephalus diaphanus* Prevost, 1803, je živel v Jezeru na Planini pri Jezeru ter v Mlaki v Dolu pod Stadorjem.

Poznavanje večjih vodnih nevterenčarjev (makroinvertebrata) je bilo do konca 80. let 20. stoletja nepopolno in je obsegalo predvsem podatke o polžih in školjkah (Mollusca: Gastropoda, Bivalvia) ter nekaterih žuželkah (Insecta). Seliškar in Pehani (1935) sta v svojem delu navedla iz obrežnega pasu Jezera na Planini pri Jezeru predstavnike nekaj rodov. Kot posamezne vrste pa sta med žuželkami navedla *Sialis lutaria* Linnaeus, 1758, *Notonecta glauca* Linnaeus, 1758, *Phryganea striata* Linnaeus, 1758 in *Aeschna cyanea* (O. F. Müller, 1764). Bole (1962) je našel školjke vrste *Pisidium caesertanum* (Poli, 1791) (Bivalvia) v štirih jezerih (Črno jezero, Dvojno jezero in Jezero v Ledvicah). V istih jezerih ter dodatno še v Zelenem jezeru pa je našel polže vrste *Lymnaea truncatula* (O. F. Müller, 1774) (Gastropoda).

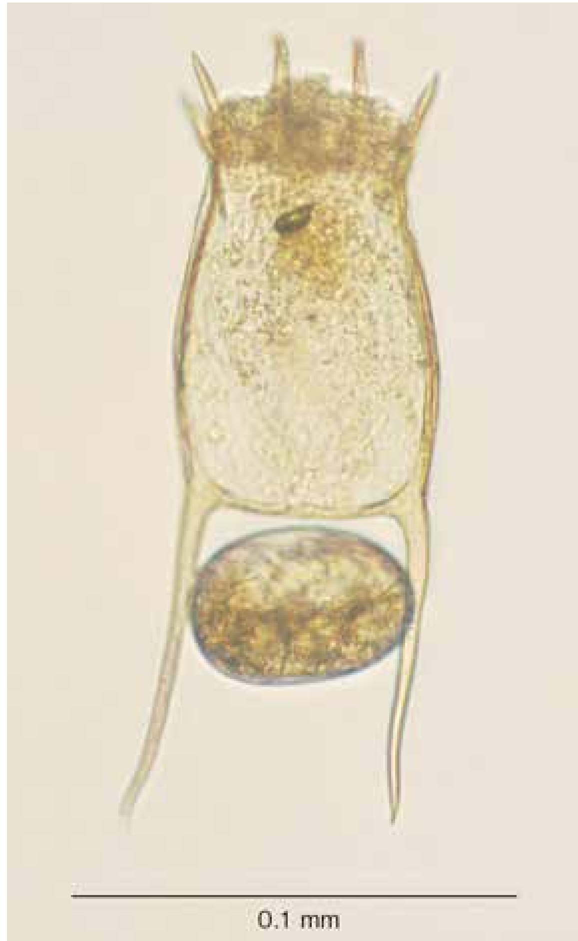
Čeprav so žuželke pogoste v visokogorskih jezerih, je bilo o njih le malo napisanega. Tako so bile vrbnice (Plecoptera) zelo podrobno raziskane (Sivec in sod., 1983), vendar je bila podrobneje navedena le vrsta *Nemoura cinerea* (Retzius, 1783) iz Dvojnega jezera (Sivec, ibid.). Krušnik (1984) je našel mladoletnico vrste *Chaetopteryx fusca* Brauer, 1957, (Trichoptera) v Dvojnem jezeru ter v Jezeru v Ledvicah, medtem ko je Gogala (1992) našel vodno stenico vrste *Arctocorisa carinata* (Sahlberg, 1819) (Heteroptera) v Krnskem jezeru ter v Mlaki v Dolu pod Stadorjem. Kiauta (1962) navaja za Jezero na Planini pri Jezeru ter za bližnjo Mlako v Dolu pod Stadorjem tri vrste kačjih pastirjev (Odonata; *Aeschna cyanea* (Müller, 1764), *A. juncea* (Linnaeus, 1758) in *Calopteryx virgo* (Linnaeus, 1758)).

Ribe niso prvotni prebivalci visokogorskih jezer, pač pa so jih tja (ne)načrtno naselili ljudje. V primerjavi z drugimi območji v Alpah ali v Tatrah so bile v jezera Julijskih Alp zanesene razmeroma pozno. Tako so v Krnsko jezero naselili ribe šele v

atives of planktonic species from the lakes. They listed *Diaphanosoma brachyurum* (Lievin, 1848), *Heterocope saliens* (Lilljeborg, 1863), *Daphnia longispina* O. F. Müller, 1785 and *Bosmina coregoni* Baird, 1857 in Jezero na Planini pri Jezeru and *Heterocope saliens* and *Daphnia longispina* from Črno jezero. Rejic (1960 a, 1960 b, 1962) made the first list of planktonic and benthic Copepoda and Cladocera from some high-mountain lakes. Petkovski (1983) contributed some new data to the list of microcrustacea there. The only representative of Anostraca, *Chirocephalus diaphanus* Prevost, 1803, was reported from Jezero na Planini pri Jezeru and from the puddle Mlaka v Dolu pod Stadorjem.

Little was known about littoral macroinvertebrates until the end of the 1980s, and was limited to snails and clams (Mollusca: Gastropoda, Bivalvia) and insects (Insecta). Seliškar and Pehani (1935) mentioned several genera from the littoral zone. At the species level, they reported *Sialis lutaria* Linnaeus, 1758, *Notonecta glauca* Linnaeus, 1758, *Phryganea striata* Linnaeus 1758 and *Aeschna cyanea* (O. F. Müller, 1764) for Jezero na Planini pri Jezeru. Bole (1962) reported *Pisidium caesertanum* (Poli, 1791) (Bivalvia) from four lakes (Črno jezero, Dvojno jezero and Jezero v Ledvicah) and *Lymnaea truncatula* (O. F. Müller, 1774) (Gastropoda) from the same lakes and also from Zeleno jezero. Insects are well represented in the high-mountains lakes, but very little data has been published. The Plecoptera group of insects located in the Triglav national park has been well studied (Sivec *et al.*, 1983), but the only specific information was for *Nemoura cinerea* (Retzius, 1783) reported from Dvojno jezero (ibid.). Krušnik (1984) found *Chaetopteryx fusca* Brauer, 1957 (Trichoptera) in Jezero v Ledvicah and Gogala (1992) reported *Arctocorisa carinata* (Sahlberg, 1819) (Heteroptera) from Krnsko jezero and for the puddle Mlaka v Dolu pod Stadorjem. Kiauta (1962) reported three taxa of dragonflies (*Aeschna cyanea* (O. F. Müller, 1764), *A. juncea* (Linnaeus, 1758) and *Calopteryx virgo* (Linnaeus, 1758)) from Jezero na Planini pri Jezeru and from the nearby Mlaka v Dolu pod Stadorjem.

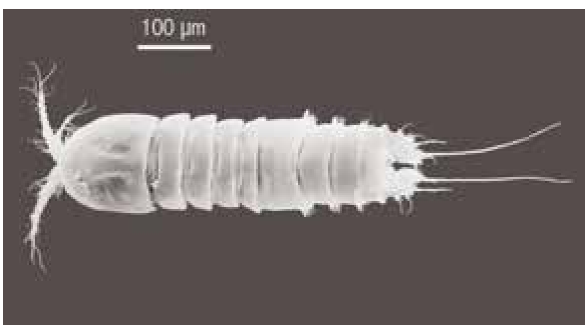
Fish are not native inhabitants of high-mountain lakes, but were introduced by man. In comparison with other areas in the Alps and the Tatras, in the Julian Alps they were introduced recently. Krnsko jezero was populated by fish in the early 1920s and Jezero na Planini pri Jezeru in the early 1950s (Povž, 1997; Brancelj, 1999 b) Before 1990, three lakes were populated by fish (Krnsko jezero, Jezero na Planini pri Jezeru and Dupeljsko jezero). Sket




Samice kotačnika vrste *Keratella quadrata* (O. F. Müller, 1786) so pogoste v Krnskem jezeru. Ovalna tvorba je jajce. (Foto: Anton Brancelj)
*Females of Rotatoria* Keratella quadrata *(O. F. Müller, 1786) are common in Krnsko jezero. The oval form is egg. (Photo: Anton Brancelj)*

začetku 20. let 20. stoletja, v Jezero na Planini pri Jezeru pa v zgodnjih 50. letih (Povž, 1997; Brancelj, 1999 b). Pred letom 1990 so bila le tri jezera naseljena z ribami (Krnsko jezero, Jezero na Planini pri Jezeru in Dupeljsko jezero). Sket (1992) sicer navaja, da so za izginotje podvrste planinskega pupka *Triturus alpestris lacus-nigri* iz Črnega jezera krive ribe, a do nedavnega o njihovi prisotnosti v tem jezeru ni bilo dokazov.

Po letu 1990 se je začelo intenzivno proučevanje zooplanktona in bentosa v jezerih v Julijskih Alpah. Raziskave so vključevale kvalitativne in kvantitativne analize zooplanktona ter kvalitativne analize bentosa. Ribe smo proučevali le občasno.




Ceponožni rak vrste *Pseudomoraria triglavensis*, Brancelj, 1994, je endemit, ki je znan samo iz Močivca. Posnetek je narejen z elektronskim vrstičnim mikroskopom. (Foto: Kazimir Drašlar)
*Scaning electron microscope micrograph of Copepod species* Pseudomoraria triglavensis, *Brancelj, 1994. The species is endemic and known only from Močivec. (Photo: Kazimir Drašlar)*

**ZOOPLANKTON**

V planktonu visokogorskih jezer smo našli predstavnike več vrst iz treh skupin živali: kotačnike (Rotatoria), vodne bolhe (Cladocera) in ceponožce (Copepoda). Od kotačnikov smo v vzorcih, pobranih poleti, našli predstavnike devetih vrst (preglednica 1). Živali niso bile prisotne v vseh jezerih, pa tudi številčnost predstavnikov posameznih vrst je bila nizka, razen pri treh vrstah. Najpogostejša vrsta je bila *Polyarthra dolichoptera* Idelson, 1925. Osebke te vrste smo našli v štirih jezerih, vendar nji-

(1992) reported that the extinction of *Triturus alpestris lacus-nigri* from Črno jezero was the result of fish in the lake, but until very recently there was no evidence of their presence.

After 1990, intensive studies on zooplankton and benthos in all the high-mountain lakes were started. They included qualitative and quantitative analyses of zooplankton and qualitative analyses of benthos. Fish have been studied only occasionally.

**ZOOPLANKTON**

Representatives of three planktonic groups have been recorded in the lakes: Rotatoria; Cladocera and Copepoda. Nine species of rotifers (Rotatoria) (Table 1) were recognised in summer samples from the lakes. They were not present in all lakes and their abundance was low, except for three taxa. The most common was *Polyarthra dolichoptera* Idelson, 1925, being recorded in four lakes, but population densities were low. *Keratella cochlearis* (Gosse, 1851) and *Keratella quadrata* (O. F. Müller, hove populacije niso bile velike. Osebke vrst *Keratella cochlearis* (Gosse, 1851) in *Keratella quadrata* (O. F. Müller, 1786) smo našli v treh jezerih, a le v Krnskem jezeru je bila populacija velika, še zlasti spomladi, ko se je stopil led. Edina vrsta, katere predstavniki so bili prisotni množično, je bila *Fillinia maior* (Colditz, 1924), in sicer v Krnskem jezeru. V poletnem času je bilo v epilimniju jezera v enem litru po nekaj deset tisoč osebkov in so močno prispevali k zmanjšanju prosojnosti jezerske vode. Vrsta je sicer značilna za evtrofna jezera. Osebki vrste *Lecane luna* (O. F. Müller, 1776) prav tako živijo le v evtrofnih jezerih. Našli smo jih v Krnskem jezeru in Jezeru na Planini pri Jezeru, vendar le v manjšem številu.

Osebki preostalih štirih vrst so bili redki in predstavniki vsake vrste so bili najdeni le v enem jezeru. Splošna značilnost za jezera v Julijskih Alpah je popolna odsotnost kotačnikov ali pa so njihove populacije zelo majhne. Planktonski kotačniki so predvsem filtratorji. Organske delce zbirajo iz vode s pomočjo migetalk kotačnega organa na "glavi", ki je pri nekaterih vrstah razdeljen v dva dela (trohalna diska). Večina visokogorskih jezer pri nas je (še) oligotrofnih in zaradi majhnih količin suspendiranih delcev je prosojnost vode velika. Ker so suspendirani delci glavni vir hrane za planktonske kotačnike, lahko v okolju z malo hrane preživi le nekaj vrst. Le v dveh evtrofnih jezerih (Krnsko jezero in Jezero na Planini pri Jezeru), kjer je koncentracija suspendiranih snovi velika, so tudi kotačniki pogosti in tudi število vrst je relativno visoko (preglednica 1).

Najpogostejši predstavniki zooplanktona so raki, in sicer ceponožci (Copepoda), in vodne bolhe (Cladocera). Pred letom 1996 so bili ceponožci in vodne bolhe prisotni v vseh jezerih (preglednica 1). V Dvojnem jezeru so popolnoma izginili po letu 1996 kot posledica naselitve rib v letu 1991 (Brancelj, 1999 b). Približno istočasno so izginili tudi iz Dupeljskega jezera. Jezero pod Vršacem je edino, kjer so planktonski raki redki brez vpliva človeka. V zgodnjih 90. letih je bilo to jezero skozi celo leto pokrito z ledom in snegom. Po letu 1994 se led na površini jezera sicer stopi vsako poletje, vendar so zaenkrat v jezeru prisotni le posamezni osebki vrste *Arctodiaptomus alpinus* (Imhof, 1885) (Copepoda).

Značilnost jezer v Julijskih Alpah je velika raznolikost v sestavi združb (Brancelj in sod., 1997). Najpogostejši planktonski vrsti sta *A. alpinus* in *Cyclops abyssorum tatricus* (Kozminski, 1927). V evtrofnih jezerih se tema dvema vrstama navadno pridružijo še predstavniki vrst *Chydorus sphaericus* (O. F. Müller, 1785) in *Eucyclops serrulatus* (Fischer, 1851) (preglednica 1). Štiri jezera (Zgornje in Sred-

1786) were each recorded in three lakes, but only in Krnsko jezero did their populations reach higher densities, particularly in early summer, after ice melt. The only species, present in abundance was *Fillinia maior* (Colditz, 1924), in Krnsko jezero. During the summer, several tens of thousands of specimens per litre can be present in the epilimnion of the lake and they contribute considerably to the low transparency of the water column. The species is an indicator of eutrophic environment. *Lecane luna* (O. F. Müller, 1776) was also found only in eutrophic lakes (Krnsko jezero and Jezero na Planini pri Jezeru) but in low numbers. Four additional species were present in low numbers, each in one lake only. It is characteristic of the lakes in the Julian Alps that rotifers are either absent of present in a very small numbers. Planktonic rotifers are predominantly filtrators. They collect organic particles from the water column by means of ciliated corona, in some groups divided into two trochal disks. Most of the lakes are still oligotrophic and have high transparency as a result of low concentrations of organic particles which are the most important food for the rotifers. In such lakes, very few taxa can exist. Only the two most eutrophic lakes (Krnsko jezero and Jezero na Planini pri Jezeru), with high concentrations of organic material, have dense populations of rotifers and higher numbers of taxa (Table 1).

The most numerous elements in zooplankton are crustaceans from the groups Cladocera and Copepoda. Before 1996, Copepoda and Cladocera were present in all lakes (see Table 1). In the two lakes of Dvojno jezero they completely disappeared after fish were introduced in 1991 (Brancelj, 1999 b) and the same happened in Dupeljsko jezero after 1996. The only lake in which, in the absence of human influence, zooplankton is rare, is Jezero pod Vršacem. In the early 1990s, the lake was covered permanently with snow and ice. Since 1994, its surface has been free during the summer, but only a few specimens of *Arctodiaptomus alpinus* (Imhof, 1885) have been found there.

The lakes in the Julian Alps are characterised by a large diversity in community structure (Brancelj *et al.*, 1997). The most common planktonic taxa are *A. alpinus* and *Cyclops abyssorum tatricus* (Kozminski, 1927). In the eutrophic lakes, both taxa are usually associated with *Chydorus sphaericus* (O. F. Müller, 1785) and *Eucyclops serrulatus* (Fischer, 1851) (Table 1). Four lakes (Zgornje and Srednje Kriško jezero, Zeleno jezero and Jezero v Ledvicah) have two zooplankton taxa in common: *A. alpinus* and *C.*

nje Kriško jezero, Zeleno jezero in Jezero v Ledvicah) imajo dve skupni planktonski vrsti: *A. alpinus*, *C. abyssorum tatricus*, medtem ko vrsto *Daphnia pulicaria* Forbes, 1893, značilno za obe Kriški jezeri, na-

*abyssorum tatricus*, while *Daphnia pulicaria* Forbes, 1893 common in both lakes of Kriška jezera is replaced in Zeleno jezero and Jezero v Ledvicah by *D. longispina*.

| | | Jezero pod Vršacem | Rjavo jezero | Zeleno jezero | Jezero v Ledvicah | Dvojno (Peto) jezero | Dvojno (Šesto) jezero | Črno jezero | Jezero na Planini pri Jezeru | Dupeljsko jezero | Krnsko jezero | Jezero v Lužnici | Zgornje Kriško jezero | Srednje Kriško jezero | Spodnje Kriško jezero |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ROTIFERA | *Brachionus angularis* Gosse, 1851 | | | | grey | | | | | | grey | | | | |
| | *Euchlanis dilatata* Ehrberg, 1832 | | | | | | | | | | | grey | | | |
| | *Euchlanis meneta* Myers, 1930 | | | | | | | | | | | grey | | | |
| | *Fillinia maior* (Colditz, 1924) | | | | | | | | | | grey | | | | |
| | *Keratella cochlearis* (Gosse, 1851) | | | | | | | | grey | | grey | grey | | | |
| | *Keratella qudrata* (O. F. Müller, 1786) | | | | grey | | | grey | | | grey | | | | |
| | *Polyarthra dolichoptera* Idelson, 1925 | grey | | | grey | | | | | | grey | | grey | grey | |
| | *Lecane luna* (O. F. Müller, 1776) | | | | | | | | grey | | grey | | | | |
| | *Trichotria pocillum* (O. F. Müller, 1776) | | | grey | | | | | | | | | | | |
| CLADOCERA | *Acroperus harpae* (Baird, 1836) | | | | | | blue | | | | | | | | |
| | *Alona affinis* (Leydig, 1860) | | | grey | | blue | blue | | | | | | | | grey |
| | *Chydorus sphaericus* (O. F. Müller, 1785) | | grey | grey | | blue | blue | | | | | | | | |
| | *Ceriodaphnia quadrangular* (O. F. Müller, 1785) | | | | | | | | green | | yellow | | | | |
| | *Daphnia longispina* O. F. Müller, 1785 | | | grey | grey | | | grey | grey | | | | | | grey |
| | *Daphnia pulicaria* Forbes, 1893 | | | | | | | | | | | | grey | grey | |
| | *Diaphanosoma brachyurum* (Lievin, 1848) | | | | | | | | grey | | | | | | |
| | *Eubosmina longispina* (Leydig, 1860) | | | | | | | | grey | | | | | | |
| | *Scapholeberis mucronata* (O. F. Müller, 1776) | | | | | | | | grey | | | | | | |
| COPEPODA | *Acanthodiaptomus denticornis* (Wierzejski, 1887) | | | | | | | grey | grey | | | | | | |
| | *Arctdiaptomus alpinus* (Imhof, 1885) | grey | grey | grey | grey | red | red | | | red | | grey | grey | grey | |
| | *Arctodiaptomus laticeps* (G. O. Sars, 1863) | | | | | | | | grey | | | | | | |
| | *Cyclops abyssorum tatricus* (Kozminski, 1927) | | | | grey | red | red | grey | | | | grey | grey | grey | grey |
| | *Cyclops strenuous* Fischer, 1851 | | | | | | | | grey | | | | | | |
| | *Cyclops vicinus* Uljanin, 1875 | | | | | | | | | | grey | | | | |
| | *Eucyclops serrulatus* (Fischer, 1851) | | grey | | | blue | blue | | | | | grey | | grey | |
| | *Eudiaptomus hadzici* (Brehm, 1939) | | | | | | | | light green | | | | | | |
| | *Heterocope saliens* (Lilljeborg, 1863) | | | | | | | grey | magenta | | | | | | |

- grey: prisotna; *present*
- red: iztrebljena leta 1996, po naselitvi rib; *eliminated in 1996, after fish introduction*;
- blue: prisotna v planktonu po letu 1996; *present in zooplankton after 1996;*
- green: občasno prisotna v planktonu; *present from time to time in plankton;*
- magenta: zelo redka / izumrla po letu 1995; *very rare/extinct after 1995;*
- yellow: prisotna v planktonu leta 2001; *present in plankton in 2001;*
- light green: prisotna le leta 1994; *present only in 1994*

Preglednica 1: Taksoni kotačnikov (Rotatoria), vodnih bolh (Cladocera) in ceponožcev (Copepoda), ki so bili v obdobju med 1991 in 2001 ugotovljeni v jezerih Julijskh Alp (Slovenija).
*Table 1: Taxa of Rotifera, Cladocera and Copepoda in zooplankton present in the lakes in the Julian Alps (Slovenia) between 1991 and 2001*

domesti v Zelenem jezeru in Jezeru v Ledvicah vrsta *D. longispina.* Naslednja štiri jezera (Jezero v Lužnici, Rjavo jezero, obe jezeri v Dvojnem jezeru) so imela podobno sestavo planktona, vendar brez predstavnikov iz rodu *Daphnia.* Danes v Dvojnem jezeru zaradi naselitve rib ni več predstavnikov planktonskih vrst, temveč so le še predstavniki vrst *C. sphaericus* in *E. serrulatus.* Le-ti se običajno zadržujejo v bentosu, v planktonu pa jih najdemo le v plitvih evtrofnih jezerih (Brancelj, 2001). Podoben pojav smo lahko opazovali v plitvem Dupeljskem jezeru. Med letoma 1991 in 1996 je bila v tem jezeru bogata populacija vrste *A. alpinus.* Vodo iz jezera pa so kot edini vir pitne vode uporabljali v bližnjem planinskem domu (Koča pri Krnskih jezerih). Po letu 1996 so naselili v jezero pisance (*Phoxinux phoxinux* Linnaeus, 1758), ki so v kratkem času povsem iztrebili populacijo ceponožca vrste *A. alpinus.* Kvaliteta vode v jezeru se je poslabšala, obenem pa so se množično razmnožile nitaste zelene alge. V vodnem stolpcu pa so se pojavili redki osebki vrst *C. sphaericus* and *E. serrulatus.*

Evtrofno Krnsko jezero ima močno osiromašeno zooplanktonsko združbo, kar je verjetno posledica naselitve rib po letu 1920. V planktonu so osebki le ene vrste ceponožcev, *Cyclops vicinus* Ulianin, 1875, ki je značilna za evtrofna jezera (kot npr. Blejsko jezero). V letu 2001 pa smo v jezeru prvič našli tudi nekaj osebkov vodne bolhe vrste *Ceriodaphnia quadrangula* (O. F. Müller, 1785), sicer značilne prebivalke toplih in evtrofnih jezer.

Največje število planktonskih vrst rakov smo ugotovili v Jezeru na Planini pri Jezeru. Od leta 1991 smo ugotovili predstavnike devetih vrst, od katerih se dve pojavljata le občasno (preglednica 1). Predstavnikov še ene vrste, *D. brachyurum,* ki sta jo navedla Seliškar in Pehani (1935), v zadnjem času nismo našli. Ribe so v jezero naselili okoli leta 1957 (Povž, 1997). Danes prevladujejo v planktonu vrste, katerih odrasli osebki so majhni. Najpogostejša je vodna bolha vrste *Eubosmina longispina* (Leydig, 1860), značilna prebivalka evtrofnih jezer. Tej vrsti po številčnosti sledijo osebki treh vrst ceponožcev: *Acanthodiaptomus denticornis* (Wierzejski, 1887), *Arctodiaptomus laticeps* (Sars, 1863) in *Cyclops strenuus* Fischer, 1851. Osebki nadaljnjih dveh vrst ceponožcev iz skupine Calanoida, *Eudiaptomus hadzici* (Brehm, 1939) in *H. saliens,* niso bili v jezeru pogosti niti pred letom 1996, po tem letu pa so povsem izginili. Vrsta *E. hadzici* je endemna za območje Balkana in Jezero na Planini pri Jezeru je bilo njeno najbolj severozahodno nahajališče. Intenzivno rdeče obarvani osebki vrste *H. saliens* spadajo med

Four more lakes (Jezero v Lužnici, Rjavo jezero and both lakes of Dvojno jezero) have a similar composition, though the genus *Daphnia* is absent. In Dvojno jezero, there have been no planktonic taxa except *C. sphaericus* and *E. serrulatus,* since the introduction of fish. Both are common inhabitants of the benthos, but frequently present in zooplankton of shallow eutrophic lakes (Brancelj, 2001). A similar process was observed in a shallow lake, Dupeljsko jezero. A rich population of *A. alpinus* existed there between 1991 and 1996. Water from the lake was used for a long time as a source of drinking water for the nearby mountain hostal. After 1996 they introduced fish (*Phoxinux phoxinux* Linnaeus, 1758), which completely exterminated *A. alpinus.* Water quality deteriorated and, together with the mass appearance of filamentous green algae, a few specimens of *C. sphaericus* and *E. serrulatus* were observed in the water column.

Krnsko jezero, a highly eutrophic lake, has a heavily modified zooplankton community, probably the result of fish introduction in the early 1920s. Only one copepod taxon, *Cyclops vicinus* Ulianin, 1875, which is characteristic of eutrophic lakes, like Lake Bled, is the main constituent of the population. In 2001 for the first time, *Ceriodaphnia quadrangula* (O. F. Müller, 1785), a common inhabitant of warm and eutrophic lakes, was also recorded there.

The greatest number of planktonic taxa was observed in the eutrophic Jezero na Planini pri Jezeru. Nine taxa have been recorded there since 1991, two of them sporadically (Table 1). An additional one, *D. brachyurum,* reported by Seliškar and Pehani (1935), has not been recorded there in recent times. The lake has been populated by fish since 1957 (Povž, 1997). Among the zooplankton, small bodied taxa prevail. *Eubosmina longispina* Leydig, 1860) is the most common species, and is characteristic of the eutrophic lakes. *Acanthodiaptomus denticornis* (Wierzejski, 1887), *Arctodiaptomus laticeps* (Sars, 1863) and *Cyclops strenuus* Fischer, 1851, are the next most common taxa. Two additional calanoids, *Eudiaptomus hadzici* (Brehm, 1939) and *H. saliens* used to be present in the lake in very low numbers, but since 1996 they have not been recorded there any more. *E. hadzici* is endemic in the Balkans and the lake has been recorded as its most north-westerly location. The intensely red coloured *H. saliens* is among the biggest calanoids in Europe and is the preferred prey for fish. This species can undergo significant oscillations in population size. In the nearby lake Črno jezero, the species was very


Odrasle samice vrste *Chydorus sphaericus* (O. F. Müller, 1785). Levo: samica s partenogenetskim jajcem; v sredini: samica s trajnim jajcem; desno: grbasta oblika, ki se pojavi le pozno v jeseni. (Foto: Anton Brancelj)

*Adult females of* Chydorus sphaericus *(O. F. Müller, 1785). Left: female with parthenogenetic egg; middle: female with resting egg; right: hump-backed form, which appears only in late autumn. (Photo: Anton Brancelj)*

največje ceponožce v Evropi in so kot taki zelo lahek plen za ribe. Velikost populacije te vrste lahko iz leta v leto močno niha. V bližnjem Črnem jezeru so bili osebki te vrste v obdobju 1991–1995 zelo pogosti tako v obrežnem pasu kot tudi v vodnem stolpcu (skupaj z osebki vrst *D. longispina*, *A. denticornis* and *C. abyssorum tatricus*). Naslednje leto pa so skoraj povsem izginili iz jezera. Istočasno so se v jezeru pojavile številne majhne vodne stenice (verjetno vrsta *Hesperocorixa sahlbergi* (Fieber, 1848)), ki jih prej v jezeru nismo opazili. Dodatno smo opazili tudi nekaj ravno izleglih mladic rib, ki smo jih določili kot pisance. Naslednje leto (1997) je populacija vodnih stenic začela upadati, temu pa je hitro sledilo povečanje populacije vrste *H. saliens*, ki je v letu 2000 dosegla podobno gostoto, kot jo je imela pred letom 1995. Vodne stenice pa so povsem izginile. Poleti leta 2001 je bil obrežni pas gosto poseljen z osebki vrste *H. saliens.* Istočasno pa smo med kamenjem na severni strani jezera opazili več majhnih ribic, verjetno pisancev, dolgih okoli 5 cm. V plitvi vodi smo opazili še dve jati komaj izleglih ribic in v vsaki jih je bilo okoli 50.

Nekoliko nenavadno sestavo zooplanktona smo ugotovili v skupini treh Kriških jezer, ki so geografsko blizu skupaj. Zgornje in Srednje Kriško jezero (nadmorska višina 2150 m in 1950 m) imata enako vrstno sestavo zooplanktona, ki pa je povsem različna od tiste v Spodnjem Kriškem jezeru (nadmorska višina 1880 m) (preglednica 1). Od štirih vrst, kolikor jih je bilo ugotovljenih v vseh treh jezerih, so le osebki ene vrste, *C. abyssorum tatricus,* prisotni v vseh treh jezerih. *A. alpinus*, katere osebki so prisotni v obeh gornjih jezerih, ni bila nikoli najdena v spodnjem jezeru. Namesto osebkov vrste *D. pulicaria*, ki ima v obeh zgornjih jezerih veliki populaciji, pa so v Spodnjem Kriškem jezeru prisotni le osebki vrste *D. longispina.* Ta vrsta je sicer pogosta v jezerih v Dolini sedmerih triglavskih jezer. Nekoliko nenavadna razporeditev osebkov navedenih štirih vrst verjetno ni posledica naravnih pogojev, ampak je k njihovi razporeditvi prispeval človek. Med prvo svetovno vojno in tudi še po njej (obdobje 1914–1945) je bila v neposredni bližini spodnjega jezera kasa-

common from 1991 to 1995 in the littoral zone as well as in the water column (along with *D. longispina, A. denticornis* and *C. abyssorum tatricus*), but in 1996 it almost disappeared. In the same year we observed a sharp increase of a population of small water bugs (probably *Hesperocorixa sahlbergi* (Fieber, 1848)) which had not been recorded there before. In the same year, we observed several newly hatched fish. The following year, in 1997, the population of water bugs started to decrease and the population of *H. saliens* to increase. In 2000, the population of *H. saliens* was at a level similar to that before 1995, while water bugs had disappeared completely. In the autumn of 2001, the littoral zone of the lake was densely populated by *H. saliens.* At the same time we observed several fish, about 5 cm in length, hiding among boulders near the shore, and two groups of newly hatched fish, each of about 50 individuals.

An unusual zooplankton community was recorded in the group of three geographically close lakes of Kriška jezera. Zgornje and Srednje Kriško jezero, at elevations of 2150 and 1950 m, respectively, have identical zooplankton compositions, but quite different from those in Spodnje Kriško jezero, an elevation of 1880 m (Table 1). Of the four planktonic taxa present, only one, *C. abyssorum tatricus*, is present in all the lakes. *A. alpinus*, a common inhabitant of both higher altitude lakes, was never recorded in the lower one. Instead of *D. pulicaria*, a common inhabitant of Zgornje and Srednje Kriško jezero, *D. longispina*, a common inhabitant of some lakes in the Triglav Lakes Valley is present in Spodnje Kriško jezero. This rather unusual distribution of taxa is probably not a result of natural conditions but of human impact. During the first Word War and for some years after (the period between 1914 and 1945), there was a military base in the vicinity of the lower lake, which was used as a water supply for humans and animals. This probably inrna, vodo iz jezera pa so rabili tudi za pitje ljudi in živine, kar je verjetno vzrok za spremembo vrstne sestave zooplanktona. Tega pa žal nismo mogli potrditi tudi z analizami ostankov vodnih bolh v sedimentu (glej poglavje 12).

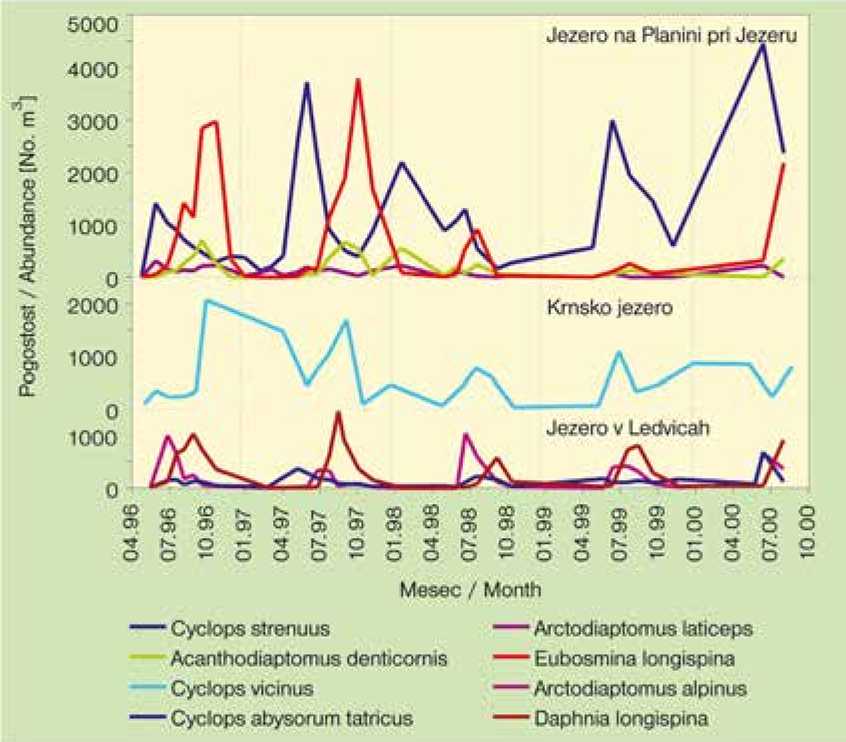
V jezerih Julijskih Alp smo v obdobju 1991–2001 opazovali več oblik dinamike zooplanktonskih združb. V eni skupini so jezera s stalno zooplanktonsko združbo. Ta jezera so oligotrofna in/ali so pod minimalnim vplivom človekove dejavnosti (vsa tri Kriška jezera, Rjavo in Zeleno jezero, Jezero v Ledvicah in Jezero v Lužnici). Nasprotno smo v treh jezerih, v katera so pred kratkim naselili ribe (obe jezeri v Dvojnem jezeru in Dupeljsko jezero), ugotovili popolno izginotje zooplanktona. V Jezeru na Planini pri Jezeru je v tem obdobju prišlo do zmanjšanja števila planktonskih vrst. V primeru dveh jezer je prišlo do povečanja števila zooplanktonskih vrst z naselitvijo ene vrste (Krnsko jezero ter Jezero pod Vršacem). V Črnem jezeru pa smo lahko spremljali ponovno naselitev osebkov ene vrste.

***Populacijsko dinamiko*** zooplanktona smo podrobneje sledili v treh jezerih (Jezero v Ledvicah, Krnsko jezero in Jezero na Planini pri Jezeru) (slika 1). V obdobju od pomladi leta 1996 do jeseni 2000 smo v naštetih jezerih jemali vzorce zooplanktona v rednih mesečnih intervalih v času, ko niso bila pokrita z ledom. Število planktonskih vrst, ki smo jih proučevali v posameznem jezeru, je bilo različno (od ene oz. dveh vrst v Krnskem jezeru do pet v Jezeru na Planini pri Jezeru). Najbolj pravilen vzorec nihanj v gostoti populacij je bil v Jezeru v Ledvicah (slika 1 – spodnji graf), kjer so bile največje gostote zooplanktona konec poletja oz. v začetku jeseni. V tistem obdobju je bilo med 500 in 1000 osebkov m$^{-3}$ za vsako od treh vrst. Spomladi, potem ko se je maja stopil led, v vodnem stolpcu ni bilo nobene odrasle živali ali mladiča. Čez približno mesec dni so se najprej pojavili navpliji (= mlajša oblika ličinke) in kopepoditi (= starejša oblika ličinke) vrste *Cyclops abyssorum tartricus*, kmalu za njimi pa še vrste *Arctodiaptomus alpinus.* Sredi junija so se pojavili še prvi mladi osebki vrste *Daphnia longispina.* Pri vseh treh vrstah so se potomci razvili iz jajc, ki so jih prejšnjo jesen odrasle samice odložile in so potem potonila na dno. V približno dveh mesecih so se kopepoditi, po več levitvah, preobrazili v odrasle živali, sposobne razmnoževanja. Pri rodovih *Cyclops* in *Arctodiaptomus* se samci razvijajo hitreje in so že spolno zreli, ko se spolno zrele samice šele začenjajo pojavljati v populaciji. Samci so bili v vseh letih za 2–3-krat bolj številčni kot samice. Samice

duced changes in zooplankton structure. Unfortunately, we were not able to confirm this with records of Cladocera remains in the sediment (see Chapter 12).

In the lakes of the Julian Alps from 1991 to 2001, we have observed several different types of dynamics of zooplankton composition. In the first group are the lakes with constant zooplankton structures. The lakes are oligotrophic and/or with low human influence (three lakes of Kriška jezera, Rjavo and Zeleno jezero, Jezero v Ledvicah and Jezero v Lužnici). In three lakes recently populated by fish (both lakes of Dvojno jezero and Dupeljsko jezero), elimination of zooplankton was recorded. In addition, in Jezero na Planini pri Jezeru, the number of zooplankton taxa decreased. In two lakes, Krnsko jezero and Jezero pod Vršacem, new species invaded the lakes, while in Črno jezero, reappearance of one species was noted.

***The population dynamics*** of zooplankton in three lakes (Jezero v Ledvicah, Krnsko jezero and Jezero na Planini pri Jezeru) were studied in detail (Figure 1). In the period from spring 1996 to autumn 2000, zooplankton samples were collected at monthly intervals during the ice-free period. The number of planktonic species studied varied from one or two in Krnsko jezero to five in Jezero na Planini pri Jezeru. The most regular pattern of population density oscillations was observed in the lake Jezero v Ledvicah (Figure 1 – lower graph), where the maximum was in late summer and early autumn. At that time, between 500 and 1000 specimens m$^{-3}$ of each of three planktonic species were recorded. In the spring, after ice melt in May, no adult or juvenile specimens could be found in the zooplankton. After about a month, nauplia and copepodites (= older stage of larvae) of *Cyclops abyssorum tartricus* appeared, followed by those of *Arctodiaptomus alpinus.* In mid-June, young specimens of *Daphnia longispina* were also present. From all three taxa, new generations developed from the resting eggs, which had been deposited on the bottom of the lake by adults in late autumn of the previous year. In a period of about two months, copepodites developed into adults capable of reproducing. In *Cyclops* and *Arctodiaptomus*, males become mature before the appearance of females, which they can outnumber by a factor of two or three. Females first collect the fertilised eggs, enveloped by a hard shell, into egg bags (one in *Arctodiaptomus*; two in *Cyclops*). After several days, they are released into the water column. The eggs sink to the bottom and rest there




Slika 1: Kvalitativni (vrstna sestava) in kvantitativni podatki (abundanca kot št. osebkov m$^{-3}$) o zooplanktonu iz treh jezer (Jezero v Ledvicah, Krnsko jezero in Jezero na Planini pri Jezeru) v Triglavskem narodnem parku (Slovenija) za obdobje od poletja 1996 do poletja 2000

*Figure 1: Qualitative (species composition) and quantitative data (abundance in No. of individuals m$^{-3}$) on zooplankton from three lakes (Jezero v Ledvicah, Krnsko jezero and Jezero na Planini pri Jezeru) from the Triglav National Park (Slovenia) for a period from summer 1996 to summer 2000*

po oploditvi zberejo jajca, ki so obdana s trdnim ovojem, v jajčne vrečke (ena pri rodu *Arctodiaptomus* in dve pri rodu *Cyclops*) in jih nato po nekaj dneh odložijo v vodni stolpec. Jajca potonejo na dno, kjer ležijo do naslednje pomladi in se iz njih izležejo navpliji. Pri obeh vrstah se tako izvali le po ena generacija na leto z množičnim pojavom navplijev vsako pomlad. Pri osebkih iz rodu *Daphnia* pa se razvije po več generacij na leto. Pozno spomladi se iz t. i. trajnih jajc, ki so obdana s trdnim ovojem (tvorba se imenuje sedelca), izležejo mlade vodne bolhe. Vsi mladiči so samice. V obdobju enega ali dveh tednov, odvisno od temperature vode, odrastejo in začnejo odlagati jajca. Ta sicer niso oplojena (t. i. deviškorodna jajca), a se kljub temu iz njih razvije popolna nova vodna bolha, običajno spet samica. Vsaka samica lahko tako izleže tudi po nekaj deset neoplojenih jajc in populacija vodnih bolh zelo hitro narašča. Proti jeseni pa se iz neoplojenih jajc izvali vse več samcev, tako da je sredi jeseni v populaciji že prav toliko samcev kot samic ali še celo več. Ko samci dokončno odrastejo, se začnejo pariti z odraslimi samicami, ki začno izlegati oplojena jajca. Značilno za ta jajca je, da so obdana s trdnejšim ovojem. Preden pa samica dokončno odloži oplojeno jajce, se še levi in del starega oklepa samice ovije jajce, tako da je še dodatno zaščiteno proti izsušitvi, nizkim ali visokim temperaturam ter nudi tudi dodatno mehansko zaščito. Jajce z

until the next spring. In both taxa, only one generation is produced each year, with a mass of larvae in late spring. In *Daphnia*, there are several generations per year. In late spring young specimens develop from the resting eggs, which are protected in a special structure called ephippium. All young specimens are females. In two or three weeks, depending on the water temperature, they become mature and start to produce eggs. Although these eggs are not fertilised by males (so-called parthenogenetic eggs), they can develop into new young *Daphnia*, the majority being females. Each female produces several tens of such eggs during the summer and the population of *Daphnia* grows fast. In the autumn, more and more males develop from non-fertilised eggs. In mid-autumn, the number of males in a population was found to be the same or even higher than number of females. They start to mate with females, and eggs produced by females get fertilised and their shells become harder. Before they are released, the female undergoes moult and part of the old carapace changes into a special envelope for additional protection of the fertilised egg. The whole structure is called the ephippium and is resistant to low and high temperatures and loss of water, and it provides additional mechanical resistance. In the following year, or even after several years, a young *Daphnia* will develop from it. In the last six years, in the lake Jezero v Ledvicah there dodatnim ovojem se imenuje sedelce (efipij oz. ephippium), ker po nastanku in obliki nekoliko spominja nanj. Iz oplojenega jajca se naslednje leto (ali šele čez nekaj let) razvije mlada vodna bolha. V zadnjih letih pri zooplanktonu iz Jezera v Ledvicah ni bilo opaziti trendov sprememb v gostoti populacije.

V Krnskem jezeru je bila v zooplanktonu do nedavnega (do leta 2000) zastopana samo ena vrsta, in sicer *C. vicinus*. Pri tej ni bilo opaziti nobene izrazite sezonske populacijske dinamike. Gostota populacije je močno nihala med majhnimi (> 100 osebkov m$^{-3}$) in velikimi gostotami (1000–2000 osebkov m$^{-3}$) (slika 1 – srednji graf). Populacija ima izrazit dolgoročen trend upadanja od leta 1996, ko je imela svojo največjo gostoto. Nestabilnosti v jezeru še dodatno potrjuje pojav osebkov toploljubne vrste *Ceriodaphnia quadrangula* poleti leta 2001. Osebki vrste *C. vicinus* so v vodnem stolpcu vse leto. V nasprotju s samicami podvrste *C. abyssorum tatricus* samice vrste *C. vicinus* ne tvorijo trajnih jajc in tudi sezona njihovega razmnoževanja je daljša. Kmalu po oploditvi se iz jajc izležejo navpliji, ki prosto plavajo po vodnem stolpcu. Po nekaj levitvah (praviloma pet) se preobrazijo v kopepodite. Le-ti se lahko naprej razvijajo in še isto sezono dosežejo spolno zrelost. Del poletne generacije kopepoditov pa ubere drugačno pot. Na določeni stopnji razvoja, običajno kopepoditi IV ali V, potonejo na dno jezera, kjer počivajo nekaj mesecev, običajno čez zimo. Pojav je poznan kot diapavza. Kopepoditi lahko nekaj časa preživijo tudi pri nizkih koncentracijah kiska, kar je običajen pojav proti koncu zime v globljih delih jezer. Naslednjo pomlad kopepoditi splavajo v vodni stolpec, kjer nadaljujejo normalen razvoj v odrasle živali.

V najbolj evtrofnem jezeru, Jezeru na Planini pri Jezeru, so v vodnem stolpcu štiri pogostejše vrste planktonskih rakov. Podobno kot v Krnskem jezeru so tudi v tem jezeru močna nihanja v gostoti populacije posamezne vrste. V nasprotju s prejšnjim jezerom pa je v Jezeru na Planini pri Jezeru splošna tendenca naraščanja gostote populacije posameznih vrst. V tem jezeru so vsako leto tri dobro definirane faze v letnem ciklu zooplanktonske združbe (slika 1 – zgornji graf). V času, ko je jezero pokrito z ledom, je gostota zooplanktonske populacije nizka. Najnižje gostote so pozno pozimi oz. zgodaj spomladi. Kmalu po stalitvi ledu (navadno aprila) se je vsako leto najprej hitro povečala gostota populacije vrste *Cyclops strenuus*. Čez nekaj časa, običajno od sredine junija naprej, se je populacija te vrste močno zmanjšala, močno pa je narasla populacija vodne bolhe vrste *Eubosmina longispina*, ki je imela običajno podobno gostoto populacije kot

has been no trend in change of summer population density.

In Krnsko jezero, until recently, only *C. vicinus* was present in the water column. No particular pattern of seasonal population dynamics could be recognised (Figure 1 – middle graph). Its population oscillates considerably between low densities (less that 100 specimens m$^{-3}$) and high densities (from 1000 to 2000 specimens m$^{-3}$). Its population has experienced a clear long-term decline from the maximum in 1996. Instability in the lake is additionally supported by the appearance of warm-water species, *Ceriodaphnia quadrangula,* in summer 2001. Specimens of *C. vicinus* were present in the water column all the time because of their life history. Unlike *C. abyssorum tatricus,* females of *C. vicinus* do not produce resting eggs and their reproduction time is longer. Within a short time of fertilisation of the eggs, nauplia are released from egg sacs. They swim freely in the water column. After five moults, they develop into copepodites. Copepodites can progress with metamorphosis and they grow into adults in the same season. Part of the autumn generation of copepodites make use of an additional strategy. At a certain moment, copepodites IV or V sink to the bottom of the lake and rest there for a few months, normally during the wintertime. The phenomenon is known as a diapause. They can survive for some time under the low oxygen concentrations, which are common in winter in deeper parts of the lake. The next spring they swim into the water column and continue with normal development into adults.

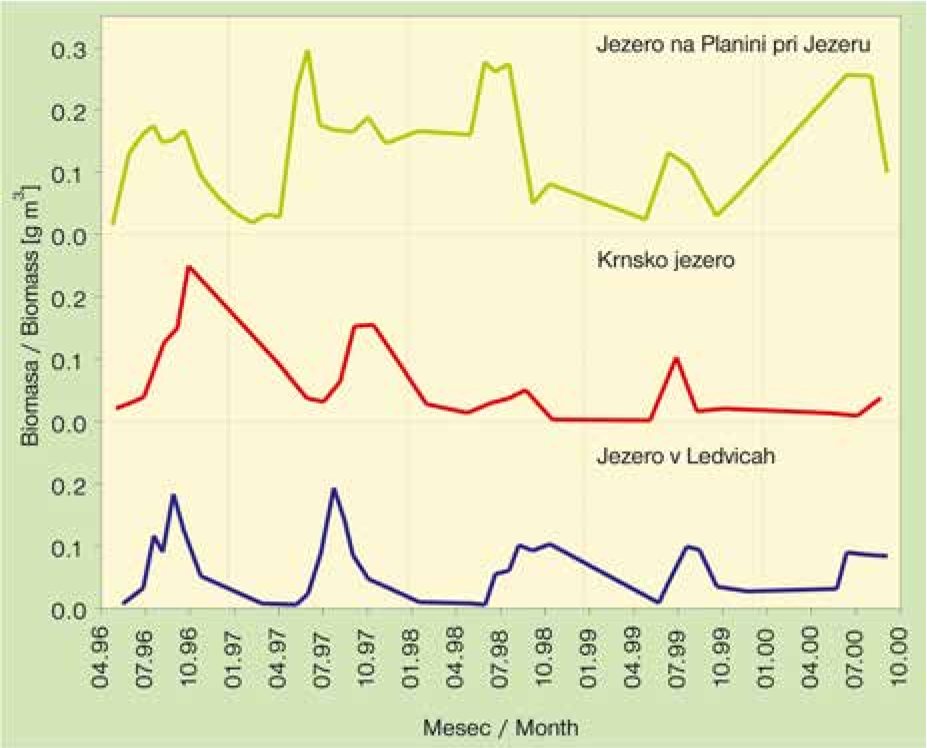
In the most eutrophic lake, Jezero na Planini pri Jezeru, four dominant species are present in the water column. As in Krnsko jezero, considerable oscillations in population density of particular species were observed. In contrast, however, there is a general tendency for the overall zooplankton density to increase. Three different and well defined stages in the zooplankton community could be distinguished each year (Figure 1 – upper graph). During the ice cover, the zooplankton population was low all the time, with a minimum in late winter or early spring. Shortly after ice melt, a sharp increase in the population of *Cyclops strenuus* was observed each year. A few months later, usually from mid-June onward, its population decreased considerably and was replaced by a population of *Eubosmina longispina,* with population densities comparable to the latter species. A further two species, *Acanthodiaptomus denticornis* and *Arctodiaptomus laticeps,* reached their population maxima in that peri-

*Cyclops*. Približno istočasno sta svoj vrh gostote populacije dosegli še drugi dve vrsti, *Acanthodiaptomus denticornis* in *Arctodiaptomus laticeps*, vendar je velikost njunih populacije precej manjša kot tista pri rodu *Eubosmina*. Zooplankton v Jezeru na Planini pri Jezeru je značilen za evtrofna jezera. Prevladujejo vrste, ki imajo majhne osebke (*E. longispina*, *A. laticeps*), ali pa prevladujejo mlajši (in s tem manjši) razvojni stadiji (*C. strenuus*). Med sezono imajo kopepoditi vrste *C. strenuus* zelo visoko stopnjo smrtnosti. V nasprotju s Krnskim jezerom, kjer kopepoditi lahko preživijo krajše obdobje na dnu jezera, to v Jezeru na Planini pri Jezeru ni možno, saj je večji del leta že pet metrov pod gladino skoraj popolna anoksija (odsotnost kisika). Tako večina osebkov, ki zaradi diapavze potonejo na dno, zaradi pomanjkanja kisika kmalu propade.

***Biomasa zooplanktona*** je v Jezeru v Ledvicah, Krnskem jezeru ter Jezeru na Planini pri Jezeru v času proučevanj v grobem sledila nihanjem gostote populacij (slika 2), vendar korelacija ni bila visoka. Razlike so rezultat različnih telesnih mas mladih in odraslih osebkov iste vrste kot tudi razlik v telesni masi osebkov različnih vrst. V Jezeru v Ledvicah biomasa doseže največje vrednosti v kratkem času in nato v pozni jeseni tudi hitro upade (slika 2 – spodnji graf). V obdobju 1996–2000 je bil trend upadanja biomase, in sicer od približno 0,2 mg DW m$^{-3}$

od, but both had much less dense populations. The presence of zooplankton in the lake is characteristic of eutrophic lakes, with small-bodied taxa (*E. longispina* and *A. laticeps*) and juvenile stages (*C. strenuus*) dominating. In the course of the season copepodites of *Cyclops* suffer high mortality. In contrast to Krnsko jezero, where copepodites are able to survive several months on the bottom of the lake, in lake Jezero na Planini pri Jezeru they cannot, because of the complete absence of oxygen below 5 m for most of the year. Thus most of specimens, which practice diapause, are condemned to die.

***The biomass of zooplankton*** in Jezero v Ledvicah, Krnsko jezero and Jezero na Planini pri Jezeru followed patterns of oscillation (Figure 2) during the period studied, which were similar to those of population density, but the correlation was not very high. The differences are a result of the different body mass of juveniles and adults as well as of adults of different taxa. In Jezero v Ledvicah, biomass reaches its maximum in a very short time and decreases sharply in late autumn. Over the last five years (1996–2000) there was a tendency of biomass to decrease from a maximum of about 0.2 mg DW m$^{-3}$ (1996–1997) to about 0.1 mg DW m$^{-3}$ (1998–2000) (Figure 2 – lower graph). A much sharper decrease of maximal biomass was observed in Krnsko jezero – from about 0.25 mg DW m$^{-3}$ in 1996 to




Slika 2: Nihanja biomase zooplanktona v Jezeru v Ledvicah, Krnskem jezeru in Jezeru na Planini pri Jezeru (Triglavski narodni park, Slovenija) za obdobje od poletja 1996 do poletja 2000
*Figure 2: Oscillations of the biomass of zooplankton in the lakes Jezero v Ledvicah, Krnsko jezero and Jezero na Planini pri Jezeru (Triglav National Park; Slovenia) in a period from summer 1996 to summer 2000*

(1996/97) na okoli 0,1 mg DW $m^{-3}$ (1998–2000) (DW = suha masa zooplanktona). Še bolj intenzivno znižanje biomase je bilo opaziti v Krnskem jezeru, kjer so se vrednosti znižale od okoli 0,25 mg DW $m^{-3}$ (v letu 1996) na okoli 0,05 mg DW $m^{-3}$ (po letu 1998) (slika 2 – srednji graf). Nasproten trend pa je bil v Jezeru na Planini pri Jezeru, kjer se je največja vrednost biomase povečala, in sicer od okoli 0,15 mg DW $m^{-3}$ v letu 1996 na blizu 0,4 mg DW $m^{-3}$ v letu 2001 (slika 2 – zgornji graf). Vendar je bila v letu 1998 ta vrednost nizka, in sicer le okoli 0,12 mg DW $m^{-3}$. Težko je narediti neke splošne zaključke o gibanju največjih vrednosti biomas, saj smo v treh jezerih opazovali dva popolnoma različna trenda.

Vzorci, ki smo jih v obdobju 1997–2000 vsak konec poletja pobrali za oceno biomase v štirinajstih jezerih v Julijskih Alpah, so imeli najvišje vrednosti, in so bili tudi najbolj stabilni, v jezerih Kriške skupine. Povprečna biomasa, izmerjena v teh treh jezerih konec vsakega poletja, je bila okoli 0,15 mg DW $m^{-3}$ (razpon od 0,1 do 0,3 mg DW $m^{-3}$). Naslednji jezeri, kjer so se te vrednosti od leta do leta najmanj spreminjale, sta bili Jezero v Ledvicah ter Jezero v Lužnici, kjer so bile povprečne vrednosti okoli 0,1 mg DW $m^{-3}$. V nasprotju z navedenimi jezeri so se biomase zooplanktona konec poletja v obravnavanem obdobju najbolj spreminjale v Jezeru na Planini pri Jezeru, in sicer od manj kot 0,05 mg DW $m^{-3}$ do okoli 0,25 mg DW $m^{-3}$. V ostalih jezerih v Dolini sedmerih triglavskih jezer so bile konec poletja razmeroma nizke vrednosti biomase, navadno pod 0,1 mg DW $m^{-3}$. Izjemi sta bili Jezero pod Vršacem (brez zooplanktona) ter Dvojno Peto jezero, kjer je bila sploh kdajkoli izmerjena najvišja vrednost biomase v Julijskih Alpah (0,45 mg DW $m^{-3}$). In sicer je bilo to leta 1997, le eno leto pred popolnim iztrebljenjem zooplanktona.

***Telesno dolžino ter število jajc v jajčnem paketu*** smo ugotavljali pri odraslih samicah vrste

*Arctodiaptomus alpinus*, ki je najbolj razširjena planktonska vrsta v Julijskih Alpah. Samice so bile nabrane jeseni leta 1994 v osmih jezerih (Vidmar, 1996). Tako telesna dolžina kot število jajc v jajčnem paketu sta se močno spreminjali od jezera do jezera (preglednica 2) in upadala z nadmorsko višino jezer. Največje vrednosti obeh parametrov smo izmerili pri samicah iz Dvojnega jezera, kjer je bilo v povprečju 60 jajc v paketu. Ta populacija je bila iztrebljena leta 1998, nekaj let po naselitvi rib. Najmanjšo telesno dolžino in najmanjše število jajc v jajčnem paketu (v povprečju okoli 10 jajc) pa so imele samice iz najvišje ležečih jezer (Zgornje Kriško jezero in Rjavo jezero). Samice iz Dvojnega je-

about 0.05 mg DW $m^{-3}$ after 1998 (Figure 2 – middle graph). In Jezero na Planini pri Jezeru, the opposite tendency was observed. In the last five years, the maximum biomass increased from about 0.15 mg DW $m^{-3}$ (in 1996) to almost 0.4 mg DW $m^{-3}$ (in 2001), with a very low value in 1998 (about 0.12 mg DW $m^{-3}$) (Figure 2 – upper graph). Two different patterns of biomass trends were observed in the three lakes and it is difficult to draw any common conclusions.

Biomass samples collected in all fourteen lakes in the Julian Alps in late summer (end of August, beginning of September) from 1997 to 2000, reached their highest, and the most constant, values in the Kriška jezera. In all three lakes, the average biomass of zooplankton was about 0.15 mg DW $m^{-3}$ (ranging from 0.1 to 0.3 mg DW $m^{-3}$). The next most stable lakes were Jezero v Ledvicah and Jezero v Lužnici, with average values of about 0.1 mg DW $m^{-3}$ and these values showed small oscillations over four years. Jezero na Planini pri Jezeru exibited large oscillations in autumnal biomass, ranging from less than 0.05 mg DW $m^{-3}$ to 0.25 mg DW $m^{-3}$. Other lakes in the Triglav Lakes Valley had relatively low autumnal biomass, usually below 0.1 mg DW $m^{-3}$. Exceptions were Jezero pod Vršacem (no zooplankton at all) and Dvojno jezero (north basin). In Dvojno jezero we recorded the highest biomass (0.45 mg DW $m^{-3}$) ever recorded in any lake of the Julian Alps. It was in 1997, just one year before the complete disappearance of zooplankton in the lake.

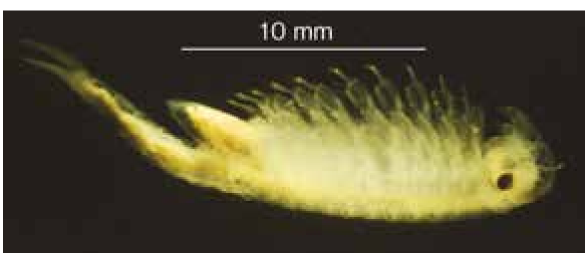
***Body size and clutch size*** (number of eggs per clutch) were studied in adult females of *Arctodiaptomus alpinus*, the most common planktonic species in the high-mountain lakes of the Julian Alps. They were collected from eight lakes in the autumn of 1994 (Vidmar, 1996). The body size of adult females and the clutch size varied considerably from one lake to another (Table 2) and decreased with altitude. The largest body size and clutch size (on average over 60 eggs) were recorded in the population from the lake Dvojno jezero. The population has been extinct since 1998, after fish introduction. The smallest females and clutch size (on average about 10 eggs) were recorded in high-altitude lakes (Zgornje Kriško jezero, Rjavo jezero). Females from Dvojno jezero had probably the biggest values ever recorded for both parameters. Introduction of fish completely eliminated the population. Re-population from resting eggs in the sediment of both lakes is unlikely because of intensive fish predation.

zera so imele verjetno največjo znano telesno dolžino za to vrsto in tudi daleč največje število jajc. Naselitev rib je to populacijo popolnoma iztrebila. Vzpostavitev prvotne populacije iz trajnih jajc, ki so še na dnu jezera, pa se iz leta v leto zmanjšuje, še zlasti zaradi intenzivnega plenjenja s strani rib.


Tri odrasle samice vrste *Arctodiaptomus alpinus* (Imhof, 1885) z različno obarvanimi jajci v jačnem paketu. Osebki iz Dvojnega jezera so bili med telesno največjimi primerki, vendar so bili po naselitvi rib iztrebljeni. (Foto: Anton Brancelj)
*Three adult females of* Arctodiaptomus alpinus *(Imhof, 1885) with differently coloured eggs in egg bags. Specimens from Dvojno jezero were among the largest known but after introduction of fish they became extinct. (Photo: Anton Brancelj)*

| | Zgornje Kriško jezero | Rjavo jezero | Srednje Kriško jezero | Zeleno jezero | Jezero v Ledvicah | Jezero v Lužnici | Dvojno (Peto) jezero | Dvojno (Šesto) jezero |
|---|---|---|---|---|---|---|---|---|
| Dolžina telesa Body length (mm) | 1.08 | 1.37 | 1.06 | 1.04 | 1.06 | 1.21 | 1.62 | 1.68 |
| Širina telesa Body width (mm) | 0.41 | 0.56 | 0.41 | 0.40 | 0.42 | 0.48 | 0.69 | 0.68 |
| Število jajc No. of eggs | 9 | 14 | 11 | 6 | 7 | 13 | 48 | 62 |

Preglednica 2: Nekateri morfometrični podatki za osebke vrste *Arctodiaptomus alpinus* (Imhof, 1885) iz osmih jezer v Julijskih Alpah (Slovenija) (populacije so bile pobrane v letu 1994)
*Table 2: Some morphometric data of* Arctodiaptomus alpinus *(Imhof, 1885) from eight lakes in the Julian Alps, (Slovenia) (populations collected in 1994)*




Rakce vrste *Chirocephalus diaphanus* Prevost, 1803 (Anostraca) lahko najdemo zgodaj spomladi v presihajoči Mlaki v Dolu pod Stadorjem. (Foto: Anton Brancelj)
*Fairy shrimp* Chirocephalus diaphanus *Prevost, 1803 (Anostraca) can be found early in spring in a temporary pool Mlaka v Dolu pod Stadorjem. (Photo: Anton Brancelj)*

## BENTOS (= živali, ki živijo na dnu)

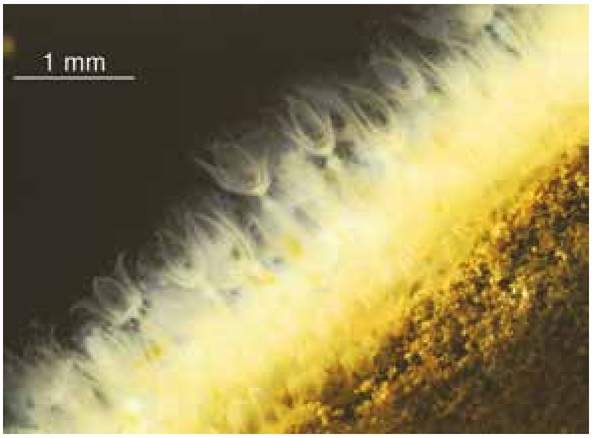
Edini ***mali vodni nevretenčarji (mikroinvertebrata***) (velikost do 5 mm), ki smo jih intenzivneje proučevali v jezerih, so bili ceponožci (Copepoda) in vodne bolhe (Cladocera). Osebki vrst *Chydorus sphaericus* (Cladocera) in *Eucyclops serrulatus* (Copepoda) so edini, ki smo jih našli v vseh jezerih, razen v Jezeru na Planini pri Jezeru (Brancelj in sod., 1997). V večini jezer živijo tudi grbasti osebki vrste *Chydorus spahericus* (Brancelj, 1996), ki jih je Kreis

## BENTHOS (= bottom-dwelling organisms)

The only ***microinvertebrates*** (size of up to 5 mm) studied qualitatively in the lakes are Copepoda and Cladocera. *Chydorus sphaericus* (Cladocera) and *Eucyclops serrulatus* (Copepoda) are the only taxa present in all the lakes, except Jezero na Planini pri Jezeru (Brancelj *et al.*, 1997). In most of them, a special hump-back form of *Chydorus* (Cladocera) was recorded (Brancelj, 1996) described from a high-mountain Swiss lake as *Chydorus mutilus* by

| | |
|---|---|
| 1 : | ***Acroperus harpae*** **(Baird, 1836)** |
| 2 : | ***Alona affinis*** **(Leydig, 1860)** |
| 3 : | ***Alona guttata*** **G. O. Sars, 1862** |
| 4 : | ***Alona quadrangularis*** **(O. F. Müller, 1785)** |
| 5 : | ***Alona rectangula*** **G. O. Sars, 1862** |
| 6 : | ***Alonella excisa*** **(S. Fischer, 1854)** |
| 7 : | ***Alonella nana*** **(Baird, 1843)** |
| 8 : | ***Chydorus piger*** **G. O. Sars, 1862** |
| 9 : | ***Chydorus sphaericus*** **(O. F. Müller, 1785)** |
| 10 : | ***Graptoleberis testudinaria*** **(Fischer, 1848)** |
| 11 : | ***Pleuroxus aduncus*** **(Jurine, 1820)** |
| 12 : | ***Pleuroxus truncatus*** **(O. F. Müller, 1785)** |
| 13 : | ***Simocephalus vetulus*** **(O. F. Müller, 1776)** |

Preglednica 3: Seznam bentoških vrst vodnih bolh iz jezer Triglavskega narodnega parka (Slovenija)
*Table 3: List of benthic Cladocera from the Triglav National Park (Slovenia)*




Mahovnjaki (Bryozoa) so pogosti v stoječih vodah, kjer je veliko suspendirane organske snovi. V Julijskih Alph živijo v Jezeru na Planini pri Jezeru ter v Krnskem jezeru. So indikatorji evtrofnega stanja jezer. (Foto: Anton Brancelj)
*Moss animals (Bryozoa) are common in standing water with a lot of suspended organic material. In the Julian Alps, they are known from Jezero na Planini pri Jezeru and Krnsko jezero They are indicators of the eutrophic condition of the lakes. (Photo: Anton Brancelj)*

(1921) iz švicarskih jezer najprej opisal kot pripadnike vrste *Chydorus mutilus*. Poleg te vrste živijo na dnu jezer še predstavniki drugih 12 vrst vodnih bolh (preglednica 3). Nekatere med njimi smo v visokogorskih jezerih našli samo v Jezeru na Planini pri Jezeru (*Graptoleberis testudinaria* (Fischer, 1848), *Pleuroxus aduncus* (Jurine, 1820), *P. truncatus* (O. F. Müller, 1785)). Ceponožci so zastopani s predstavniki 17 vrst, od katerih jih večina pripada skupini Cylopoida, šest pa skupini Harpacticoida. Iz skupine Cyclopoida so zlasti pogosti osebki vrste *Megacyclops viridis* (Jurine, 1820), ki živijo kar v devetih jezerih. Iz skupine Harpacticoida so najpogostejši osebki vrste *Bryocamptus rhaeticus* (Schmeil, 1893), ki jih najdemo v istih jezerih kot osebke predhodne vrste. Med vsemi vrstami iz skupine Harpacticoida je verjetno najbolj zanimiva *Pseudomoraria triglavensis*, Brancelj 1994, ki je bila opisana po osebkih iz izvira Močivec, poleg Dvojnega jezera. To je zaenkrat edino znano nahajališče te vrste na svetu. V obrežnem pasu Jezera na Planini pri Jezeru smo našli tudi osebke nekaterih drugih pogostih vrst ceponožcev in vodnih bolh (*Elaphoidella gracilis* (G. O. Sars, 1863)*, Cryptocyclops bicolor* (G. O. Sars, 1863), *Eucyclops macrurus* (G. O. Sars, 1863) in *Macrocyclops albidus* (Jurine, 1820)).

***Veliki vodni nevretenčarji (macroinvertebrata)*** (velikost > 5 mm) živijo v obrežnem pasu vseh jezer, vendar število vrst in osebkov z nadmorsko višino upada. Osebki preko 50 različnih taksonov (kar ni enako vrst) so bili najdeni v obrežnem pasu jezer, vendar jih je bilo le okoli polovica določenih do

Kreis (1921). An additional 12 taxa of Cladocera were recorded in the lakes (Table 3), and some of them, *Graptoleberis testudinaria* (Fischer, 1848), *Pleuroxus aduncus* (Jurine, 1820) and *P. truncatus* (O.F. Müller, 1785) only from Jezero na Planini pri Jezeru. Copepoda are represented by 17 taxa, eleven of them belonging to the group Cylopoida and six to Harpacticoida. Among Cyclopoida, the next most common species is *Megacyclops viridis* (Jurine, 1820) (in nine lakes). Of the Harpacticoida, the most common species is *Bryocamptus rhaeticus* (Schmeil, 1893), found in the same nine lakes. The most interesting species is *Pseudomoraria triglavensis* Brancelj, 1994. It was described from the spring Močivec, near Dvojno jezero. This is the only known location of the species. In the littoral zone of the lake Jezero na Planini pri Jezeru, some additional and well-known taxa were found (*Elaphoidella gracilis* (G. O. Sars, 1863) *Cryptocyclops bicolor* (G. O. Sars, 1863), *Eucyclops macrurus* (G. O. Sars, 1863) and *Macrocyclops albidus* (Jurine, 1820)).

***Macroinvertebrates*** (> 5 mm) were recorded in the littoral zone of all the lakes, but there is a clear decrease in quality and quantity with altitude. More than 50 different taxa were recorded in the lakes, vrste. Tako po številu vrst kot po številu osebkov izstopajo dvokrilci iz skupine trzač (Chironomidae, Diptera; Insecta), kjer je bilo ugotovljenih preko 24 taksonov, ter maloščetinci (Oligochaeta), kjer smo našli predstavnike štirih družin. Osebki iz teh dveh skupin so bili najdeni v vseh jezerih, vendar je podrobno poznavanje njihove vrstne sestave zelo pomanjkljivo.

Pijavke (Hirudinea) živijo v treh jezerih. V Krnskem in Dupeljskem jezeru živijo osebki vrste *Helobdella stagnalis* (Linnaeus, 1758), medtem ko v Jezeru na Planini pri Jezeru živijo predstavniki druge vrste, *Erpobdella octoculata* Linnaeus, 1758. Školjke so zastopane le z osebki vrste *Pisidium casertanum* (Poli 1791) (grašec), ki jih lahko najdemo v jezerih v Dolini sedmerih jezer (od 3. do 7. jezera ter v Jezeru na Planini pri Jezeru). Dodatno smo jih našli tudi v Dupeljskem jezeru. Podobno razporeditev ima tudi polž mali mlakar (*Lymnaea truncatula* (O. F. Müller, 1774)), ki živi tudi v Krnskem jezeru, medtem ko so bili polži vrste *Gyraulus cristatus* (Linnaeus, 1758) najdeni le v Jezeru na Planini pri Jezeru. Kačje pastirje (Odonata) lahko opazujemo le okoli Jezera na Planini pri Jezeru. Doslej so bile tam ugotovljene štiri vrste: *Aeshna cyanea* (O. F Müller, 1764), *A. juncea*, (Linnaeus, 1758), *Somatochlora metallica* (van der Linden, 1825) in *Calopteryx virgo* (Linnaeus, 1758). Ličinke in odrasle živali so plenilci. Medtem ko ličinke lovijo druge nevretenčarje v vodi, jih odrasli lovijo na kopnem med letom. Enodnevnice (Ephemeroptera) smo doslej našli le v jezerih v Dolini sedmerih jezer. Osebki vrste *Siphlonurus lacustris* (Eaton, 1870) so bili pred naselitvijo rib pogosti v petih jezerih. Njihova populacija je še sedaj zelo velika v Jezeru v Ledvicah, za katero so značilne tudi zelo velike larve. Osebki druge vrste, *Ecdyonurus aurantiacus* (Burmeister, 1839), so bili pred naselitvijo rib zelo pogosti v Dvojnem jezeru, sedaj pa so skoraj izginili. Vodni hrošči (Colleoptera) so prav tako pogosti v jezerih, manjkajo le v Jezeru pod Vršacem ter Jezeru na Planini pri Jezeru. Osebki vrste *Agabus bipustulatu* (Linnaeus, 1758) so bolj razširjeni kot osebki vrste *Hydroporus nivalis* (Heer, 1839), ki jih lahko najdemo le v Kriških jezerih, Rjavem jezeru ter Jezeru v Ledvicah.

Med bolj zanimivimi je tudi vrsta *Chirocephalus diaphanus*, Prevost, 1803, ki spada v skupino primitivnih rakov Anostraca. Osebki te vrste živijo v Mlaki v Dolu pod Stadorjem, na pol poti med Črnim jezerom ter Jezerom na Planini pri Jezeru (Brancelj in Gorjanc, 1999). Jajca, ki jih odlagajo samice v blato na dno mlake, lahko vzdržijo tako ekstremne temperature kot tudi sušo (t. i. trajna jajca). Le

but only some of them have been determined to the species level. The most numerous groups, qualitatively and quantitatively, are Chironomidae (Diptera, Insecta; more that 24 taxa recorded) and Oligochaeta (representatives of four families). They were found in all the lakes, but knowledge about their taxa is still very poor.

Leeches (Hirudinea) are present in three lakes. In Krnsko jezero and Dupeljsko jezero *Helobdella stagnalis* (Linnaeus, 1758) is present, while lake Jezero na Planini pri Jezeru is populated by *Erpobdella octoculata* Linnaeus, 1758. Clams (Bivalvia) are represented by one species, *Pisidium casertanum* (Poli 1791), which is present in the Triglav Lakes Valley (3rd – 7th lakes) and in Jezero na Planini pri Jezeru and Dupeljsko jezero. Snails (Gastropoda) have a similar distribution. *Lymnaea truncatula* (O. F. Müller 1774) was found in the Triglav Lakes Valley (3rd – 7th lake) and in Krnsko jezero. In Jezero na Planini pri Jezeru, *Gyraulus cristatus* (Linnaeus, 1758) was found. Dragonflies (Odonata) are present only in Jezero na Planini pri Jezeru. Up to now, four species (*Aeshna cyanea* (O. F. Müller, 1764), *A. juncea*, (Linnaeus, 1758), *Somatochlora metallica* (van der Linden, 1825), and *Calopteryx virgo* (Linnaeus, 1758)) were recorded. Larvae and adults are predators. Larvae prey upon water invertebrates, while adults catch their prey during flight. Mayflies (Ephemeroptera) are present only in the Triglav Lakes Valley. Specimens of *Siphlonurus lacustris* (Eaton, 1870) were present before fish introduction in five lakes in the Triglav Lakes Valley. The population in the lake Jezero v Ledvicah is very abundant and individual larvae are very large. The second species from the same group, *Ecdyonurus aurantiacus* (Burmeister, 1839), was present in both lakes of Dvojno jezero but is now almost extinct because of intensive fish predation. Beetles (Colleoptera) are among the most common taxa in high-mountain lakes though absent in two lakes (Jezero pod Vršacem and Jezero na Planini pri Jezeru). Specimens of *Agabus bipustulatu* (Linnaeus, 1758) were found in most of the lakes, while specimens of *Hydroporus nivalis* (Heer, 1839) are present only in Kriška jezera, Rjavo jezero and Jezero v Ledvicah.

Among the most interesting taxa is *Chirocephalus diaphanus*, Prevost, 1803, from the group of Anostraca, the most primitive group of crustaceans. It was found in the puddle Mlaka v Dolu pod Stadorjem, between lakes Črno jezero and Jezero na Planini pri Jezeru (Brancelj & Gorjanc, 1999). Its resting eggs can survive extreme temperatures and dry conditions in mud or dust. Just a few days after nekaj dni potem, ko mlako napolni deževnica ali snežnica, se iz jajc izležejo larve, ki čez dva do tri tedne odrastejo in se parijo. Samice nato do konca življenja odložijo na dno mlake po nekaj sto trajnih jajc.

V nekaj jezerih živijo pod kamni v bližini brega tudi rakci iz skupine postranic (Amphipoda), natančneje iz rodu slepih postranic (*Niphargus*). Predstavniki tega rodu so sicer zelo pogosti v jamah in izvirih. Ker je zaledje vseh jezer kraško, njihova prisotnost v obrežnem pasu ni presenetljiva, še zlasti, ker je njihovih plenilcev oziroma tekmecev tam malo.

Ličinke mladoletnic (Trichoptera) so v vseh jezerih zelo pogoste, izjema je le Jezero na Planini pri Jezeru. Predstavniki vsaj sedmih različnih vrst živijo v visokogorskih jezerih, med njimi pa so najpogostejši osebki vrst *Allogamus uncatus* (Brauer, 1857), *Chaetopteryx fusca* Brauer, 1857 in *Limnephilus coenosus* Curtis, 1834 (Brancelj in sod., 1995). V zadnjih petih letih sta se populaciji vrst *A. uncatus* in *L. coenosus* v Dvojnem jezeru močno zmanjšali kot posledica plenjenja s strani rib.

Mahovnjaki (Bryozoa) so kolonijske živali, ki živijo v stoječih ali počasi tekočih vodah z veliko suspendirane organske snovi. So pokazatelji evtrofnega stanja jezer. V Julijskih Alpah so znani iz dveh jezer – Jezero na Planini pri Jezeru in Krnsko jezero. V Jezeru na Planini pri Jezeru smo prve kolonije našli leta 1993 pod kamni v bližini ponora. V Krnskem jezeru smo jih prvič opazili leta 1996, in sicer med kamenjem plazu, ki prihaja v jezero izpod Velikega Šmohorja. Za mahovnjake je značilna produkcija posebnih prezimovalnih razmnoževalnih oblik (statoblastov), ki navadno lebdijo na vodi v bližini brega med drugimi organskimi delci. To jim omogoča, da se na perju ptic ali na krznu sesalcev prenašajo od enega jezera ali mlake do drugega in tam osnujejo nove kolonije.

## RIBE

Trenutno je šest jezer naseljenih z ribami: Krnsko jezero, Dupeljsko jezero, Jezero na Planini pri Jezeru, Črno jezero ter obe jezeri v Dvojnem jezeru. Za večino jezer so znani le kvalitativni podatki, t.j. vrstna sestava rib.

V Dupeljskem jezeru smo ribe prvič opazili leta 1992, in sicer so bili to pisanci (*Phoxinus phoxinus* (Linnaeus, 1758)). Verjetno so bili naseljeni šele pred kratkim, in sicer so jih tja prinesli turisti. Jezero je bilo v tistem času še vir pitne vode za bližnjo kočo. Da ribe niso bile prav dolgo tam, se je videlo tudi po tem, da je bila takrat v jezeru še velika po-

rain, larvae hatch from the eggs. Within two or three weeks, they become mature and copulate. During their lifetime females produce several hundred resting eggs, which are deposited on the bottom of the puddle.

In several lakes, specimens of the blind shrimp (Amphipoda) from the genus *Niphargus* were found under the stones near the shore. Specimens of the genus are very common in caves and springs. As the surroundings of all the lakes are karstic, their appearance in the littoral zone of the lakes is expected, particularly because of absence of predators or competitors.

Larvae of caddis flies (Trichoptera) are very common in all the lakes except Jezero na Planini pri Jezeru. At least seven different species were recorded, with *Allogamus uncatus* (Brauer, 1857), *Chaetopteryx fusca* Brauer, 1857 and *Limnephilus coenosus* Curtis, 1834, being the most common (Brancelj *et al.*, 1995). Over the last few years, the population of *A. uncatus* and *L. coenosus* in Dvojno jezero decreased because of intensive fish predation.

Moss animals (Bryozoa) are colonial inhabitants of standing water or slow rivers with a lot of suspended organic material. They are indicators of eutrophication. In the Julian Alps they are known in two lakes – Jezero na Planini pri Jezeru and Krnsko jezero. In the former, colonies were found in 1993 under the stones next to the sinkhole. In Krnsko jezero, they were found in 1996 under the stones on the scree slope entering the lake from the foothill of the mountain Veliki Šmohor. The production of overwintering statoblasts is characteristic of moss animals and they float among the debris on the surface of water. In this way, they may be transported on the plumage of birds or on animal fur to other ponds, where they start new colonies.

## FISH

At present, fish inhabit six lakes: Krnsko jezero, Dupeljsko jezero, Jezero na Planini pri Jezeru, Črno jezero and both lakes in Dvojno jezero. For most of the lakes only qualitative data about species composition exist.

In Dupeljsko jezero, we saw fish for the first time in 1992. It was the minnow (*Phoxinus phoxinus* (Linnaeus, 1758)), most likely introduced recently by tourists in the end of 1980s. The lake was at that time still used as a water supply for the nearby hut. The existence of a large population of *A. alpinus* indicated that fish had recently been introduced. Wapulacija ceponožcev vrste *A. alpinus*. Kvaliteta vode v jezeru se je začela slabšati po letu 1997, ko so se ob bregu okoli jezera pojavile nitaste zelene alge. Populacija *A. alpinus* se je začela krčiti in v letu 2000 je popolnoma izginila.

V Črnem jezeru smo prvič opazili pisance jeseni leta 1996, ko smo ulovili 12 mm dolgo mladico. Leta 1999 smo v plitvi vodi na seveni strani jezera, v zavetju skal, opazovali še več podobno velikih ribic. V letu 2001 smo na istem mestu opazili več okoli 5 cm dolgih osebkov, v plitvi vodi pa dve jati ribic. V vsaki je bilo okoli 50 mladic. O naselitvi rib v Črno jezero ni nobenih pisnih virov. Sket (1992) navaja, da je verjetno izginotje neotenične oblike planinskega pupka iz tega jezera posledica rib, a za to nimamo nobenih dokazov. Kot zanimivost naj navedem, da smo vsako leto, od leta 1991 naprej, v vodem stolpcu lahko opazovali številne odrasle osebke planinskega pupka (*Triturus alpestris*), ki so se hranili s planktonskimi rakci (*Daphnia, Heterocpe*).

V Krnsko jezero so naselili ribe kmalu po letu 1920, in sicer jezersko zlatovčico (*Salvelinus alpinus* (Linnaeus, 1758)) ter pisance (Povž, 1997). Osebki obeh vrst še vedno živijo v jezeru in jezersko zlatovčico celo lovijo. Koliko rib ujamejo vsako leto in kakšne so njihove mere (dolžina in masa), ni znano. Trenutno je v planktonu le ena vrsta rakov, in sicer *Cyclops vicinus* (poleg redkih osebkov vrste *Ceriodaphnia quadrangula*). Analize ostankov vodnih bolh v sedimentu, ki so obsegale obdobje zadnjih 100 let, so potrdile odsotnost planktonskih vodnih bolh v jezeru tudi pred naselitvijo rib (Brancelj, neobjavljeno). Iz tega ne moremo sklepati, kako so ribe vplivale na spremembo sestave zooplanktona v zadnjem stoletju. Posredni dokaz o močnem vplivu rib na živalstvo v jezeru najdemo le med bentoškimi organizmi. Kljub intenzivnemu vzorčenju v obrežnem pasu skozi več let, smo le redko nabrali večje število velikih vodnih nevretenčarjev. Nekaj osebkov si je našlo zavetje le med velikimi kamni in skalami ob bregu. Glavni razlog za razredčeno živalstvo v obrežnem pasu so jate pisancev, ki ves čas "patruljirajo" vzdolž brega. V nasprotju z nekaterimi drugimi vrstami rib pisanci pri svojem hranjenju ne brskajo po sedimentu, ampak iščejo svoj plen z očmi in ga pobirajo posamič.

V Jezeru na Planini pri jezeru so ribe od leta 1951, ko so vanj naselili klena (*Leuciscus cephalus* (Linnaeus, 1758)), koreslja (*Carassius carassius* (Linnaeus, 1758)) ter eno salmonidno vrsto, verjetno jezersko zlatovčico (Povž, 1997). Sedaj v jezeru najdemo le klene in koreslje, saj je tretja vrsta izginila iz jezera kmalu po naselitvi. Analize ostankov vod-

ter quality started to decline after 1997, when a rim of filamentous green algae appeared all around the lake shore. The population of *A. alpinus* started to decreaase and it had completely disappeared in 2000.

Minnows were observed for the first time in Črno jezero in 1996, when a 12 mm long specimen was caught. In 1999, several specimens of the same size were observed among boulders in the shallow water on the northern bank. In 2001 several specimens about 5 cm long were observed at the same spot and two groups of about 50 specimens, about 12 mm long, were seen nearby. There is no information about the introduction of fish into the lake. Sket (1992) reported that the extinction of a neotenic form of alpine newt from the lake was probably a result of fish, but there is no proof for this. In fact, each year since 1991 we have observed several adults of *Triturus alpestris* in the water column, feeding on zooplankton (*Daphnia, Heterocope*).

Krnsko jezero was populated by fish in the early 1920s, when arctic charr (*Salvelinus alpinus* (Linnaeus, 1758)) and minnow were introduced (Povž, 1997). Both species are still present and arctic char is considered as a game fish. The number of fish removed from the lake each year, and their biometric data (length and weight) are not available. At present, the only planktonic crustacean there is *Cyclops vicinus* (apart from the rare *Ceriodaphnia quadrangula*). Analysis of a sediment core, covering a time span of the past 100 years or so, confirms the absence of other pelagic Cladocera before fish introduction (Brancelj, unpubl.). There is no information on how fish changed the zooplankton community during the last century. Indirect evidence of intensive fish predation on invertebrates can be recognised in the benthos. We carried out an exhaustive sampling programme over several years, but found hardly any macroinvertebrates in the littoral zone. Some can just survive in crevices among the boulders and rocks in the littoral zone. The main reason for their complete absence is the dense population of minnows, continually "patrolling" the lake shore. Minnows do not disturb sediment during their feeding but they detect and pick up their prey individually by sight.

In the lake Jezero na Planini pri Jezeru fish have been present since 1951 when chub (*Leuciscus cephalus* (Linnaeus, 1758)), crucian carp (*Carassius carassius* (Linnaeus, 1758)) and one unidentified salmonid species, probably an arctic charr, were put into the lake (Povž, 1997). Today, only chub and crucian carp are present, the salmonid species having disappeared soon after being introduced. Analnih bolh v sedimentu so pokazale, da je kmalu po naselitvi rib prišlo do velikih sprememb v sestavi zooplanktona, še zlasti v velikosti populacij posameznih vrst (Brancelj in sod., 2000). Največje spremembe so bile v populaciji vrste *D. longispina*, ki je priljubljena hrana rib. Ta vrsta je skoraj povsem izginila iz jezera v zgodnjih 60. letih in jo je nadomestila telesno manjša vrsta *Eubosmina longispina* (Leydig, 1860). Istočasno pa sestava sedimenta kaže na povečano evtrofizacijo. Osebkom vrste *E. longispina* delajo dandanašnji družbo še osebki petih drugih vrst ceponožcev in vodnih bolh in so bodisi telesno majhni ali pa imajo majhne populacije (Brancelj in sod., 1997). Majhne telesne velikosti zooplanktonskih organizmov niso v tolikšni meri rezultat intenzivnega plenjenja s strani rib kot v nekaterih drugih jezerih (Wetzel, 1983), temveč so posledica evtrofnega stanja jezera. Glavni vzrok zanj so prehranjevalne navade koreslja, ki si išče hrano v velikih skupinah v bližini brega. Normalen način prehrane pri koresljih je brskanje po blatu, kjer iščejo večje nevretenčarje. Zato tudi v tem jezeru najdemo le manjše število osebkov raznih nevretenčarjev. Ob iskanju hrane živali ves čas dvigajo blato. Hranilne snovi iz sedimenta, skupaj s tistimi, ki jih deževnica spere s travnikov oz. so prišle v jezero z odplakami iz bližnje koče, povzročajo bujno rast alg. Goste populacije velikih alg močno ovira zbiranje hrane velikim zooplanktonskim organizmom in v tem primeru so majhne živali v prednosti. Kot posledica je sprememba vrstne sestave zooplanktona (Wetzel, ibid.). Populaciji obeh vrst rib sta danes precej stabilni in med drstenjem koresljev lahko tik pod površino jezera opazujemo velike jate rib, ki plavajo sem ter tja.

Do naselitev rib, natančneje jezerske zlatovčice (*S. alpinus*) v Dvojno jezero, je prišlo leta 1991, ko so vanj vložili okoli 20 osebkov. V desetih letih smo v jezeru lahko spremljali njegovo spremembo iz oligotrofnega v evtrofno kot posledica naselitve (Brancelj, 1999 b, 2001). Drstenje je bilo prvič opaženo v oktobru leta 1994. Najljubše mesto je bilo ob iztoku majhnega izvira, ki je zapolnjen z gruščem, v severnem delu jezera. V prvem letu smo opazovali 10–12 odraslih samic, ki so se zadrževale na posameznih mestih ob obali severnega (Petega) jezera, medtem ko jih v južnem (Šestem) jezeru ni bilo. Po letu 1994 smo lahko opazovali drstenje vsako jesen in število rib je do leta 1999 že močno naraslo. V novembru leta 1999 smo naredili prvi poskus izlova rib. Uporabili smo lebdeče mreže in v štirih urah se je ulovilo blizu 200 rib. Naslednji poskus je bil spomladi leta 2000. Vsega skupaj smo ulovili

ysis of cladoceran remains in a sediment core indicate that considerable changes in the zooplankton community occurred soon after fish introduction, particularly in relative species abundance (Brancelj *et al.*, 2000). The most affected planktonic species was *D. longispina*, a preferred prey of fish. It almost disappeared from the lake in the early 1960s and was replaced by the small-bodied *Eubosmina longispina* (Leydig, 1860). At the same time, the sediment structure indicates an increase of eutrophication. *E. longispina* now co-exists with five Copepoda and Cladocera taxa which are either small or have small population sizes (Brancelj *et al.*, 1997). The small body size of zooplankton in the lake is not a result of intensive fish predation, as in some other lakes (Wetzel, 1983), but of intense eutrophication of the lake. The main reason for this is the feeding behaviour of the crucian carp, which search for food in big shoals in the littoral zone. Their most common way of feeding is to ransack the sediment in shallow water for different invertebrates. Consequently, only a limited number of species and specimens of invertebrates can be found in the littoral zone of the lake. During feeding, carp re-suspend sediment all the time. Nutrients from the sediment, together with those in-washed from the lake shore, and additional input of wastewater from the nearby hut intensified the growth of algae. The dense population of large algae interfere with the food gathering of large-bodied zooplankton and small-bodied species are thus favoured, leading to a shift in zooplankton size (Wetzel, ibid.). Populations of both fish taxa are today quite stable and, during the spawning season, shoals of carp can be seen in several groups roaming the lake or near the shore.

Arctic charr, *S. alpinus*, were intrduced into Dvojno jezero in 1991, when about 20 specimens were released. Within ten years, there was clear evidence of transformation of the lake from oligotrophic to eutrophic status, induced by fish (Brancelj, 1999 b, 2001). Spawning was observed for the first time in October 1994. The preferred spawning spot was at the stone-filled mouth of a small underwater spring in the northern basin. A total of 10–12 adult females were observed at that period at different points in the shallow water of the northern basin, but not in the southern one. From 1994, spawning was observed regularly each year and the population increased considerably until 1999. In November 1999, there was an attempt to remove fish from the lake. Gill nets were used and within four hours about 200 specimens were caught. In spring 2000, an additional attempt was made. In total, about 240 okoli 240 rib, neznano število rib, predvsem manjših, pa je še ostalo v jezeru.

Najdaljša zlatovčica, ki smo jo ujeli, je bila samica in je merila v dožino 36 cm, njena masa pa je bila 290 g. Bilo je tik pred drstenjem in je bila zato še polna iker. Najmanjša ujeta samica, ki je imela ikre, je bila dolga 22 cm in je tehtala 89 g. Ulovili pa smo tudi odraslo samico, ki je merila v dolžino 19,5 cm in je tehtala 59 gr, a je že odložila ikre. Razmerje med telesno maso in telesno dolžino je naraščalo eksponentno po formuli:

$$\text{telesna masa} = e^{[2{,}77 * \ln \text{(telesna dolžina)} -4{,}22]}$$

(r = 0,996; N = 64; november 1999) (slika 3). Razmerje spolov pri odraslih osebkih je bilo približno ena samica na štiri samce.

Pred naselitvijo rib sta v jezeru živeli dve planktonski vrsti ceponožcev (*Cyclops abyssorum tatricus* in *Arctodiaptomus alpinus*). V prvih petih letih po naselitvi rib sta bili populaciji obeh ceponožcev dokaj stalni. Do največje spremembe je prišlo v letih 1994–1995, ko so se zlatovčice drstile prvič. Od tedaj se je populacija vrste *A. alpinus* v južnem (Šestem) jezeru zelo naglo manjšala in je leta 1998 povsem izginila. V severnem (Petem) jezeru je bilo izumrtje odloženo za eno leto. Nabolj ranljivi osebki (t. j.

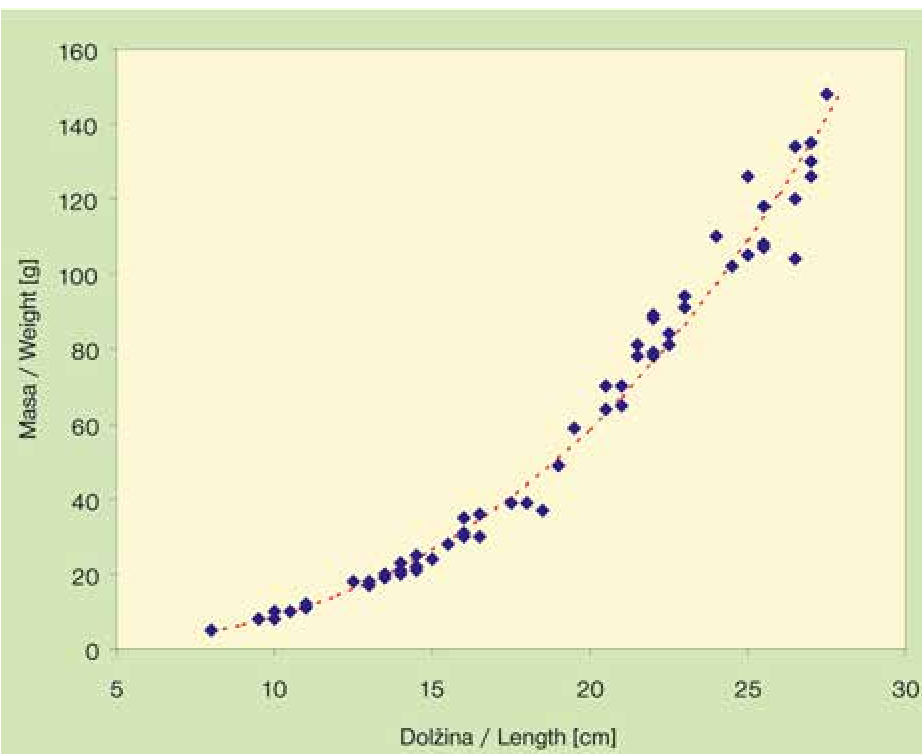
fish were removed, leaving an unknown number, mainly of small specimens.

The longest specimen caught, was a female with a body length of 36 cm and body mass of 290 g. It was the period just before spawning and she was full of eggs. The smallest female caught with eggs at that time measured 22 cm and weighed 89 g, but we found a 19.5 cm long female (weight of 59 g) which had already released her eggs. The relation between body mass and body length follows an exponential curve:

$$\text{body mass} = e^{[2.77 * \ln \text{( body legth)} -4.22]}$$

(r = 0.996; N = 64, November 1999) (Figure 3). The sex ratio in adults at that time was about one female to four males.

Before fish introduction, two copepod species (*Cyclops abyssorum tatricus* and *Arctodiaptomus alpinus*) constituted the macrozooplankton community. In the first few years after fish introduction, the population of both species was relatively constant. The most extreme change was noticed in 1994/1995, when charr spawned for the first time. From then on, the population of *A. alpinus* in the southern basin declined sharply and it disappeared completely in 1998. In the northern basin, the decline of *A.*




Slika 3: Razmerje med telesno dolžino in telesno maso pri jezerski zlatovčici (*Salvelinus alpinus* (Linnaeus, 1758)) iz Dvojnega jezera (Triglavski narodni park, Slovenija). Razmerje temelji na podlagi podatkov 64 osebkov, ujetih v novembru leta 1999

*Figure 3: The relation between body length and body mass of Arctic charr (Salvelinus alpinus (Linnaeus, 1758)) from the lake Dvojno jezero (Triglav National Park, Slovenia). The relation is based on data from 64 specimens, caught in November 1999*

najbolj vidni) so bile odrasle samice z jajčnimi vrečkami. Te so najprej izginile v južnem jezeru (leta 1996), naslednje leto pa še v severnem bazenu. Vzporedno z izginevanjem zooplanktona je upadalo tudi število bentoških nevretenčarjev, še zlasti ličink enodnevnic (Ephemeroptera: *Ecdyonurus aurantiacus* in *Siphlonurus lacustris*) ter mladoletnic (Trichoptera: *Allogamus uncatus* in *Limnephilus coenosus*). Hiter in intenziven upad ličink lahko pripišemo intenzivnemu plenjenju s strani rib. V samo dveh letih (1997–1998) sta iz jezera skoraj povsem izginili obe skupini živali. Istočasno pa so se začele hitro množiti nitaste zelene alge (Brancelj, 2001), kar je kazalo na slabšanje stanja v obeh jezerih.

*alpinus* was delayed by one year. The most vulnerable group were ovigerous females. They disappeared first in the southern basin (in 1996) and next year in the northern basin. Parallel with the decline of zooplankton we observed a decline in the populations of benthic invertebrates, particularly larvae of Ephemeroptera (*Ecdyonurus aurantiacus* and *Siphlonurus lacustris*) and Trichoptera (*Allogamus uncatus* and *Limnephilus coenosus*). Decline probably resulted from intensive fish predation. In only two years (1997/1998), almost complete elimination of the two groups was observed in both lakes. In the same period, intensive growth of filamentous benthic algae started (Brancelj, 2001), indicating worse conditions in both lakes.

## ZAKLJUČKI

Raziskave favne v visokogorskih jezerih Julijskih Alp nimajo dolge tradicije, saj so se intenzivnejše raziskave začele šele v 90. letih 20. stoletja. Zajele so sicer vse najpomembnejše habitate v jezerih, vendar je bilo težišče raziskav na planktonu, še posebej na skupinah ceponožcev in vodnih bolh, manj pa na živalih v obrežnem pasu ali celo v globljih delih jezer. Najbolje raziskane skupine so vodne bolhe (Cladocera) in ceponožni raki (Copepoda), ki so v jezerih razmeroma bogato zastopani. Skupno je bilo v jezerih ugotovljenih 19 vrst vodnih bolh, od tega 6 izključno plaktonskih, ter 25 vrst ceponožcev, od tega 8 izključno planktonskih. Druge skupine živali so v jezerih zastopane z manj vrstami, pogosto le ze eno ali dvema. Izjema je skupina trzač (Chironomidae), ki po številu vrst verjetno presega ceponožce, vendar je poznavanje vrst, ki živijo v jezerih, še zelo nepopolno. V jezerih so poleg tega tudi ličinke nekaterih drugih skupin žuželk, med katerimi so najpomembnejše enodnevnice, kačji pastirji, mladoletnice ter hrošči. Od drugih skupin najdemo tudi pijavke, školjke in polže in celo mahovnjake.

Le nekaj vrst je takih, ki živijo v večini jezer, druge pa najdemo le ve enem ali nekaj jezerih. Med najbolj razširjenimi sta vodna bolha *Chydorus sphaericus* in ceponožni rak *Eucyclops serrulatus*. Število vrst v planktonu in v obrežnem pasu je najmanjše v najviše ležečih jezerih (Zgornje Kriško jezero, Jezero pod Vršacem), medtem ko je vrstno najbolj bogato Jezero na Planini pri Jezeru. Zaradi naseljevanja rib v nekatera jezera je naknadno prišlo do zmanjševanja števila vrst v njih. Najbolj očitna primera sta Krnsko jezero in Dvojno jezero, kjer je prizadet predvsem zooplankton, medtem ko so v Je-

## CONCLUSIONS

The investigation of fauna in high-mountain lakes in the Julian Alps has a short tradition. The first intensive research started in the 1990s. All the most important habitats in the lakes were included. Most effort was put into studies of zooplankton, particularly Cladocera and Copepoda and less into the zoobenthos and animals living in deeper parts of the lakes. In total, we found 19 taxa of Cladocera, six of them being exclusively planktonic and 25 taxa of Copepoda, eight of them being exclusively planktonic. Other groups of animals have fewer representatives in the lakes, some of them only one or two species. The exception is the group Chironomidae, which probably outnumbers both former groups in terms of number of species. Unfortunately, our knowledge on species composition and their distribution is insufficient. Apart from Chironomidae, larvae of some other groups of insects inhabit the lakes. The most important groups are mayflies, dragonflies, caddis flies and beetles. In addition, representatives of leeches, clams, snails and even moss animals can be found in some lakes.

Representatives of only a few species can be found in most of the lakes. Mainly they live in just a few lakes. The most common species are *Chydorus sphaericus* (Cladocera) and *Eucyclops serrulatus* (Copepoda). Only a few species of zooplankton and species living in the littoral zone could be found in the lakes at high elevations (Zgornje Kriško jezero, Jezero pod Vršacem). In contrast, Jezero na Planini pri Jezeru has the highest number of species. In the lakes populated by fish, a reduction of the number of species started after fish introduction. The most outstanding examples are Krnsko jezero

Množica rib (koreslji) ob bregu Jezera na Planini pri Jezeru v času drsta. V to jezero so ribe naselili v 50. letih prejšnjega stoletja. (Foto: Anton Brancelj)
*A shoal of fish (crucian carp) in Jezero na Planini pri Jezeru at spawning time. Fish were introduced into the lake in 1950s. (Photo: Anton Brancelj)*

zeru na Planini pri Jezeru bolj prizadete živali V obrežnem pasu. Globlji deli tega jezera pa so zaradi pomanjkanja kisika povsem bre živali.

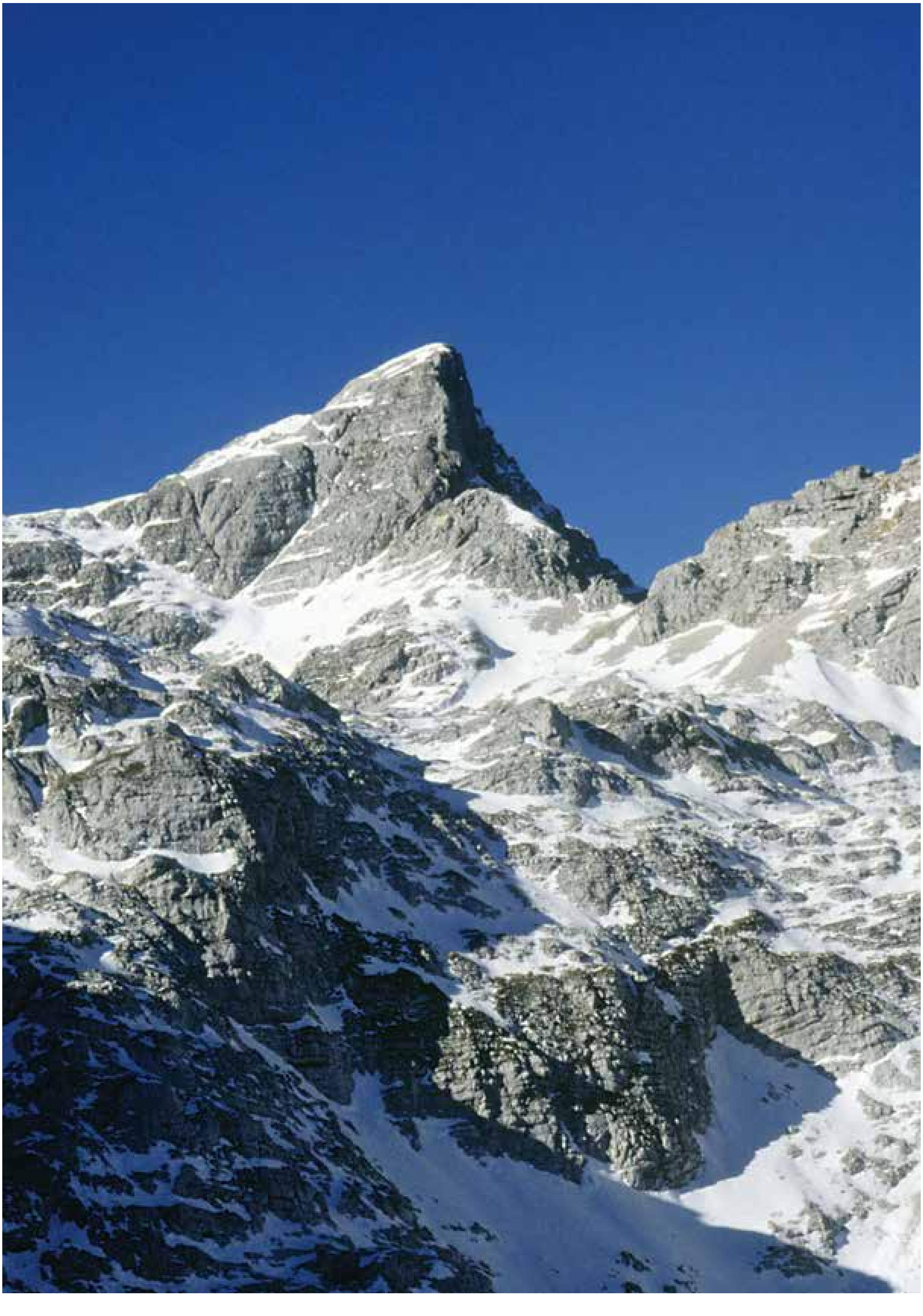
Prve ribe so bile naseljene v jezera v 20. letih 20. stoletja. Doslej so bile štiri vrste rib naseljene v šest jezer, pri čemer sta najpogostejši vrsti jezerska zlatovčica ter pisanec. Naseljevanje rib ima, poleg neposrednega onesnaževanja jezer, najbolj negativne posledice za jezera.

Med zanimive vrste, ki živijo v jezerih Julijskih Alp, velja omeniti posebno grbasto obliko vodne bolhe *Chydorus sphaericus,* ki je bila podrobneje opisana po primerkih iz Rjavega jezera. Druga taka vrsta je *Pseudomoraria triglavensis,* opisana po osebkih iz Močivca. Ta po do sedaj znanih podatkih živi le tam in nikjer drugje.

and Dvojno jezero, where the most affected group is zooplankton, while in Jezero na Planini pri Jezeru animals from the littoral zone are more affected. Deeper parts of the lake suffer oxygen depletion resulting in the absence of animals.

Fish were introduced to the lakes for the first time in the1920s. To date four species have been introduced in six lakes, with arctic charr and minnow being the most common. Apart from direct pollution, the introduction of fish has had the most negative effects on the lakes.

The hump-backed form of the cladoceran *Chydorus sphaericus*, studied in detail in the lake Rjavo jezero is one of the most interesting species in the lakes of the Julian Alps. Another species, *Pseudomoraria triglavensis*, was described from the spring Močivec, which is the only known living place of the species.



# Poglavje 10 Chapter

# Fizikalne lastnosti sedimentov in onesnaževalci v sedimentih

# Physical Properties of Sediments and Sediment Pollutants

Gregor MURI*, Zvonka JERAN**, Radojko JAĆIMOVIĆ**, Olga URBANC-BERČIČ*

## UVOD

Jezerski sediment je netopna usedlina, ki jo sestavljajo delci kamnin, organski ostanki in kemijske oborine. Sestavni deli sedimenta se odlagajo v jezera z rekami, potoki, spiranjem s površja in vetrovi. Zaradi gravitacije se ta material nalaga na dno jezera, plast za plastjo. Vsaka plast sedimenta predstavlja pogoje, ki so vladali v jezeru in pojezerju, ko se je ta plast vgradila v sediment. Mnoge biogene spojine in onesnaževalci so adsorbirani na delce sedimenta in se posledično nalagajo v njem, kar pomeni, da sediment predstavlja začasni ali celo dolgočasovni rezervoar teh spojin. Organska snov v sedimentu je podvržena mnogim biogeokemijskim procesom, ki lahko občutno spremenijo molekulsko strukturo kot tudi porazdelitev organskih spojin v sedimentu (Engel in Macko, 1993). Vendar obstajajo tudi spojine, ki so relativno nereaktivne in obstojne ter so zato odporne na biogeokemijske procese. Te spojine se uporabljajo kot sledilci dogodkov, ki so se zgodili v preteklosti in so zapisani v sedimentu (Clark in sod., 1997).

Sedimenti iz odmaknjenih visokogorskih jezer vsebujejo dobro ohranjen zapis zgodovine jezera in pojezerja, ki ga lahko obnovimo, če analiziramo vertikalno porazdelitev določenih spojin v sedimentu. Glede na to, da ležijo visokogorska jezera v okolju, kjer ni lokalnih virov onesnaženja, lahko enostavno ocenimo tudi zgodovino atmosferske depozicije za celotno regijo, v kateri se jezero nahaja.

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## INTRODUCTION

Lake sediment is a deposit of insoluble material and is primarily derived from rock, as well as organic debris and chemical precipitates. Sediment constituents are transported to lakes by rivers, streams, surface run-off and winds, where they accumulate on the bottom of the lake, layer by layer. Each layer represents the condition of the lake and the lake catchment at the time, when that layer was deposited. In addition, many biogenic and pollutant compounds are adsorbed on to particles and are subsequently deposited into sediment, so that sediment represents a temporary or sometimes a long-term reservoir of these compounds. Organic matter in sediments undergoes a variety of biogeochemical processes, which may significantly alter its molecular structure as well as the distribution of these compounds (Engel & Macko, 1993). However, there are some compounds present, which are relatively inert and persistent and hence, they are not affected by biogeochemical processes. These compounds can be used as temporal indicators of events, which occurred in the past and are recorded in the sediment (Clark *et al.*, 1997).

Remote mountain lake sediments contain a well-preserved record of the lake and the lake catchment history, which can be revealed if vertical distributions of characteristic compounds are determined. Since mountain lakes are generally situated in areas with no, or low, local pollution sources,

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Do nedavnega so bili podatki o sedimentih iz slovenskih visokogorskih jezer redki. V letu 1994 pa se je pričela serija slovenskih in mednarodnih raziskovalnih projektov, z namenom oceniti splošno stanje teh jezer. Poleg drugega raziskovalnega dela je bil velik poudarek tudi na analizi sedimentov. Največ podatkov je bilo tako zbranih v okviru treh evropskih projektov, in sicer AL:PE 2, MOLAR in EMERGE ter enega slovenskega raziskovalnega projekta.

atmospheric deposition history of the whole region can be also easily assessed.

Until recently, the data on Slovenian alpine lake sediments were scarce. From 1994 onwards, a series of national as well as international research projects was initiated, in order to assess the overall condition of these lakes. Among other research work, various analyses of sediments were also conducted. Most of the data were collected in the framework of three European research projects i.e., AL:PE 2, MOLAR and EMERGE and one Slovenian research project.

## FIZIKALNE LASTNOSTI SEDIMENTOV

Velikost delcev, njihova oblika in usmerjenost posameznih delcev so najpomembnejše fizikalne lastnosti sedimentov. Delci sedimenta so lahko veliki od manj kot µm pa do nekaj centimetrov in odsevajo vrsto transporta in procese razgradnje. Obstajajo mnoge različne oblike delcev: od skoraj okroglih do lističastih in podolgovatih delcev. Usmerjenost delcev je ravno tako odvisna od oblike. Vsi ti trije osnovni parametri vplivajo na ostale fizikalne lastnosti sedimentov, kot so gostota in poroznost (Boggs, 1987). Poroznost je razmerje med vsebnostjo vode in trdnimi delci v sedimentu. Večja je v površinski plasti sedimenta, kjer večkrat preseže 90 %, kar pomeni, da je večina sedimenta samo vodna faza. Z globino poroznost pada. Sediment je v glo-

## PHYSICAL PROPERTIES OF SEDIMENTS

Grain size, shape and orientation of individual sediment grains are among the most important physical properties of lake sediments. Particles in sediments range in size from less than a micrometre to a few centimetres and reflect the nature of transport and depositional processes. There are many different shapes of particles, from almost spherical to bladed and elongated. Grain orientation also depends on the shape of particles. All three primary parameters control other physical properties of sediments, such as bulk density and porosity (Boggs, 1987). Porosity is the ratio between water content and solid particles in the sediment. It is higher in the surface sediment layers, where it often exceeds 90 %, meaning that most of the sediment is largely in a water phase, but it generally decreases with depth. Since deeper parts of sediments are more mineralized, they tend to be more compact.

Štiri jedra sedimenta, odvzeta iz Jezera v Ledvicah, z zelo rahlo zgornjo plastjo, v kateri prevladuje organska snov (levo). Na desni so tri jedra sedimenta iz Spodnjega Kriškega jezera, ki so na vrhu pokrita s skorjo, v kateri je tudi veliko purpurnih žveplovih bakterij. To kaže na pomanjkanje kisika v plasti tik nad dnom. (Foto: Anton Brancelj)

*Four sediment cores from Jezero v Ledvicah with a loose topmost part containing a lot of organic material (on the left). On the right are three sediment cores from Spodnje Kriško jezero. They are covered with a crust, containing also the purple sulphuric bacteria, indicators of oxygen depletion in the near-the -bottom layer. (Photo: Anton Brancelj)* bljih plasteh bolj mineraliziran, zaradi česar je bolj gost, kar pomeni tudi zmanjšano poroznost.

Barva sedimenta se spreminja po jedru navzdol in je pogojena z mineralno sestavo in vsebnostjo organske snovi v sedimentu. Vrhnje plasti sedimenta običajno vsebujejo več organske snovi, zato so temnejše, črne barve. V globljih plasteh je organska snov večinoma razgrajena. Prisotni so samo minerali, zato je barva sedimenta mnogo svetlejša, običajno sive barve.

Kemijski in biološki procesi, ki se odvijajo v sedimentih, so v osnovi kontrolirani s fizikalnimi lastnostmi sedimentov. Vendar so fizikalni, kemijski in biološki parametri medsebojno močno povezani. Zato moramo pri ocenjevanju biogeokemijskih procesov v sedimentih upoštevati vse tri dejavnike.

## DOLOČANJE STAROSTI SEDIMENTOV

Znano je, da se jezerski sedimenti nalagajo kronološko in predstavljajo časovni letopis dogajanj v jezeru in njegovi okolici. Ker so jezerski sedimenti lahko stari do nekaj 100 ali celo 1000 let, lahko s sistematično analizo kemijskih, fizikalnih in bioloških parametrov sedimentov ugotavljamo okoljske spremembe, ki so lahko ali naravne ali pa so bile posledica delovanja človeka. Pogoj za časovno opredelitev preteklih dogajanj v jezeru je čimbolj natančna določitev starosti globinskega profila sedimenta. Za določanje starosti sedimentov se izredno uspešno uporabljajo naravni in nekateri umetni radioaktivni elementi. Metoda določanja starosti sedimentov s pomočjo radionuklidov namreč temelji na osnovni značilnosti radioaktivnih snovi, in sicer, da je radioaktivni razpad neodvisen od drugih fizikalnih, kemijskih ali bioloških procesov, ki potekajo v okolju (Krishnaswamy in sod., 1971; Joshi in sod., 1988). Na izbor primernega naravnega radionuklida za določanje starosti vpliva predvsem razpolovni čas radioaktivnega elementa in njegova razširjenost v okolju. Za ugotavljanje starosti jezerskih sedimentov do starosti med 100–200 let se najpogosteje uporablja svinčev izotop $^{210}$Pb. To je naravni radioaktivni element v uran–radijevi razpadni vrsti z razpolovnim časom 22,3 let. Neprestano nastaja v ozračju v procesu radioaktivnega razpada njegovega predhodnika radioaktivnega plina radona $^{222}$Rn. Med vsemi potomci $^{222}$Rn ima $^{210}$Pb najdaljši razpolovni čas in se hitro veže na partikulatne delce zraka. Z usedanjem delcev se nato v obliki suhe ali mokre depozicije vrača na tla oziroma v vodna telesa. V jezerih $^{210}$Pb postopoma sedimentira in se

Sediment colour usually varies down the sediment core and is dependent upon mineralogical composition and organic matter content in sediments. Upper layers of lake sediments are generally rich in organic matter. Consequently, this part of the sediment is of dark, black colour. In the deeper layers of sediments, organic matter is more or less degraded and only minerals are present. Hence, a much brighter, usually grey colour is observed.

Nevertheless, chemical and biological processes, which occur in sediments, are primarily controlled by physical characteristics of sediments. In fact, physical, chemical and biological factors are all strongly interrelated and thus, they all have to be kept in mind when assessing biogeochemical processes in sediments.

## SEDIMENT DATING

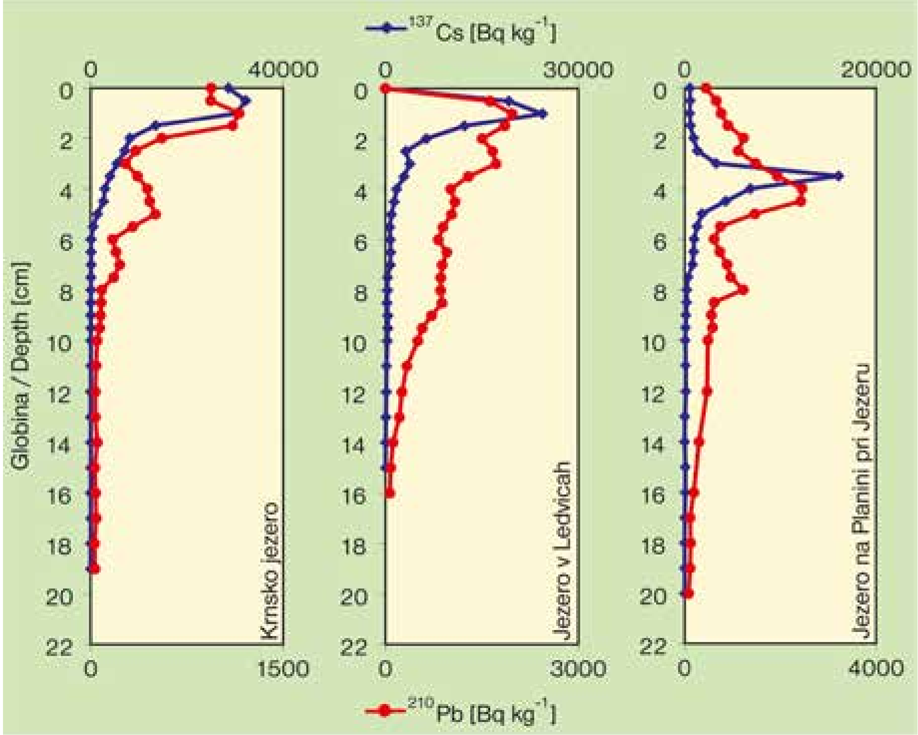
It is known that lake sediments are deposited in chronological order. Since sediment cores can cover a time span of several years to several hundred or thousands of years, their analysis can enable us to reconstruct environmental (natural and anthropogenic) changes in the lake and in its surroundings. However, for such a reconstruction we need to know the age of particular sediment slices at different depths. For dating purposes, naturally occurring radionuclides as well as some artificial ones can be used since the rate of decay of radionuclides is independent of chemical, biological or physical processes in the environment (Krishnaswamy *et al.*, 1971, Joshi *et al.*, 1988). The choice of radionuclide, to be used for dating lake sediments, is dependent on its half-life and its occurrence in the environment. For short time spans up to 150 years, measurements of the lead isotope $^{210}$Pb can be successfully applied. $^{210}$Pb is a naturally occurring radionuclide with a half-life of 22.3 years and is constantly produced in the atmosphere from its parent radon $^{222}$Rn gas during the radioactive decay of natural uranium –radium chain. In the atmosphere, $^{210}$Pb is rapidly attached to small particles and by sedimentation and wash-out of aerosols it is then transferred to the water column and finally into the sediment. Its atmospheric flux is considered to be constant at a given locality and so the activity of $^{210}$Pb in a sample (or in sediment) indicates the date of the incorporation of the isotope. The aqueous residence time of $^{210}$Pb is only a year or two before adsorption onto sediment. However, since part of the $^{210}$Pb in sediment is also produced useda na dno. Nastajanje $^{210}$Pb v ozračju je stalno in konstantno za določeno okolje, zato nam meritve tega radionuklida v nekem vzorcu ali sedimentu povedo, kdaj je ta izotop nastal. Zadrževalni čas $^{210}$Pb v vodnem stolpcu je sorazmerno kratek in v obdobju 1–2 let se ves veže na sedimente. Ker $^{210}$Pb nastaja tudi v sedimentu z radioaktivnim razpadom urana oziroma radija, ki se nahajata v mineralih sedimenta, se za določanje starosti sedimentov uporablja samo $^{210}$Pb, ki je nastal v ozračju (unsupported $^{210}$Pb). Poleg $^{210}$Pb pa lahko za določanje starosti sedimentov uporabljamo tudi umetni radioaktivni izotop, in sicer cezij $^{137}$Cs z razpolovnim časom 30 let (Appleby, 1998), ki se je prvič sprostil v ozračje pri nadzemnih preizkusih jedrskega orožja v 50. in 60. letih preteklega stoletja in leta 1986 ob jedrski nesreči v Černobilu. Tako nam prisotnost tega radionuklida lahko dodatno pomaga pri opredelitvi starosti sedimenta.

Starost jezerskih sedimentov smo določali v treh visokogorskih jezerih: v Krnskem jezeru, v Jezeru v Ledvicah in v Jezeru na Planini pri Jezeru. Odvzem vzorcev smo opravili v vseh treh jezerih v letu 1996. V Krnskem jezeru pa smo vzorčenje ponovili še leta 1998. Vzorce smo jemali na najglobljih točkah jezera s Kajakovim gravitacijskim vzorčevalnikom. Prvih 10 cm jedra sedimenta smo razrezali na 0,5 cm debele rezine, ostali del pa na 1 cm debele rezine.

by radioactive decay of $^{226}$Ra present in the sediment minerals, only the so-called unsupported $^{210}$Pb is used to determine the sedimentation rates of particular lake sediments and the age of sediment cores. Besides $^{210}$Pb, the artificial radionuclide cesium $^{137}$Cs, with a half-life of 30 years, can also be used as a dating method for recent events in the environment (Appleby, 1998). This radionuclide was first emitted to the atmosphere from the testing of nuclear weapons in the atmosphere in the early 1950s and 1960s, and most recently its appearance in sediment is an indicator of the Chernobyl accident in 1986.

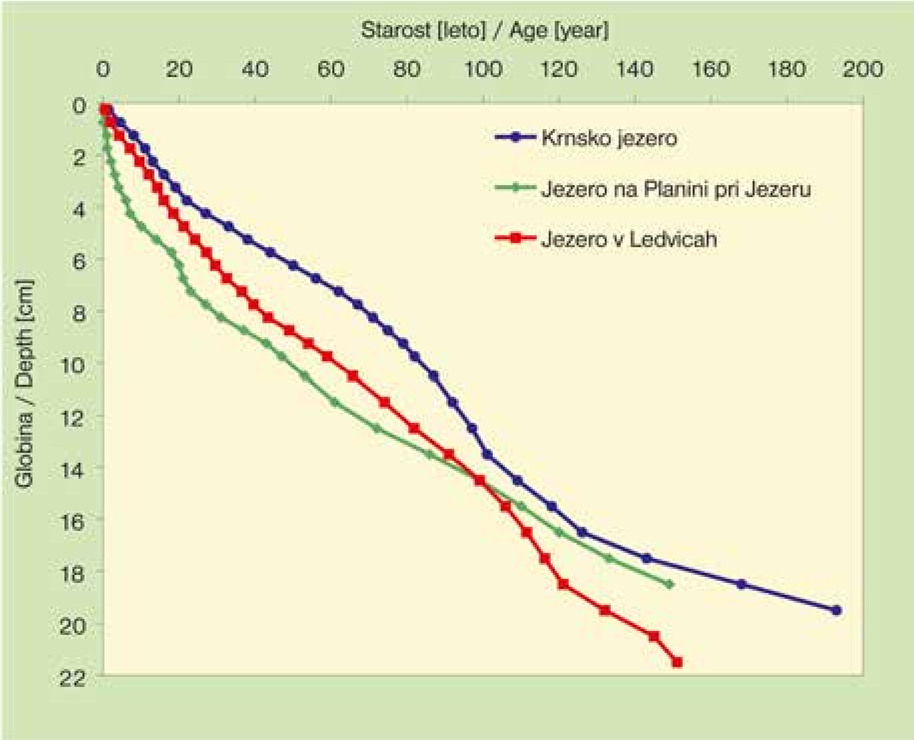
The dating of sediments was performed in three lakes, namely in Krnsko jezero, Jezero v Ledvicah and Jezero na Planini pri Jezeru. Sediment cores were taken in 1996 (lakes Jezero v Ledvicah and Jezero na Planini pri Jezeru) and in 1996 and 1998 in Krnsko jezero. Each core was taken from the deepest part of the lake and then the first 10 cm was cut into 0.5 cm slices and the rest of the core into 1 cm slices. In each slice, the activity of $^{210}$Pb, $^{137}$Cs and $^{226}$Ra was determined.

It was found that in all the investigated lakes the equilibrium between the total $^{210}$Pb activity and supporting $^{226}$Ra occurred at a depth of about 20 cm and that the total $^{210}$Pb activity in all the lakes declined irregularly since besides a well resolved




Slika 1: Specifična aktivnost $^{210}$Pb in $^{137}$Cs (Bq/kg) v sedimentu iz: a) Krnskega jezera, b) Jezera v Ledvicah in c) Jezera na Planini pri Jezeru (Triglavski narodni park, Slovenija)

*Figure 1: Specific activity of $^{210}$Pb and $^{137}$Cs (Bq/kg) in sediment profiles of lakes: a) Krnsko jezero, b) Jezero v Ledvicah and c) Jezero na Planini pri Jezeru (Triglav National Park, Slovenia)*




Slika 2: Starost sedimentov v treh visokogorskih jezerih (Krnsko jezero, Jezero v Ledvicah in Jezero na Planini pri Jezeru) (Triglavski narodni park, Slovenija)
*Figure 2: Radiometric chronology of three high-mountain lakes (Krnsko jezero, Jezero v Ledvicah and Jezero na Planini pri Jezeru) (Triglav National Park, Slovenia)*

V suhih vzorcih smo nato merili specifično aktivnost vseh treh radionuklidov: $^{210}$Pb in $^{137}$Cs ter $^{226}$Ra.

Ugotovili smo, da je v vseh treh jezerih v globini približno 20 cm specifična aktivnost skupnega $^{210}$Pb in $^{226}$Ra enaka, kar pomeni, da v tej globini prevladuje $^{210}$Pb, ki nastaja neposredno iz $^{226}$Ra v sedimentu. Prav tako smo ugotovili, da v vseh treh jezerih skupna specifična aktivnost $^{210}$Pb pada neenakomerno, saj smo poleg večjega vrha v zgornjih nekaj cm sedimenta našli še dva manjša vrhova (slike 1 a–c). Takšna razporeditev $^{210}$Pb v globinskem profilu sedimenta kaže, da je nek, po vsej verjetnosti zunanji dejavnik, povzročil prekinitev normalne sedimentacije in "razredčitev" specifične aktivnosti $^{210}$Pb. Ti dogodki so še posebno izraziti v Krnskem jezeru in jih lahko povezujemo s potresno aktivnostjo. Znano je namreč, da so ta del Slovenije prizadeli trije močnejši potresi, in sicer leta 1895, 1942 in 1975/76 (Ribarič, 1982; Vidrih in sod., 1995). Kot smo že omenili, nam prisotnost $^{137}$Cs v sedimentih še dodatno pomaga pri določitvi njihove starosti, saj je čas sprostitve tega radionuklida v okolje znan. Tako lahko vsebnost $^{137}$Cs v zgornjih plasteh sedimenta povežemo s černobilsko nesrečo, ki se je pripetila leta 1986. Zanimivo je, da se položaj fotovrha $^{137}$Cs v profilu sedimenta spreminja od jezera do jezera, saj se nahaja v različnih globinah, in sicer med 1,0–1,5 cm (Jezero v Ledvicah), 0,5–1,0 cm (Krnsko jezero) in 3,5–4,0 cm (Jezero na Planini

$^{210}$Pb peak in the first few centimetres two other much smaller peaks were observed (Figures 1 a–c). It seems that something dramatic happened which caused a dilution of $^{210}$Pb activity. These events are especially pronounced in the lake Krnsko jezero and are most likely linked to the earthquakes recorded in this region in 1895, 1942 and 1975/76 (Ribarič, 1982; Vidrih *et al.*, 1995). The position of the well-resolved peak of $^{137}$Cs, which records the fallout from the 1986 Chernobyl accident, differs from lake to lake and shows that each of the lakes has different sedimentation rates. Namely, the $^{137}$Cs peak was found at depths of 1.0-1.5, 0.5-1.0 and 3.5-4.0 cm, in Jezero v Ledvicah, Krnsko jezero and Jezero na Planini pri Jezeru, respectively (Figures 1 a–c). Smaller $^{137}$Cs peaks, which could represent weapons fallout in the early 1950s and 1960s, were hardly distinguishable from the background.

Radiometric chronology calculated on the basis of $^{210}$Pb activity levels using the so-called CRS (Constant Rate Supply) model of Shukla (1997), as presented in Figure 2., showed that at the depth of 18-19 cm sediments reach the age of approximately 120 - 190 years in the lakes Jezero v Ledvicah and Krnsko jezero. Higher sedimentation was found in Jezero na Planini pri Jezeru, especially in the first 10 cm of core. Although the sedimentation rates have been relatively uniform in all three investigated lakes they were interrupted by the episodes of

Vzdolžni prerez jedra sedimenta iz Krnskega jezera kaže različne plasti, ki so posledica dogodkov v jezeru ali ob njem. Temne plasti kažejo na organsko snov, ki se je odlagala v okolju brez kisika, svetlejše plasti v zgornjem delu pa so posledica plazov ali hudournikov, ki so odlagali predvsem mineralne delce. (Foto: Anton Brancelj)
*Longitudinal cross-section of the sediment core from Krnsko jezero shows different layers reflecting events within the lake and around it. Dark layers are organic matter deposited in the environment with oxygen depletion and white bands in the upper section are the result of material deposited in the lake by earthquakes and torrents, containing mainly inorganic particles. (Photo: Anton Brancelj)*

pri Jezeru) in kaže na različno hitrost sedimentacije jezer (slike 1a–c). Manjših fotovrhov $^{137}Cs$, ki bi kazali na nadzemne poskuse jedrskega orožja v 50. in 60. letih prejšnjega stoletja, pa ni mogoče ločiti od ozadja.

Starost jezerskih sedimentov na podlagi analiz $^{210}Pb$ smo opravili z uporabo tako imenovanega CRP-modela programskega paketa, ki so ga razvili v Kanadi (Shukla, 1997) in upošteva konstantno hitrost vnosa $^{210}Pb$ v jezero. Izračun starosti sedimentov (slika 2) je pokazal, da je starost sedimentov v globini med 18–19 cm v Jezeru v Ledvicah približno 120 let, v Krnskem jezeru pa v isti globini doseže starost 190 let. Iz istega grafa je tudi razvidno, da je v Jezeru na Planini pri Jezeru hitrost sedimentacije, posebno v prvih 10 cm, najvišja, nekoliko nižja je v Jezeru v Ledvicah in najnižja v Krnskem jezeru. V vseh treh jezerih je opaziti najmanj tri različna obdobja, kjer se hitrost sedimentacije nekoliko poviša oziroma zniža. Zanimivo je, da je globina, kjer se hitrost sedimentacije spremeni, v vseh treh jezerih različna, starost sedimentov pa je približno enaka. Tako se npr. v Jezeru na Planini pri Jezeru hitrost sedimentacije spremeni v globini 6,0–6,5 cm (1976), 10,0–10,5 cm (1942) in v globini 14,0–14,5 cm (1895), v Krnskem jezeru pa v globini 3,0–3,5 cm (1976), 6,5–7,0 cm (1942) in pri 12–13 cm (1895). To pomeni, da so se spremembe dogajale v vseh jezerih v istem časovnem obdobju. Ta dogajanja pa bi ponovno lahko povezali s potresno aktivnostjo.

rapid sedimentation. It is interesting to note that the turning points in all lakes are found at different depths which all correspond to the same age of the sediment and which could be linked to the earthquakes in this region in 1895, 1942 and 1975/76. For example, in Jezero na Planini pri Jezeru, at the depth of 6.0-6.5 cm (1976), 10.0-10.5 cm (1942) and 14.0-14.5 cm (1895), and in Krnsko jezero these points were at depths of 3.0 - 3.5 cm (1976), 6.0-6.5 cm (1942) and 12-13 cm (1895).

## ONESNAŽEVALCI V SEDIMENTIH

V sedimentih visokogorskih jezer najdemo številne onesnaževalce, kot so črni ogljik (BC), policiklični aromatski ogljikovodiki (PAH), težke kovine. BC je težko definirati, saj vsebuje niz spojin, od

## POLLUTANTS IN SEDIMENTS

In remote high-mountain lake sediments, various pollutants can be found, for example, black carbon (BC), polycyclic aromatic hydrocarbons (PAH), heavy metals. BC is hard to define. It com-

Potresi in z njimi povezani plazovi lahko prispevajo veliko materiala za jezerske sedimente. (Foto: Anton Brancelj)

*Earthquakes, and slumps induced by them, contribute a lot of material for the lake sediments. (photo. Anton Brancelj).*

močno poliaromatskih do elementnega ali grafitnega ogljika. Tudi kroglasti ogljikovi delci (SCP) so prepoznani kot BC. Od ostalih delcev jih razlikujemo po sferoidni obliki. PAH so spojine, ki običajno vsebujejo od dva do šest aromatskih obročev. BC, PAH in SCP predstavljajo relativno nereaktivno obliko ogljika. Večina teh onesnaževalcev nastaja v procesih gorenja. Njihov glavni vir je nepopolno izgorevanje fosilnih goriv pri visokih temperaturah v termoelektrarnah, industriji, gospodinjstvih in prometu (Goldberg, 1985). Med procesom gorenja se onesnaževalci sprostijo v ozračje, po katerem lahko preko različnih procesov prepotujejo dolge razdalje od vira onesnaženja. Ozračje zapustijo preko suhe ali mokre depozicije. Glede na prevladujočo smer vetra, zračne tokove in atmosferske procese lahko dosežejo vsak kraj na Zemlji, saj so jih zaznali celo v tako odmaknjenih krajih, kot so Arktika, Antarktika in visokogorska jezera (Rose, 1995; Fernandez in sod., 1999).

Glavni vir onesnaževalcev v visokogorskih jezerih je atmosferska depozicija (Stumm in Morgan,

prises a range of materials from highly polyaromatic to elemental or graphitic carbon. Spheroidal carbonaceous particles (SCP) are also included in the term BC and are defined by their spheroidal form. PAH are compounds containing typically two to six aromatic rings. They all represent a relatively inert form of carbon. Most of these pollutants are combustion-derived substances. Their main source is incomplete high temperature fossil-fuel combustion in power plants, industry, households and traffic (Goldberg, 1985). During combustion processes, pollutants are emitted into the atmosphere. Once in the atmosphere, they can get dispersed over wide areas and can travel long distances from the initial source of emission. They are removed from the atmosphere by wet and dry deposition. Depending on prevailing wind directions, air currents and atmospheric conditions, they can reach virtually every place on the Earth. They have even been detected in remote places such as the Arctic, the Antarctic and remote high-mountain areas (Rose, 1995; Fernandez *et al.*, 1999).

The main source of pollutants in high-mountain lake sediments is long distance atmospheric pollution (Stumm & Morgan, 1996). Pollutants are washed out to the lake catchment during precipitation events. They can then enter into the lake water column from surface run-off, and ultimately into

1996). Padavine izperejo onesnaževalce iz ozračja v pojezerje, od koder jih voda odnese v vodni stolpec in končno pristanejo v sedimentu. Kljub temu da so BC, PAH in SCP del organske snovi v sedimentu, so to kemijsko in mikrobiološko odporne spojine. Potem ko se vgradijo v sediment, se ne razgrajujejo in ne spreminjajo več (Goldberg, 1985).

BC, PAH in SCP v sedimentu lahko uporabljamo kot okoljske indikatorje, saj so se vse od začetka industrijske revolucije v čedalje večjih količinah sproščali v okolje. Zaradi svoje nereaktivnosti so v sedimentu obstojni daljše časovno obdobje, zato lahko porazdelitev BC, PAH in SCP po globini recentnega, mladega sedimenta uporabimo kot sledilec porabe fosilnih goriv, predvsem v preteklem stoletju. Poleg tega lahko z njimi ovrednotimo tudi časovni in prostorski vpliv človeka na okolje ter zgodovino onesnaževanja jezerske okolice. Tudi mnogi ostali onesnaževalci so v odvisnosti z BC, PAH in SCP, zato nam vsebnost BC, PAH in SCP v sedimentu služi tudi za oceno obsega onesnaženja z ostalimi atmosferskimi onesnaževalci v preteklosti (Griffin in Goldberg, 1983).

## PORAZDELITEV BC IN PAH V SEDIMENTIH

Vsebnost BC v slovenskih visokogorskih sedimentih je znašala okrog 1 % BC DW (DW = suha masa sedimenta) v površinski plasti sedimenta, z globino pa je upadala. V plasteh sedimenta, globljih od 20 cm, je koncentracija BC padla pod 0,4 % BC DW in je nato ostala precej konstantna. Radiokemijske analize so pokazale, da so te plasti sedimenta starejše od 150 let in torej predstavljajo vnos BC v okolje v predindustrijskem času.

Primerjava absolutnih koncentracij BC ni najbolj ustrezna, ker se obravnavani sedimenti razlikujejo glede na vsebnost organskega ogljika (OC). Poleg tega se od jezera do jezera spreminjajo tudi meteorološki pogoji, vse to pa moramo upoštevati, če hočemo ovrednotiti podatke o BC. Ker je BC del organske snovi v sedimentu, smo za primerjavo rezultatov uporabili razmerje BC/OC, ki je značilnost vsakega merilnega mesta posebej. S tem je bila primerjava med jezeri omogočena.

Razmerja BC/OC v površinski plasti sedimentov so predstavljena na sliki 3. Najvišje razmerje BC/OC smo izmerili v Zgornjem Kriškem jezeru, in sicer 7 %. V Krnskem jezeru in v Jezeru v Ledvicah se je razmerje BC/OC zmanjšalo na 6 %, medtem ko je v Jezeru na Planini pri Jezeru padlo pod 4,5 %. Zasledili smo torej gradient razmerij BC/OC, saj

the sediment. Despite the fact that BC, PAH and SCP are components of organic matter in the sediment, they are all chemical and microbial resistant substances and are not degraded and altered any further after being deposited in the sediment. (Goldberg, 1985).

BC, PAH and SCP in sediments can be used as environmental indicators. They have been emitted into the environment in increased quantities since the beginning of the industrial revolution. Due to their inertness, they can persist in sediments over long periods of time and consequently, the depth profiles of BC, PAH and SCP in recent sediments can be used as a relevant tracer of fossil fuel usage in past centuries. Also, the temporal and spatial impact of anthropogenic activities on the environment and a pollution history of the lake surrounding area can be evaluated. Since many other pollutants are well correlated with BC, PAH and SCP, their signatures in sediments also indicate the extent of contamination by other air-borne pollutants in the past (Griffin & Goldberg, 1983).

## DISTRIBUTION OF BC AND PAH IN SEDIMENTS

The BC content in Slovenian alpine lake sediments ranged around 1 % BC DW (DW = dry weight sediment) at the surface layer and decreased in the deeper parts of the sediments. In the sediment layers deeper than 20 cm, the BC concentration generally dropped to less than 0.4 % BC DW and remained quite constant further down. According to radiochemical analyses, these sediment depths are older than 150 years and thus, represent the BC input to the environment in the pre-industrial time.

However, it is rather inconvenient to compare the absolute BC concentrations, since the sediments under consideration differ in the organic carbon (OC) content. Meteorological conditions also vary from lake to lake and both factors are important when BC data are to be evaluated. As already indicated, BC is a part of organic matter in the sediment and hence, the BC/OC ratio was used in order to enable a comparison of the results. A calculated BC/OC ratio is a characteristic property of each study site. Therefore a comparison between different sampling sites is possible.

The surface BC/OC ratios are represented in Figure 3. The highest BC/OC ratio was determined in the lake Zgornje Kriško jezero and amounted to 7 %. The BC/OC ratio in the lakes Krnsko jezero smo najvišje vrednosti določili v severozahodnem delu Julijskih Alp, proti vzhodu pa so vrednosti začele upadati. To je skladno z letno količino padavin, ki se v Julijskih Alpah geografsko spreminja. Količina padavin je največja v Zgornjem Kriškem jezeru in presega 3200 mm na leto, nato pa se proti vzhodu zmanjšuje. Pri Jezeru na Planini pri Jezeru znaša že manj kot 3000 mm na leto, medtem ko znaša pri Krnskem jezeru in Jezeru v Ledvicah okrog 3000 mm na leto (Kastelec, 1999). Glede na to da je glavni vnos BC v visokogorje posledica atmosferske depozicije, se BC/OC razmerja spreminjajo skladno s spremembami količine padavin posameznega merilnega mesta, kar je posledica različne geografske lege jezer. Večina vremenskih motenj doseže Julijske Alpe najprej na njegovem zahodnem in severozahodnem robu. Pred tem pa so se vremenske motnje gibale nad industrijskimi, močno onesnaženimi območji v srednji Evropi. Tam lahko v ozračje vstopijo številni onesnaževalci, ki se potem prenašajo drugam. Zgornje Kriško jezero se nahaja na robu Julijskih Alp, najbolj severozahodno od vseh merilnih mest. Letna količina padavin je največja in tudi najbolj intenzivna, zato so onesnaževalci bolj učinkovito izprani iz ozračja kot v primeru ostalih jezer. S tem je razumljivo, da je razmerje BC/OC tam najvišje in da nato upada proti vzhodu.

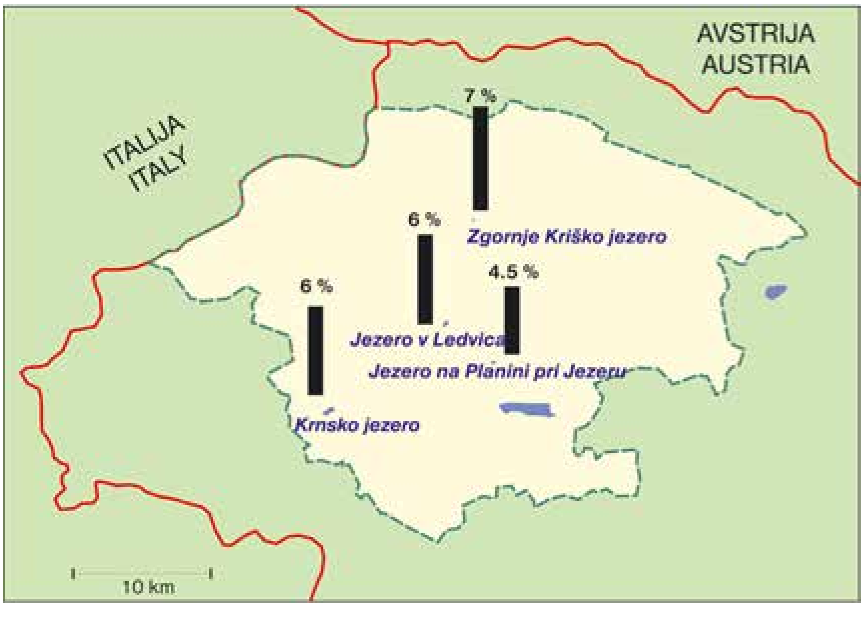
Vertikalno porazdelitev PAH smo bolj podrobno analizirali v sedimentu iz Jezera na Planini pri Jezeru. Določali smo 14 "starševskih" oz. izvornih (nealkiliranih) PAH in metil ter dimetil fenantrene.

Vertikalne porazdelitve posameznih spojin PAH v sedimentu so bile precej podobne. Iz tega smo sklepali, da imajo te enak vir nastanka in da

and Jezero v Ledvicah decreased to 6 %, while in Jezero na Planini pri Jezeru it dropped to 4.5 %. Thus, a gradient of the BC/OC ratios was observed, with the highest values determined in the north-western part of the Julian Alps and with values decreasing toward the east. The BC/OC gradient is consistent with the annual precipitation rate, which varies across the Julian Alps. The lake Zgornje Kriško jezero receives the highest amount of precipitation, exceeding 3200 mm per year. The annual precipitation rate then decreases toward the east and at Jezero na Planini pri Jezeru, it amounts to less then 3000 mm per year. At the lakes Krnsko jezero and Jezero v Ledvicah, it is estimated to be around 3000 mm per year (Kastelec, 1999). Most weather systems reach the Slovenian Alps on its western to north-western edge first. But they previously move across highly industrialised and polluted areas in central Europe, where many pollutants are emitted to the atmosphere. The lake Zgornje Kriško jezero is the most north-western lake studied, situated just at the frontier of the Julian Alps, where precipitation is the highest and the most intense. Thus, pollutants are more effectively washed out from the atmosphere than at the other studied lakes. It is therefore reasonable that the BC/OC ratio is the highest there and that it decreases towards the east.

The vertical profile of PAH distribution was studied in more detail in the sediment of the lake Jezero na Planini pri Jezeru. 14 parent (non-alkylated) PAH and the methyl and dimethyl phenanthrenes were analysed in the samples.

The vertical distributions of most individual




Slika 3: Razmerja BC/OC v površinski plasti sedimentov iz štirih visokogorskih jezer (Krnsko jezero, Jezero v Ledvicah, Jezero na Planini pri Jezeru in Zgornje Kriško jezero) (Triglavski narodni park, Slovenija; BC = črni ogljik; OC = organski ogljik). (Podatki iz Muri in sod., 2002)

*Figure 3: BC/OC ratios in surface sediment layers of four high-mountain lakes (Krnsko jezero, Jezero v Ledvicah, Jezero na Planini pri Jezeru and Zgornje Kriško jezero) (Triglav National Park, Slovenia; BC = black carbon; OC = organic carbon). (Data from Muri et al., 2002)*

podepozicijski procesi, ki bi lahko bistveno spremenili porazdelitev sedimentiranih PAH spojin, niso bili prisotni v sedimentu. Zaradi tega smo lahko posamezne spojine PAH sešteli. Dobljeno vsoto smo definirali kot celokupno koncentracijo PAH ($PAH_{tot}$) ter s tem poenostavili obdelovanje in predstavitev rezultatov. Glede na to, da ima večina spojin PAH v sedimentu iz Jezera na Planini pri Jezeru enak (to je pirolitski) izvor, je koncentracija $PAH_{tot}$ precej dober približek splošne porazdelitve PAH v tem sedimentu. Zasledili pa smo dve spojini PAH, ki nista sledili poteku $PAH_{tot}$, in sicer perilen in reten. Ta dva PAH sta poznana, da imata tudi naravni izvor (Wakeham in sod., 1980). Na kratko: vsebnost perilena je naraščala z globino, medtem ko sta se profila retena in $PAH_{tot}$ ujemala le v globljem delu sedimenta. V zgornjem, mlajšem delu sedimenta (zadnjih 50 let) so prevladovali PAH pirolitskega izvora, ki so predstavljali do 90 $\%PAH_{tot}$ koncentracije. Med njimi so bili najbolj pogosti benzofluorantani, ki so predstavljali med 10–20 $\%PAH_{tot}$ koncentracije. V globjih plasteh sedimenta (starejših od 100 let) je koncentracija pirolitskih PAH hitro padla in perilen je postal najbolj pogost PAH. Vsebnost perilena je v teh plasteh znašala do 77 % koncentracije $PAH_{tot}$. Podobne porazdelitve perilena v sedimentih jezer, ki so obdani z iglastim gozdom, smo zasledili tudi v obstoječi literaturi (Wakeham in sod., 1980).

$PAH_{tot}$ koncentracija na dnu jedra sedimenta je znašala 620 ng g $DW^{-1}$ in je bila precej konstantna do začetka 20. stoletja. Okrog leta 1925 je koncentracija $PAH_{tot}$ začela močno naraščati. Najvišjo vrednost smo določili v začetku 50. let, in sicer 12.800 ng g $DW^{-1}$. V naslednjih desetletjih je koncentracija $PAH_{tot}$ malenkostno upadla, vendar je še zmeraj znašala med 8000 in 9200 ng g $DW^{-1}$. V 90. letih pa smo zasledili občutno znižanje koncentracije $PAH_{tot}$. V zadnjih letih se je tako gibala okrog 1500 ng g $DW^{-1}$.

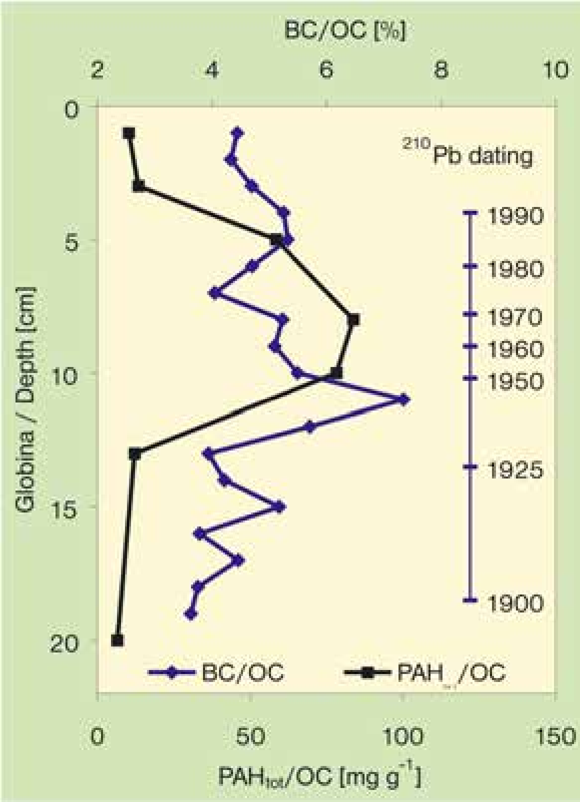
Tudi koncentracije $PAH_{tot}$ smo normalizirali na vsebnost OC v sedimentu. Koncentracije $PAH_{tot}$ in BC smo merili v dveh različnih jedrih, zato brez normalizacije rezultatov ne bi mogli primerjati. Poleg tega smo normalizirano koncentracijo $PAH_{tot}/OC$ lahko primerjali tudi z rezultati, dobljenimi na drugih merilnih mestih. Porazdelitev $PAH_{tot}$ je v sedimentu iz Jezera na Planini pri Jezeru podobna $PAH_{tot}/OC$ profilu, ki je prikazan na sliki 4.

Tudi ujemanje med porazdelitvijo BC/OC in $PAH_{tot}/OC$ je dobro (slika 4). Korelacija med BC in PAH je pravzaprav pričakovana, saj imata oba onesnaževalca enak vir nastanka, to je visokotem-

PAH compounds in the sediment were quite similar, suggesting that their source is the same and that post depositional processes in the sediment, which could significantly change the distribution of the deposited PAH compounds, were absent. In order to facilitate presentation of the results, a sum of all individual PAH compounds was calculated and defined as the total PAH concentration ($PAH_{tot}$). Since most PAH in that sum have the same (pyrolytic) origin, the $PAH_{tot}$ concentration is a fairly good illustration of the general PAH distribution in the sediment of Jezero na Planini pri Jezeru. However, there were two exceptional PAH compounds, which did not follow the general profile: perylene and retene. These PAH are known for their natural origin (Wakeham *et al.*, 1980). Briefly, the abundance of perylene increased with depth and retene only followed the general profile in the deeper sediments. In the upper, younger part of the sediment (most recent 50 years), PAH of pyrolytic origin dominated and represented up to 90 % of the $PAH_{tot}$ concentration. Among them, benzofluoranthenes were the most abundant, amounting to between 10–20 % of the $PAH_{tot}$ concentration. In the deeper part of the sediment (older than 100 years), the concentration of pyrolytic PAH decreased rapidly and perylene became the most abundant compound, comprising up to 77 % of the $PAH_{tot}$ concentration. Similar behavior has been reported for perylene in the literature and has been observed in lake sediments situated in a coniferous area (Wakeham *et al.*, 1980).

The $PAH_{tot}$ concentration at the bottom of the sediment core amounted to 620 ng g $DW^{-1}$ and was quite constant until the beginning of the 20th century. Around 1925, the $PAH_{tot}$ concentration started to increase rapidly. The peak value was achieved in the 1950s and amounted to 12,800 ng g $DW^{-1}$. In the following decades, the $PAH_{tot}$ concentration dropped slightly, but still remained in the range from 8000 to 9200 ng g $DW^{-1}$. In the 1990s, the $PAH_{tot}$ content eventually decreased and at present, the $PAH_{tot}$ concentration tends to be around 1500 ng g $DW^{-1}$.

Again, it is more appropriate to normalise the $PAH_{tot}$ concentration to OC content in the sediment. The BC and $PAH_{tot}$ contents were measured in two different sediment cores, and without normalisation a comparison between these two pollutants would not be possible. Besides, the $PAH_{tot}/OC$ presentation of the data enables a comparison with other studied sites. In the sediment of the lake Jezero na Planini pri Jezeru, the $PAH_{tot}$ profile is simi-




Slika 4: Porazdelitev BC/OC in $PAH_{tot}$/OC v sedimentu iz Jezera na Planini pri Jezeru (Triglavski narodni park, Slovenija; BC = črni ogljik; OC = organski ogljik; PAH = policiklični aromatski ogljikovodiki) (Podatki iz Muri in sod., v pripravi)

*Figure 4: BC/OC and $PAH_{tot}$/OC distribution in the sediment of Jezero na Planini pri Jezeru (Triglav National Park, Slovenia; BC = black carbon; OC = organic carbon; PAH = polycyclic aromatic hydrocarbons) (Data from Muri et al., in preparation)*

peraturno izgorevanje fosilnih goriv. Najvišjo vrednost razmerja BC/OC smo določili okrog 1950. V letu 1948 je bil v okolici Jezera na Planini pri Jezeru velik gozdni požar, v katerem je pogorelo okrog 100 ha gozda. Ker je gozdni požar tudi pomemben vir BC (Clark in sod., 1997), je ta dogodek ostal zapisan v sedimentu. Drugo potrditev gozdnega požara smo dobili iz koncentracijske porazdelitve retena, katerega najvišjo vrednost smo izmerili v istem časovnem obdobju, okrog leta 1950. Reten je PAH, ki so ga v literaturi predlagali za molekulski marker izgorevanja lesa (Ramdahl, 1983).

Vertikalna porazdelitev $PAH_{tot}$/OC je posebej značilna. Podobne porazdelitve za mnoga merilna mesta v Evropi smo zasledili v literaturi (npr. Fernandez in sod., 2000). Koncentracija PAH se je povsod močno povečala ob koncu 19. oziroma v začetku 20. stoletja. Predpostavlja se, da je bilo povečanje povzročeno zaradi razvijajoče se industrializacije in posledično zaradi močnega povečanja porabe fosilnih goriv, kot sta premog in nafta. Najvišje emisije onesnaževalcev so bile zasledene po drugi svetovni vojni, ko naj bi bili industrializacija in poraba fosilnih goriv najbolj intenzivni. V poznih 70. in zgodnjih 80. letih so koncentracije onesnaževalcev hitro upadle. V tem obdobju so bile nameščene številne čistilne naprave, polega tega so

lar to the $PAH_{tot}$/OC distribution, represented in Figure 4.

There is a good agreement between the BC/OC and the $PAH_{tot}$/OC distribution in the sediment, too (Figure 4). A correlation between BC and PAH is expected, since it is known that these two pollutants have the same origin, namely high temperature fossil fuel combustion. The peak value of BC/OC ratio was determined to be around the year 1950. In 1948, there was a huge forest fire in the vicinity of the lake Jezero na Planini pri Jezeru. Approximately 100 ha of forest burned and since forest fire is also a substantial source of BC (Clark *et al.*, 1997), this event was recorded in the sediment. Another confirmation of the forest fire was a peak value of retene, which appeared in the same time period, around 1950. According to the literature, retene is a PAH compound which has been proposed as a molecular marker for wood combustion (Ramdahl, 1983).

The vertical $PAH_{tot}$/OC distribution is particularly characteristic. Similar distributions have been reported for many other study sites in Europe (e.g. Fernandez *et al.*, 2000). The PAH concentration steeply increased everywhere in the late $19^{th}$ early $20^{th}$ century. It is assumed that this increase was mainly caused by growing industrialisation and subsequently, a rapid consumption of fossil-fuels e.g., coal and oil. As a rule, the highest emissions of pollutants were observed after World War II, since industrialisation and fossil-fuel consumption were the most intense in this period. In the late 1970s and early 1980s, concentrations of pollutants decreased rapidly because of installation of emission control devices and a shift from coal and oil to cleaner fuel, like natural gas. Emissions of pollutants were effectively reduced, which may be inferred from the sediment record of this time at Jezero na Planini pri Jezeru.

Remote high-mountain lakes, although being premog in nafto zamenjala čistejša goriva, kot je npr. zemeljski plin. Zaradi tega so se emisije onesnaževalcev občutno zmanjšale, kar se vidi tudi v sedimentu Jezera na Planini pri Jezeru.

Odmaknjena visokogorska jezera so bila in še vedno so pod vplivom atmosferskega onesnaževanja na dolge razdalje, čeprav so ta jezera precej oddaljena od virov onesnaževanja. Onesnaženost teh jezer je odvisna od njihove geografske lege. Če primerjamo naše rezultate z rezultati, ki so bili dobljeni v drugih študijah po Evropi, lahko razberemo, da trenutno Julijske Alpe prejemajo podoben delež atmosferskih onesnaževalcev kot ostale regije v centralnih evropskih Alpah. Najbolj zahodni evropski gorski masivi in severna Evropa so precej manj izpostavljeni procesom atmosferskega onesnaževanja, medtem ko na drugi strani jezera v vzhodni Evropi spadajo med najbolj onesnažena. Iz teh študij lahko opazimo očitno znižanje koncentracij onesnaževalcev v zadnjih nekaj desetletjih, vendar so njihove koncentracije še vedno precej višje kot v predindustrijski dobi. Nekateri rezultati so zbrani v preglednici 1.

distant from any pollution sources, have been, and are still, affected by long distance atmospheric pollution, depending upon their geographical position. Comparing the results obtained in this study with other studied sites across Europe, one can conclude that currently the Julian Alps receive a similar proportion of air-borne pollutants as sites situated in the central European Alps. However, the far west European high-mountain massifs and northern Europe are less exposed to atmospheric deposition but that the eastern European high-mountain lakes are by far the most polluted studied sites. A present day decline is obvious but PAH concentrations are still much higher than in the pre-industrial era. Some results are summarised in Table 1.

| | $PAH_{pyr}$/OC [μg/g] | Literatura Bibliography |
|---|---|---|
| Jezero na Planini pri Jezeru (zadnje desetletje)<br>Jezero na Planini pri Jezeru (last decade) | 5.5 - 12 | Muri in sod., v pripr.<br>Muri et al., in prep. |
| Jezero na Planini pri Jezeru (najvišje vrednosti)<br>Jezero na Planini pri Jezeru (peak values) | 54 - 76 | Muri in sod., v pripr.<br>Muri et al., in prep.. |
| Jezero na Planini (pred letom 1875)<br>Jezero na Planini (before 1875) | 1 | Muri in sod., v pripr.<br>Muri et al., in prep.. |
| Severna Evropa (Skandinavija)<br>Northern Europe (Scandinavia) | 4.5 - 5 | Fernandez in sod., 1999<br>Fernandez et al., 1999 |
| Zahodna Evropa (Iberski polotok)<br>Western Europe (Iberian Peninsula) | 7 - 8 | Fernandez in sod., 1999<br>Fernandez et al., 1999 |
| Osrednja Evropa (Alpe)<br>Central Europe (the Alps) | 13 - 17 | Fernandez in sod., 1999<br>Fernandez et al., 1999 |
| Vzhodna Evropa (Tatre)<br>Eastern Europe (the Tatra Mts.) | 130 | Fernandez in sod., 1999<br>Fernandez et al., 1999 |

Preglednica 1: $PAH_{pyr}$/OC koncentracije v Jezeru na Planini pri Jezeru (Triglavski narodni park, Slovenija) in površinski plasti sedimentov evropskih visokogorskih jezer (PAH = policiklični aromatski ogljikovodiki; OC = organski ogljik)

*Table 1: $PAH_{pyr}$/OC concentrations in the lake Jezero na Planini pri Jezeru (Triglav National Park, Slovenia) and surface sediment concentrations in European remote high-mountain lakes (PAH = polycyclic aromatic hydrocarbons; OC = organic carbon).*

$PAH_{pyr}$ (celokupna pirolitska koncentracija PAH) je vsota vseh "starševskih" oz. izvornih PAH spojin, razen perilena in retena.

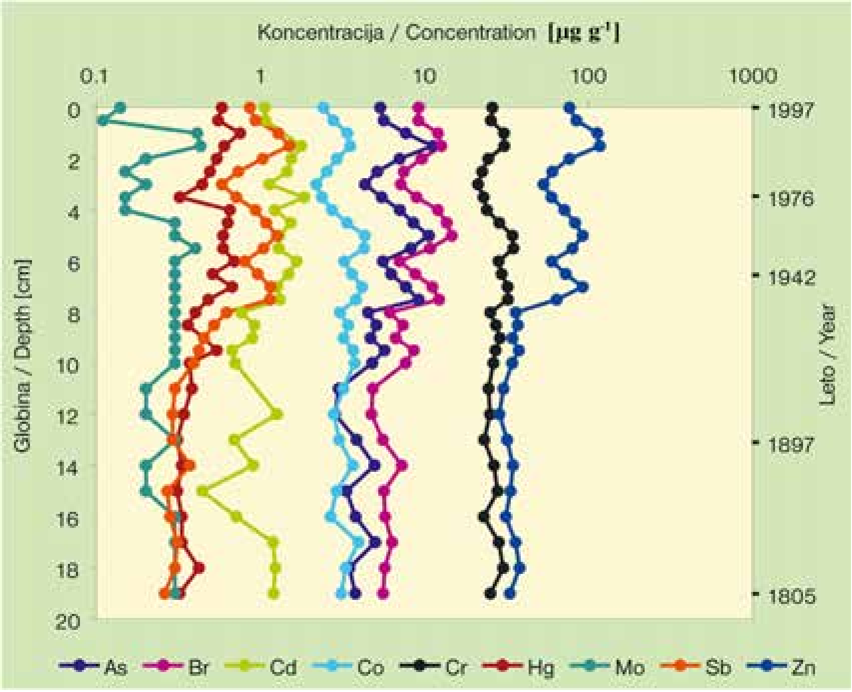
*$PAH_{pyr}$ (total pyrolytic PAH concentration) is a sum of all parent PAH compound, except perylene and retene.*

## PORAZDELITEV ELEMENTOV V SLEDOVIH V SEDIMENTIH

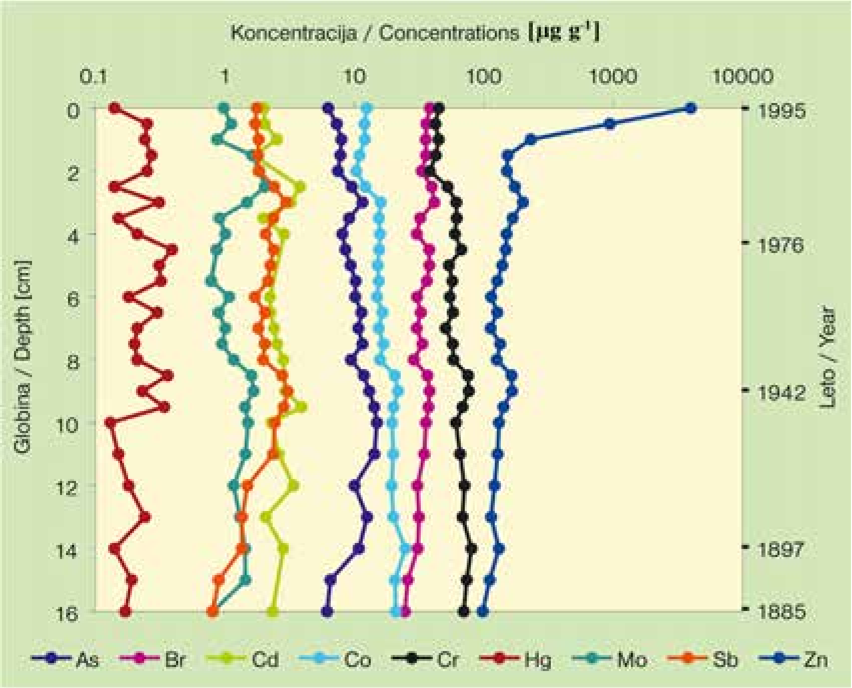
V Krnskem jezeru, Jezeru v Ledvicah in Jezeru na Planini pri Jezeru smo v sedimentih določali tudi porazdelitev nekaterih elementov v sledovih, kot so: arzen (As), brom (Br), kadmij (Cd), kobalt (Co), krom (Cr), živo srebro (Hg), molibden (Mo), antimon (Sb) in cink (Zn), za katere je znano, da imajo poleg naravnega izvora lahko svoj izvor tudi v delovanju človeka in so povezani z industrializacijo, prometom, izgorevanjem fosilnih goriv in drugim (Nriagu in Davidson, 1986). Za te elemente je tudi značilno, da se lahko z zračnimi masami prenašajo na velike razdalje, včasih zelo daleč od virov emisij. Poleg naštetih elementov smo v Jezeru na Planini pri Jezeru določili tudi svinec (Pb). Kot je razvidno iz slik 5 a–c, se koncentracije praktično vseh kovin in elementov v sledovih spreminjajo z globino, vendar pa so te spremembe zelo neenakomerne. Največje nihanje koncentracij po globinskem profilu je opazno v Krnskem jezeru, bistveno manj pa v ostalih dveh jezerih. Ponovno kaže, da so potresi tisti glavni vzrok, ki tako drastično vpliva na procese v majhnih jezerih, kot so alpska jezera. Kaj se je med potresom v jezerih dejansko dogajalo, je zelo težko reči, vendar rezultati porazdelitve kovin in elementov v sledovih kažejo (slike 5 a–c), da je prišlo do nenadnega znižanja koncentracij praktično vseh analiziranih kovin, temu sta sledili povečana sedimentacija in postopna povišana koncentra-

## DISTRIBUTION OF METALS IN SEDIMENTS

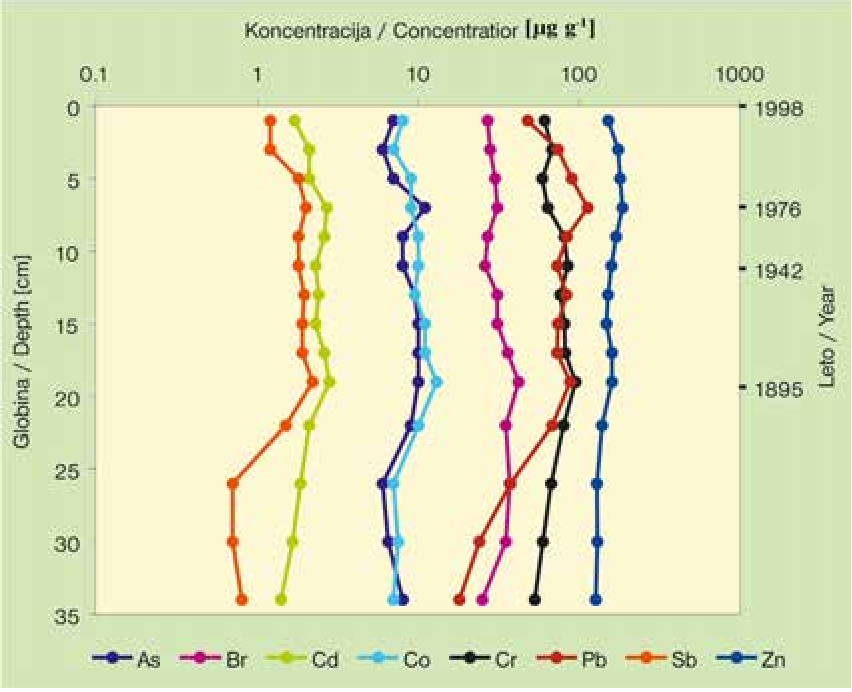
The distribution of some heavy metals and trace elements, namely arsenic (As), bromine (Br), cadmium (Cd), cobalt (Co), chromium (Cr), mercury (Hg), molybdenum (Mo), antimony (Sb) and zinc (Zn), which besides a natural origin are known to have also an anthropogenic origin (Nriagu & Davidson, 1986) and which can be atmospherically transported over long distances from their emission, were investigated at different sediment depths in the lakes Krnsko jezero, Jezero v Ledvicah and Jezero na Planini pri Jezeru. In Jezero na Planini pri Jezeru, lead (Pb) was also determined. As seen from Figures 5 a–c, the concentrations of all investigated elements change with depth, however, an irregular decrease is noticed. This irregularity is particularly apparent in Krnsko jezero, and much less in the other two lakes. It seems that natural events such as earthquakes played an important role in the environment of these small lakes. What really happened during the earthquake in the lake itself is very difficult to say. However, Figures 5 a–c show that a dilution of elemental concentrations is observed in all lake sediment cores, followed by increased sedimentation rates and higher concentrations. Brancelj *et al.* (2000) presumed that the effect of earthquakes was to trigger slope collapse on the land, which then affected sediment re-suspension rather than sediment slumping within the lake itself. A detailed in-




5a




5b




5c

Slika 5: Porazdelitev elementov v sledovih v jezerih a) Krnsko jezero, b) Jezero v Ledvicah in c) Jezero na Planini pri Jezeru. Označene so tudi letnice potresov (Triglavski narodni park, Slovenija)

*Figure 5: Distribution of trace elements in sediment profiles of lakes a) Krnsko jezero, b) Jezero v Ledvicah and c) Jezero na Planini pri Jezeru. The years of earthquakes are also marked on the Figures (Triglav National Park, Slovenia)*

cija kovin. Brancelj s sod. (2000) sklepajo, da so potresi povzročili zdrs okoliških kamnin in zemlje v jezero in posledično povišano sedimentacijo tega materiala na jezersko dno. Prav tako isti avtorji menijo, da ob potresih ni prišlo do zdrsa materiala v jezeru samem. Podrobni pregled globinskega profila sedimenta Krnskega jezera je pokazal, da so koncentracije kovin in elementov v sledovih v zgornjih 8 cm sedimenta v povprečju bistveno višje od koncentracij v globljih plasteh sedimenta, kar je lahko posledica večjega onesnaževanja okolja po prvi svetovni vojni. V zgornjih 8 cm sedimenta je opazno tudi ciklično nihanje koncentracij s tremi izrazitimi depresijami pri 3–3,5 cm, 6–6,5 cm in 8 cm. Glede na starost sedimentov prvi dve depresiji lahko povežemo s potresi leta 1976 in 1942, tretjo pa s povečano industrializacijo po prvi svetovni vojni. Med 8–18 cm so koncentracije kovin relativno konstantne, vendar nižje kot v zgornjih 8 cm. Opazni sta ponovno dve manjši depresiji pri 9 cm in 11–12 cm. Prvo bi lahko pripisali prvi svetovno vojni, saj je znano, da je bilo področje Krna na frontni liniji in da je bilo tu v času vojne več močnejših detonacij, ki so lahko povzročile zdrs materiala v jezero. Druga depresija pa je verjetno potres leta 1895.

Analiza sedimentov Jezera na Planini pri Jezeru je pokazala, da v tem jezeru lahko ločimo 3 obdobja jezerske zgodovine. V prvem, to je med 1996 do začetka sedemdesetih let (0–7 cm), je opaziti naraščanje koncentracij nekaterih elementov. V globini med 9–19 cm so koncentracije analiziranih elementov dokaj konstantne, od 19 cm navzdol pa sledi izrazito znižanje koncentracij z globino. Za analizo kovin in elementov v sledovih je bilo jedro sedimenta Jezera na Planini pri Jezeru razdeljeno na 2-centimetrske rezine, v ostalih dveh jezerih pa na 0,5 do 1 centimetrske rezine, kar je po vsej verjetnosti vzrok, da v sedimentu Jezera na Planini pri Jezeru ni opaziti takih nihanj vsebnosti kovin kot v ostalih dveh.

Porazdelitev kovin in elementov v sledovih v Jezeru v Ledvicah je zelo podobna tisti v Jezeru na Planini pri Jezeru. Preseneča le izjemno visoka vsebnost cinka v zgornjem sloju (1 cm). Po vsej verjetnosti je posledica onesnaževanja neposredno v jezeru.

sight to the sediment profile of the lake Krnsko jezero showed that although the concentrations in the upper 8 cm of the core were higher than below this depth, the decrease is irregular and is interrupted with three well expressed depressions of all investigated elements at depths of 3.0-3.5 cm, 6.0-6.5 cm and 8 cm. The first two could be linked to two earthquakes in this region in 1976 and 1942 and the third can be used as the starting point of industrialisation after World War I. Between 8-18 cm, elemental concentrations are relatively constant, but on average, lower than in the upper section, with only two smaller depressions at depths of 9 and 11-12 cm. The first one can be connected to World War I since it is known that there were huge detonations in this region during this war and which could have caused the slope collapse, while the second one can again be related to the earthquake in 1895.

In the sediment from Jezero na Planini pri Jezeru, three periods of lake history can be distinguished. An increase of some elements is found at depths from 0-7 cm, which cover the years between 1998 to the beginning of the 1970s. Concentrations were relatively constant in the segment between 9-19 cm and after this depth they decrease rapidly. Since trace elements in sediments of Jezero na Planini pri Jezeru were determined in slices of 2 cm, whereas in the other two lakes thinner slices of 0.5-1.0 cm were used for analysis, less fluctuation with depth was observed.

In Jezero v Ledvicah, the distribution of elements down the core is similar to that found in the lake Jezero na Planini pri Jezeru, with the exception of the zinc level which is extremely high in the first 1 cm of the core and may be connected with some human activity in the lake.

## SCP V SEDIMENTACIJSKIH PASTEH IN SEDIMENTIH

Procese sedimentiranja smo zasledovali z analiziranjem vsebine sedimentacijskih pasti. Določali smo število SCP, ki jih zlahka ločimo od drugih delcev sedimenta, in tako ocenili procese sedimentiranja ter časovnega in prostorskega onesnaženja, ki se širi po zraku. Metodo, ki smo jo uporabili za analizo SCP, je opisal Rose (1994). Ekstrahirane SCP iz sedimentiranega materiala smo šteli pod svetlobnim mikroskopom pri 400-kratni povečavi. Koncentracijo smo izrazili kot število delcev SCP na $cm^2$ na dan ($cm^{-2}$ $d^{-1}$).

Sedimentacijske pasti smo postavili v jezera

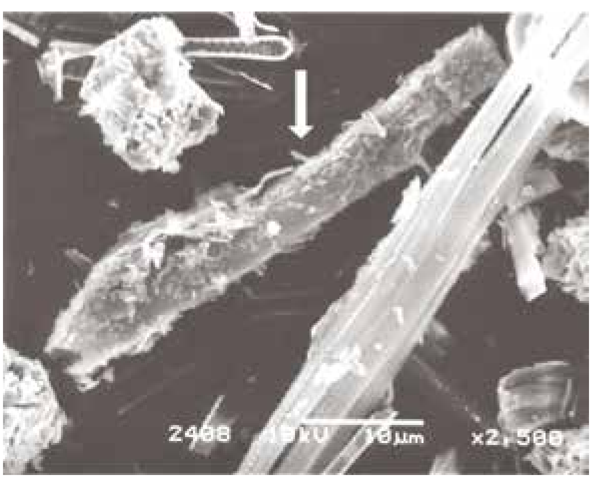
## SCP IN SEDIMENTATION TRAPS AND SEDIMENTS

Sedimentation processes were studied by analysing sediment material in sedimentation traps. SCPs were counted as markers of these processes, since they are easily distinguished from sediment material. They are, in addition, a useful tool in recording the temporal and spatial distribution of atmospheric pollution. The method used for SCP analyses was that described by Rose (1994). SCP were first extracted from the sediment material, then counted at 400 times magnification using a light microscope. Concentration was expressed as the number of SCP per $cm^2$ per day ($cm^{-2}$ $d^{-1}$).


Kroglasti delec črnega ogljika (SCP), ki nastaja pri izgorevanju premoga in nafte, posnet z vrstičnim elektronskim mikroskopom. (Foto: Zoran Samardžija)
*Scaning electron microscope micrograph of spheroidal black carbon particles (SCP) originating from coal and oil combustion. (Photo: Zoran Samardžija)*

spomladi 1996. Na ploščo smo pritrdili 4 valje, past potopili in zasidrali v višini 1 metra nad jezerskim dnom. Pasti smo praznili mesečno in vsebino ustrezno obdelali.

Količina usedline je bila različna. Vzroki so v različnosti pojezerij, tako glede na geografske značilnosti, zadrževalne kapacitete in človekove aktivnosti ter glede na trofično stanje jezer. Povprečne dnevne količine usedlin so prikazane v preglednici 2. Najmanjšo povprečno dnevno količino usedline smo določili v Jezeru v Ledvicah, medtem ko sta bili v Krnskem jezeru in Jezeru na Planini pri Jezeru vrednosti višji. Kumulativne vrednosti so pokazale, da je bila najnižja skupna količina usedline 0,33 g DW $m^{-2}$ $d^{-1}$ v oligotrofnem Jezeru v Ledvicah,



Podolgovati delec črnega ogljika, ki nastaja pri izgorevanju biomase in lesa, posnet z vrstičnim elektronskim mikroskopom. (Foto: Zoran Samardžija)
*Scaning electron microscope micrograph of elongated BC particle originating from biomass and wood combustion. (Photo: Zoran Samardžija)*

Sedimentation traps were installed in the lakes in spring 1996. Four cylinders were fastened to a plate, dipped into the water and anchored 1 metre above the lake bed. Sediment material was gathered monthly and prepared for analyses.

The amount of sediment varied between lakes. Different types of watershed in relation to geography, water retention capacity and human activity, as well as the trophic status of the lakes, affect deposition rates. The average daily amount of deposited sediment is shown in Table 2. The smallest amount was observed in the lake Jezero v Ledvicah. Cumulative values for a 4-year period showed that in the oligotrophic lake Jezero v Ledvicah the lowest amount of 0.33 g DW $m^{-2}$ $d^{-1}$ was trapped. In the other two lakes, the amount of sedimented material was greater, reaching 6.72 g DW $m^{-2}$ $d^{-1}$ in the eutrophic lake Krnsko jezero and 4.9 g DW $m^{-2}$ $d^{-1}$ in the hypertrophic lake Jezero na Planini pri Jezeru. It is likely that pasturing and recreation activities in the catchment of the latter lakes had a conspicuous influence on fluxes and internal cycles in the lakes (Brancelj *et al.*, 1997).

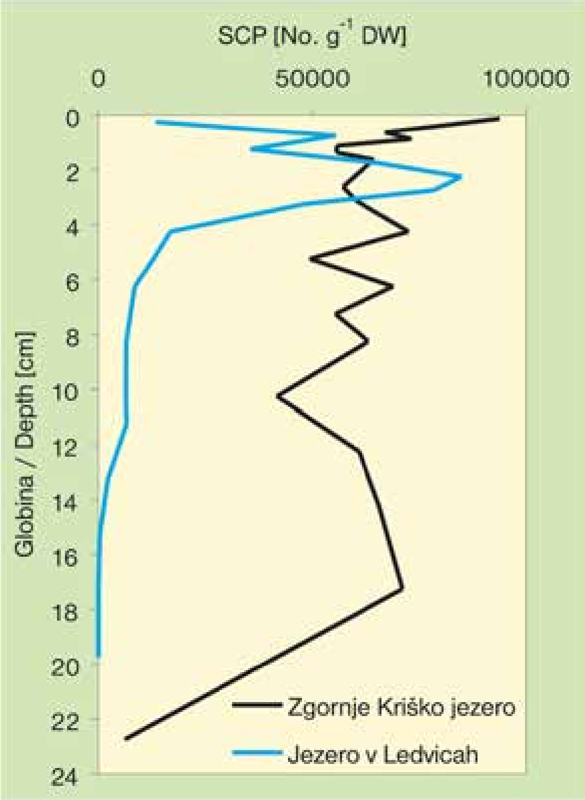
The situation was different considering the SCP content in sedimentation traps. In 1996, the highest concentration of 3.6 SCP $cm^{-2}$ $d^{-1}$ was determined in the lake Jezero na Planini pri Jezeru. In the two other lakes, the concentrations were 2.2 SCP $cm^{-2}$ $d^{-1}$ in Krnsko jezero and 0.4 SCP $cm^{-2}$ $d^{-1}$ in Jezero v Ledvicah. In 1997, SCP deposition increased in all three lakes but in reverse order. The highest concentration of 15 SCP $cm^{-2}$ $d^{-1}$ was determined in Jezero v Ledvicah, with 12 SCP $cm^{-2}$ $d^{-1}$ in Krnsko jezero and 3 SCP $cm^{-2}$ $d^{-1}$ in Jezero na Planini pri Jezeru. In 1998, concentrations of SCP decreased again to 4 particles $cm^{-2}$ $d^{-1}$, 3.7 particles $cm^{-2}$ $d^{-1}$ and 0.9 particles $cm^{-2}$ $d^{-1}$ for the respective lakes.

These results were not paralleled by other measured parameters in the trapped material, i.e., sediment volume, organic matter content and dry mass, since the material originated from different sources, internal as well as external. A better relationship could be expected with meteorological data. However, longer records of SCP fluxes, wind patterns and precipitation data are needed before clear correlation patterns can be made. Fott *et al.* (1998) has v evtrofnem Krnskem jezeru je bila 6,72 g DW $m^{-2}$ $d^{-1}$ in v hiperevtrofnem Jezeru na Planini pri Jezeru 4,9 g DW $m^{-2}$ $d^{-1}$. Velika verjetnost je, da imajo aktivnosti v bližnjem zaledju obeh zadnjih jezer, kot npr. paša in planinarjenje, precejšen vpliv na pretoke snovi in njihovo kroženje v jezerih (Brancelj in sod., 1997).

Analiza SCP-delcev v sedimentacijskih pasteh pa je pokazala drugačno sliko. Leta 1996 smo najvišje število delcev, 3,6 $cm^{-2}$ $d^{-1}$ (število delcev SCP na kvadratni centimeter na dan), določili v Jezeru na Planini pri Jezeru, 2,2 SCP $cm^{-2}$ $d^{-1}$ v Krnskem jezeru in 0,4 SCP $cm^{-2}$ $d^{-1}$ v Jezeru v Ledvicah. Leta 1997 je depozicija SCP narasla v vseh treh jezerih, toda v drugačnem vrstnem redu. V Jezeru v Ledvicah smo določili največje število 15 SCP $cm^{-2}$ $d^{-1}$, v Krnskem jezeru 12 SCP $cm^{-2}$ $d^{-1}$in v Jezeru na Planini pri Jezeru 3 SCP $cm^{-2}$ $d^{-1}$. V naslednjem letu se je število delcev spet zmanjšalo na 4 SCP $cm^{-2}$ $d^{-1}$ v Jezeru v Ledvicah, 3,7 SCP $cm^{-2}$ $d^{-1}$ v Krnskem jezeru in 0,9 SCP $cm^{-2}$ $d^{-1}$ v Jezeru na Planini pri Jezeru. Dobljeni rezultati niso v korelaciji z ostalimi merjenimi parametri, t. j. s količino sedimenta, organskim deležem in sušino. To je razumljivo, saj sta izvora teh snovi samo jezero kot tudi pojezerje. Boljšo korelacijo lahko pričakujemo v povezavi z meteorološkimi podatki, vendar bi za tako oceno potrebovali dolgotrajnejše podatke o količini SCP, o vetrovnih rožah ter padavinah. Analize SCP-delcev v površinski plasti sedimenta iz 31 umetnih in v enem naravnem jezeru na Češkem, ki jih je naredil Fott s sod. (1998), so pokazale, da obstaja korelacija z geografskimi značilnostmi lokacije, t. j. z nadmorsko višino in površino jezera.

Težave, ki smo jih imeli pri razlagi prvih rezultatov o izvoru SCP (Gaberščik in sod., 1997), so nas pripeljale do odločitve, da razvrstimo delce po velikosti v tri razrede: najmanjši 2–5 μm, 5–20 μm in 20–50 μm. V vseh vzorcih so bili majhni delci, ki lahko potujejo dlje od vira emisij kot večji delci, številčnejši. V Krnskem jezeru je bilo razmerje med velikostnimi razredi podobno čez celo leto. Majhni delci (< 5 μm) so predstavljali okoli 60 %, medtem ko je delež največjih delcev (med 20 in 50 μm) znašal manj kot 3 %vseh SCP. Letna nihanja v razmerju med posameznimi velikostnimi razredi so bila pri ostalih dveh jezerih večja.

Število SCP je bilo prvič določeno v sedimentu Zgornjega Kriškega jezera in Jezera v Ledvicah leta 1994 (slika 6). Analize je opravil Rose v okviru evropskega projekta. Obe sta čisti oligotrofni jezeri, vendar je bila najvišja koncentracija SCP v obeh visoka in je znašala okrog 90.000 SCP g $DW^{-1}$. Najvišje




Slika 6: Porazdelitev kroglastih ogljikovih delcev (SCP) v sedimentu iz Jezera v Ledvicah in Zgornjega Kriškega jezera (Triglavski narodni park, Slovenija)

*Figure 6: SCP concentration profile in the sediment of the lake Jezero v Ledvicah and Zgornje Kriško jezero (Triglav National Park, Slovenia)*

reported SCP contents in surface sediments from 31 man-made and one natural lake in the Czech Republic. A good relationship was found only to site characteristics, i.e., altitude and lake area.

Because of the difficulty in interpreting the variability of the first year's SCP data-set (Gaberščik *et al.*, 1997) the particles were analysed by size range. Particle size ranged from 2 to 5 μm, 5 to 20 μm and 20 to 50 μm. In all samples, small particles, which could be transported farther from sources of emission than the larger ones, were more abundant. The size distribution of SCPs in the sedimentation trap in the lake Krnsko jezero was similar throughout the year. Small particles (< 5 μm) constituted about 60 %, and the largest ones (> 20 μm) less than 3 % of all SCPs. Annual variability of size was higher in the other two lakes.

In 1994, the first determinations of SCPs were made in the sediments of the lakes Zgornje Kriško jezero and Jezero v Ledvicah (Figure 6). Analyses were carried out by Rose in the framework of the

| Jezero / Lake \ Leto / Year | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|
| Krnsko jezero | 0.84 | 1.01 | 3.68 | 1.19 |
| Jezero v Ledvicah | 0.16 | 0.19 | 0.86 | 0.09 |
| Jezero na Planini pri Jezeru | 1.97 | 1.12 | 0.88 | 0.93 |

Preglednica 2: Povprečna dnevna količina usedline v sedimentacijskih pasteh (v g DW $m^{-2}$ $day^{-1}$ ) v treh jezerih v Julijskih Alpah (Triglavski narodni park, Slovenija)
*Table 2: Average daily amount of the sediment deposited in sediment traps (in g DW $m^{-2}$ $day^{-1}$ ) in three lakes of the Julian Alps (Triglav National Park, Slovenia)*

vrednosti v Zgornjem Kriškem jezeru so bile v površinski plasti. V ostalih globinah je bilo število nižje, vendar precej enakomerno. V Jezeru v Ledvicah je bila najvišja vrednost v globini 2,5 cm, potem pa je število ves čas padalo.

V Krnskem jezeru smo leta 1997 analizirali jedro sedimenta do globine 23 cm. Koncentracija SCP se je precej spreminjala po plasteh. V površinski plasti sedimenta smo določili 65.400 SCP g $DW^{-1}$. Nato se je koncentracija znižala in se pri 6 cm ponovno povečala ter dosegla najvišjo vrednost 125.000 SCP g $DW^{-1}$. Potem je koncentracija ponov-

EU project. Both lakes are of oligotrophic character but high concentration of SCPs in some layers indicated accelerated deposition of air-borne particles. A concentration of over 90,000 SCP $gDW^{-1}$ was determined in the upper sediment of Zgornje Kriško jezero while a similar value was determined at a depth of 2.5 cm in the sediment of Jezero v Ledvicah.

In Krnsko jezero, a sediment core of 23 cm was analysed. The concentration varied considerably between the layers. In the surface layer, 65,400 SCP g $DW^{-1}$ were found. Concentration decreased to a depth of 6 cm, where the maximum of 125,000 SCP

| | SCP g DW<br>SCP g DW | Vsebnost vode<br>Water content<br>[%] | Žarilni ostanek<br>Loss-on-ignition<br>[%] |
|---|---|---|---|
| **Rjavo jezero** | 1233 | 70.5 | 89.6 |
| **Zeleno jezero** | 2448 | 86.6 | 76.0 |
| **Jezero v Ledvicah** | 5426 | 93.5 | 62.7 |
| **Dvojno jezero** | 5491 | 92.0 | 64.8 |
| **Črno jezero** | 1988 | 88.6 | 68.2 |
| **Jezero na Planini pri Jezeru** | 4822 | 93.8 | 68.9 |
| **Dupeljsko jezero** | 672 | 87.4 | 78.6 |
| **Krnsko jezero** | 9150 | 87.2 | 82.8 |
| **Jezero v Lužnici** | 5972 | 92.9 | 55.4 |
| **Zgornje Kriško jezero** | 24017 | 89.3 | 79.6 |
| **Srednje Kriško jezero** | 9923 | 87.2 | 76.7 |
| **Spodnje Kriško jezero** | 5306 | 90.4 | 85.0 |

Preglednica 3: Koncentracije kroglastih ogljikovih delcev (SCP), vsebnost vode in žarilni ostanek (LOI) v površinski plasti sedimentov (0–0,5 cm) v dvanajstih visokogorskih jezerih v Julijskih Alpah (Triglavski narodni park, Slovenija) (Rose, osebni podatek; projekt EMERGE)
*Table 3: Spheroidal carbonaceous particles (SCP) concentration, water content and loss-on-ignition (LOI) in surface sediments (0–0.5 cm) of twelve high-mountain lakes in the Julian Alps (Triglav National Park, Slovenia) (Rose, pers. comm.; EMERGE project)*

no upadla in je v globljih plasteh sedimenta znašala med 6000 in 8000 SCP g $DW^{-1}$.

Leta 2001 je Rose naredil analizo SCP v površinski plasti sedimentov v 12 jezerih v TNP. Rezultati so prikazani v preglednici 3. Najvišje število SCP, in sicer 24.000, je bilo določeno v Zgornjem Kriškem jezeru, kjer se odlagajo onesnaževalci, ki se po zraku prenašajo iz onesnaženih okolij srednje Evrope in se odložijo v pojezerju najvišje ležečega jezera. Opaziti je gradient v smeri nižje ležečih jezer. V jezerih v Dolini Triglavskih jezer, kjer so jezera nanizana v smeri sever–jug, pa so večji atmosferski vplivi prepoznavni z južne smeri, na kar kaže tudi postopno upadanje koncentracije SCP proti višje ležečim jezerom.

g $DW^{-1}$ occurred, followed by a decrease again in the lower layers, where values were between 6000 and 8000 SCP g $DW^{-1}$.

In 2001, Rose (pers. comm.) analysed SCPs in the surface layers of 12 lakes in the Triglav National Park. Results are presented in Table 3. The highest number of 24,000 SCP g $DW^{-1}$ was determined in the lake Zgornje Kriško jezero. It is likely that pollutants, deposited here, are transported from central Europe. A gradient toward the lower lakes is observed. In the Triglav Lakes Valley, which is oriented north - south, the atmospheric influences are coming from the south therefore a gradient toward the upper lakes is observed.

## ZAKLJUČKI

Jezerski sedimenti odmaknjenih visokogorskih jezer vsebujejo dobro ohranjene zapise o zgodovini jezer in njihovega zaledja. Prirast sedimenta v jezerih v vzhodnem delu Julijskih Alp je različen in se giblje v območju 1 do 3 mm na leto. Evtrofikacija jezer in potresi ta proces pospešijo. Med drugim najdemo v sedimentih tudi ostanke različnih onesnaževalcev, ki so se tja nalagali, sedaj pa jih lahko uporabljamo kot pokazatelje dogodkov v preteklosti. Glavni vir teh snovi je onesnaževanje na dolge razdalje, ki se prenaša po zraku.

V sedimentih izbranih jezer smo ugotavljali prisotnost črnega ogljika (BC), težkih kovin, policikličnih aromatskih ogljikovodikov (PAH) in kroglastih ogljikovih delcev. Ti onesnaževalci imajo najpogosteje izvor pri izgorevanju različnih snovi. V vseh primerih smo v podpovršinski plasti, ki časovno ustreza sredini 20. stoletja, ugotovili najvišje koncentracije teh snovi. Po tem sklepamo, da so bile emisije ugotovljenih snovi v tistem času največje. Absolutno največje koncentracije so v sedimentu jezer iz severozahodnega dela Julijskih Alp. Proti vzhodu se količina onesnaževalcev zmanjšuje, in sicer skladno z upadanjem količin padavin.

## CONCLUSIONS

Remote mountain lake sediments contain a well preserved record of the lake and the lake catchment history. A sediment accumulation rate in the lakes in the Julian Alps differs from lake to lake, ranging from 1 to 3 mm per year. Eutrophication of the lakes and earthquakes accelerate the process. Various pollutants can be found in these sediments which can be used as indicators of environmental changes that have occurred in the past. Their main source in alpine areas is long distance atmospheric pollution.

Black carbon (BC), heavy metals, polycyclic aromatic hydrocarbons (PAH) and spheroidal carbonaceous particles (SCP) were determined in selected lake sediments. These pollutants are mainly combustion-derived substances. Subsurface peaks were observed in all cases, with maximum values in the mid 20$^{th}$ century. It seems that emissions of pollutants were most intense in that period. The highest concentrations of pollutants were determined in the north-western part of the Julian Alps but concentrations decreased towards the East, in accordance with the annual precipitation rate, which decreases in the same direction.

# *Poglavje* 11 *Chapter*

# *Izvori in mineralizacija organske snovi v visokogorskih jezerih*

# *Origins and Mineralisation of Organic Matter in High-mountain Lakes*

Tatjana SIMČIČ*, Polona VREČA**, Gregor MURI*, Sonja LOJEN** & Nives OGRINC**

## UVOD

Osnovni problem jezer predstavlja evtrofikacija, ki jo pospešuje človek z intenzivnimi posegi v okolje. Vnos onesnaževalcev je lahko neposreden ali pa gre za spremembe in onesnaženje večjih razsežnosti v povodju ter onesnaženje preko zraka (Lerman in sod., 1995). Zaradi povečanega vnosa hranil v jezero se poruši naravno ravnotežje, posledica pa je povečanje primarne produkcije in pospešitev procesa evtrofikacije. Organska snov, ki nastane v površinski plasti vodnega stolpca (epilimniju), počasi tone in se razgrajuje (mineralizira) v spodnjem delu vodnega stolpca (hipolimniju). Le nekaj % organske snovi doseže dno jezera in se lahko vgradi v sediment, kjer je izpostavljena nadaljnjim diagenetskim spremembam, ali pa se mineralizira z mikrobnimi procesi in tako neposredno vpliva na koncentracijo hranil v vodnem okolju (Lerman in sod., 1995). Prenos raztopljenih zvrsti na meji med vodo in sedimentom ter vgrajevanje v sedimentni stolpec določajo predvsem kemijski, biološki in hidrodinamski procesi. Na procese v sedimentih pa v veliki meri vpliva mikrobna oksidacija organske snovi z akceptorji elektronov $O_2$, $NO_3^-$, $MnO_2$, $Fe_2O_3$, $SO_4^{2-}$ in $CO_2$ (Froelich in sod., 1979). Posledica razgradnje organske snovi je nastanek novih hranil v obliki reduciranih kemijskih zvrsti ($HCO_3^-$, $N_2$, $Mn^{2+}$, $NH_4^+$, $Fe^{2+}$, $H_2S$ in $CH_4$), ki se sprostijo v porno vodo sedimenta. Izmenjava snovi med porno vodo v sedimentu in vodo na dnu jezera je pomemben proces, ki vpliva na koncentracijo

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## INTRODUCTION

One of the biggest concerns related to lakes is eutrophication induced by anthropogenic activities in the environment. Input of pollutants can be direct (point sources) or be related to wider activities in the watershed and to long-range atmospheric transport (diffuse source) (Lerman *et al.*, 1995). The response to a disturbed natural equilibrium and higher nutrient concentrations in water is an increase in bioproduction and the process of eutrophication. Much of the organic matter produced in the surface water (epilimnium) is degraded (mineralisation) as it sinks through the water column (hypolimnium) and only a small amount reaches the sediment interface (Lerman *et al.*, 1995). Organic matter that reaches the lake bottom can be either incorporated into the sediment where it is exposed to diagenetic processes, or be mineralised by microbial processes and directly influence the concentration of nutrients in the water (Lerman et al., 1995). Mass transfer of dissolved species across the sediment–water interface and permanent burial in the sediment column are controlled to a large extent by chemical, biological and hydrodynamic processes. Most processes in sediments are regulated by the microbial oxidation of organic matter using $O_2$, $NO_3^-$, $MnO_2$, $Fe_2O_3$, $SO_4^{2-}$ and $CO_2$ (Froelich *et al.*, 1979). Many of the compounds produced and subsequently released to the sediment pore water ($HCO_3^-$, $N_2$, $Mn^{2+}$, $NH_4^+$, $Fe^{2+}$, $H_2S$ and $CH_4$) are important nutrients. Exchange

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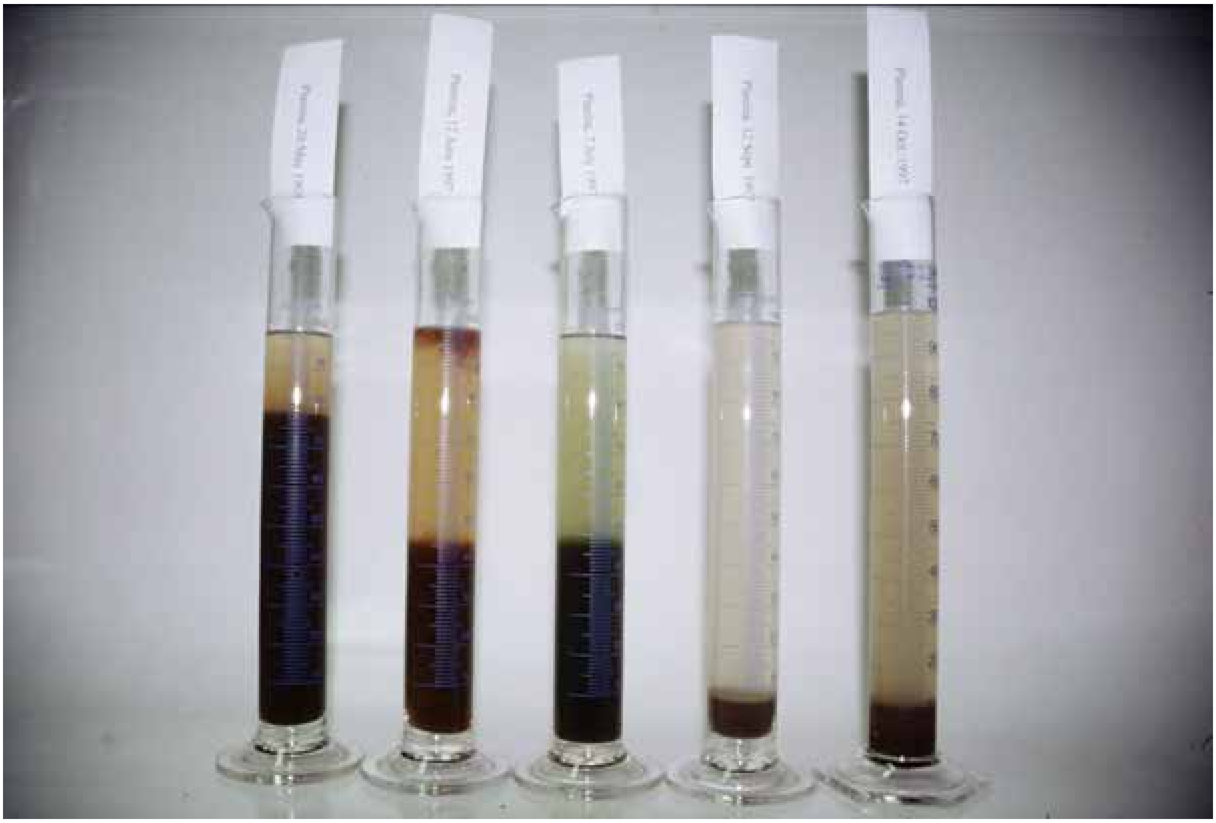


Količina in sestava materiala, ki se odlaga na dno jezer, se preko leta spreminja. Na sliki je pet zaporednih vzorcev iz sedimentacijskih pasti, ki so bili pobrani iz Jezera na Planini pri Jezeru od maja do oktobra 1997. (Foto: Anton Brancelj)

*The quality and quantity of material sinking to the bottom of the lakes, changes in the course of the year. On the photo are five samples from a sediment trap from Jezero na Planini pri Jezeru, collected in the period from May to October 1997. (Photo: Anton Brancelj)*

$O_2$ v vodi nad sedimentom kot tudi na celotno množino hranil, ki so na razpolago za fotosintezo (McNichol in sod., 1991). Posledica razgradnje organske snovi je lahko nastanek anoksičnih pogojev v hipolimniju in sedimentu, saj večino razpoložljivega $O_2$ porabljajo mikroorganizmi za oksidacijo $CH_4$, $NH_4^+$ in $H_2S$ (Sweerts in sod., 1991; Sinke in sod., 1992). Razgradnja organske snovi v času zgodnje diageneze je torej pomemben proces, ki vpliva na stanje površinskih voda in geokemijo sedimentov.

V sedimentu akumulirana organska snov nam daje pomembno informacijo o jezerskem paleookolju, zgodovini klimatskih sprememb in človeškem vplivu na lokalne in regionalne spremembe ekosistema. Načini vnosa organske snovi v jezera so zelo različni. Terigena (alohtona) organska snov se v jezero vnese pretežno iz jezerskega povodja s površinsko erozijo, deloma pa je lahko transportirana iz bolj oddaljenih območij s padavinami in vetrom.

between pore water and the overlying water means that the oxidation of organic matter in sediments can have an important effect on the amount of $O_2$ in the overlying water, as well as on the total amount of nutrients available for photosynthesis (McNichol *et al.*, 1991). As a consequence of mineralisation of organic matter anoxic conditions can appear in the hypolimnium and in the sediment, since most of the $O_2$ may be consumed by microorganisms that oxidise $CH_4$, $NH_4^+$ and $H_2S$ (Sweerts *et al.*, 1991; Sinke *et al.*, 1992). Decomposition of organic matter during early diagenesis is thus an important process that affects the quality of surface waters and the geochemistry of the sedimentary deposits.

The organic matter accumulated in lake sediments constitutes an important archive that provides information important in studies of the lacustrine palaeoenvironment, the history of climate change, and the effects of humans on local and regional ecosystems. It is introduced to lakes by multiple

Živali, rastline in bakterije v vodnem stolpcu in sedimentu pa predstavljajo vodno (avtohtono) komponento organske snovi. Različne vrste organizmov, ki naseljujejo jezero in njegovo povodje, prispevajo organsko snov z določeno biokemijsko sestavo. Spremembe teh združb organizmov se kažejo v spremembah količine in vrste organske snovi, ki se je v preteklosti odložila na dnu jezera (Lerman in sod., 1995). Pogosto uporabljamo za ugotavljanje izvora sedimentirane organske snovi razmerje C/N, ki znaša za vodne alge med 4 in 10, v vaskularnih rastlinah pa je to razmerje običajno ≥ 20 (Meyers, 1994). Poleg razmerja C/N predstavlja pomemben indikator izvora organske snovi razmerje stabilnih izotopov ogljika ($^{13}C/^{12}C$) izraženo relativno ($\delta^{13}C$) v promilih (‰) glede na standard V-PDB (Deines, 1980; Fry in Sherr, 1984). Pogosto pa se za sledenje izvora sedimentirane organske snovi uporabljajo tudi stabilni izotopi dušika (Letolle, 1980).

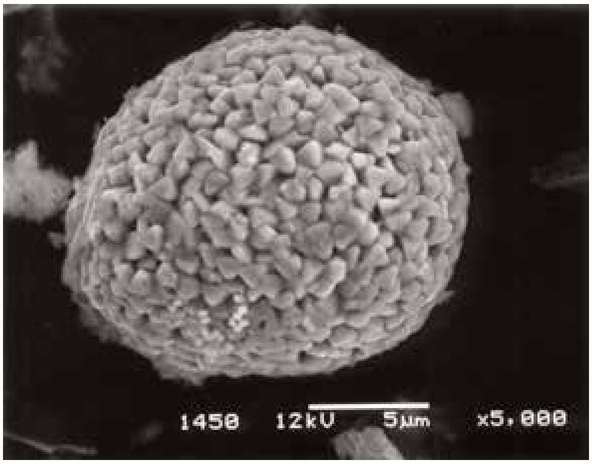
Odvzem ogljika iz atmosferskega rezervoarja ogljikovega dioksida in površinskih vod s fotosintetsko vezavo v obliko kompleksnih organskih molekul je eden od pomembnejših procesov, povezan s spremembami izotopske sestave ogljika v geokemijskem kroženju. Najpomembnejša načina vezave ogljika sta poznana kot Calvin-Bensonov ($C_3$) cikel, v katerem poteka fotosinteza prek encima ribuloze-1,5-difosfat karboksilaze in Hatch-Slackov ($C_4$) cikel, kjer poteka fotosinteza prek encima fosfoenolpiruvat karboksilaze. Pri rastlinah z metabolizmom CAM (Crassulacean Acid Metabolism) sta prisotni obe karboksilazi. Z vrsto fotosinteze je povezana vsebnost $^{13}C$ v rastlini. Tako imajo rastline tipa $C_3$ vrednosti $\delta^{13}C$ od –24 ‰ do –34 ‰, rastline tipa $C_4$ od –6 ‰ do –19 ‰, rastline tipa CAM pa pokrivajo celoten razpon rastlin $C_3$ in $C_4$ (Deines, 1980). Tako lahko s pomočjo vrednosti $\delta^{13}C$ določimo izvor rastlinske organske snovi, ohranjene v sedimentu (Fry in Sherr, 1984).

Bentoški organizmi imajo pomembno vlogo pri mineralizaciji organske snovi v sedimentu, zato z določitvijo hitrosti njihovih metabolnih procesov dobimo osnovne podatke o kroženju hranilnih snovi in o pretoku ogljika v sedimentih. V večini plitvih vodnih sistemov poteka največji del mineralizacije v metabolnih procesih organizmov, ki živijo v sedimentu, manjši del organske snovi pa se mineralizira že v vodnem stolpcu (Vosjan in Olanczuk – Neyman, 1977). To pomeni, da se z naraščajočo globino jezer metabolna aktivnost bentoških organizmov niža, kar pa vodi v občutno zniževanje deleža sedimenta v celotni mineralizaciji (vodni stolpec + sediment) (Christensen, 1983).

pathways. Terrigenous (alochthonous) organic matter originates mostly from the catchment area by land run-off, but additional contributions from more distant sources are delivered by precipitation and wind. On the other hand biota (animals, plants and bacteria) within the water column and the sediments contribute aquatic (autochthonous) organic matter. The different types of biota populating a lake and its watershed produce organic matter having a distinctive biochemical composition. Changes in the community structure of these biota create variations in the amounts and types of organic matter deposited at different times in the history of a lake (Lerman *et al.*, 1995). To distinguish between the different origins of sedimentary organic matter C/N ratios have often been used. It is well known that algae have C/N ratios between 4 and 10, whereas vascular plants have C/N ratios of ≥ 20 (Meyers, 1994). In addition to C/N ratios, stable carbon isotopic ratios ($^{13}C/^{12}C$) expressed in relative ($\delta^{13}C$) notation as a deviation per mil (‰) from the V-PDB standard are used to identify different sources of sedimentary organic matter (Deines, 1980; Fry & Sherr, 1984). Furthermore the stable isotopes of nitrogen are widely used as natural tracers of sources of sedimentary organic matter (Letolle, 1980).

One of the most important processes affecting changes in the carbon isotopic composition in the geochemical cycle is the abstraction of carbon from the carbon dioxide reservoir of the atmosphere and surface waters by photosynthetic fixation in the form of complex organic molecules. The two most important pathways of carbon fixation are known as the Calvin-Benson ($C_3$) cycle where photosynthesis takes place via the enzyme ribulose-1.5-diphosphate carboxylase and the Hatch-Slack ($C_4$) cycle where photosynthesis takes place via the enzyme phosphoenolpyruvate carboxylase. In plants with crassulacean acid metabolism (CAM) both carboxylases are present. The $^{13}C$ content of plant is correlated with the type of photosynthesis followed by the organism. The $\delta^{13}C$ values of $C_3$ plants vary from –24 ‰ to –34 ‰, of $C_4$ plants from –6 ‰ to –19 ‰ while those of CAM plants cover the whole range of $C_3$ and $C_4$ plants (Deines, 1980). This different $\delta^{13}C$ values can help us to identify different sources of plant organic matter preserved in lake sediments (Fry & Sherr, 1984).

Benthic organisms play an important role in the mineralisation of organic matter in the sediment of aquatic environments. Determination of the rate of benthic metabolism provides basic information on nutrient cycling and the carbon flux in sedi-




Framboidalni pirit iz evtrofnega Jezera na Planini pri Jezeru, posnet z vrstičnim elektronskim mikroskopom (Foto: Zoran Samardžija)
*Scaning electron microscope micrograph of framboidal pyrite from the eutrophic Jezero na Planini pri Jezeru (Photo: Zoran Samardžija)*

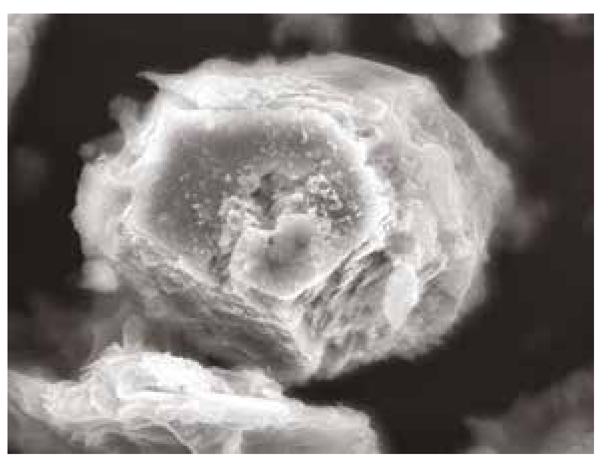
Bakterije predstavljajo glavne razgrajevalce organske snovi v vodnih sistemih. Ker so za dva do tri rede velikosti številčneje zastopane v sedimentu kot pa v enakem volumnu vode nad njim (Schallenberg in Kalff, 1993), prav v sedimentih poteka večji delež metabolnih procesov, ki se dogodijo v hipolimniju. Delež porabe kisika v sedimentu tako lahko znaša tudi 85 % celotne porabe kisika v hipolimniju (Cornett in Rigel, 1980). Poraba kisika se pogosto uporablja v raziskavah metabolnih procesov v jezerih (Cornett in Rigler, 1987), saj aerobno dihanje predstavlja najbolj učinkovito pot v procesu razgradnje organske snovi (Heyer in Kalff, 1998). V anoksičnem okolju pa poteka anaerobno dihanje, v katerem sodelujejo drugi sprejemniki elektronov, npr. kovinski hidroksidi, nitrati ali sulfati. Končni produkti redukcije, ki nastanejo v anaerobnih procesih, nato difundirajo po koncentracijskem gradientu in so lahko v aerobnih procesih donorji elektronov (Relexans, 1996 a).

Dejanska poraba kisika je določena s trenutno metabolno aktivnostjo organizmov. Ker predstavlja elektronski transportni sistem (ETS) v dihalni verigi most med oksidacijo organske snovi in molekularnim kisikom, lahko ocenimo intenziteto metabolizma tudi z merjenjem aktivnosti encimov v ETS.

ments. In most shallow–water systems, the majority of mineralisation takes place in the sediment through benthic metabolism rather than in the water column (Vosjan & Olanczuk – Neyman, 1977). However, as lake depth increases, the metabolic activity of the benthos as well as its contribution to the total mineralisation (water column + sediment) strongly decreases (Christensen, 1983).

Bacteria are the major decomposers of organic matter in aquatic systems and they are some two to three orders of magnitude more abundant in the sediment than in the equivalent volume of overlying water (Schallenberg & Kalff, 1993). The sediments dominate hypolimnetic metabolism. As much as 85 % of oxygen consumption in the hypolimnium of lakes occurs in the sediments (Cornett & Rigel, 1980). Research on metabolism in lakes has traditionally focused on oxygen consumption (Cornett & Rigler, 1987), as aerobic respiration is the most efficient pathway for organic matter degradation (Heyer & Kalff, 1998). In anoxic environments, anaerobic respiration takes place with other electron acceptors, e.g. metal hydroxides, nitrate or sulphate. The reduced end- products of these anaerobic processes then diffuse into the environment according to their concentration gradients and, in turn, may be used as electron donors (Relexans, 1996 a).

The actual oxygen consumption is determined by the momentary metabolic activity of organisms. As in most cases the respiratory electron transport



Kalcitno zrno iz površinskega sedimenta Jezera na Planini pri Jezeru, posneto z vrstičnim elektronskim mikroskopom (Foto: Zoran Samardžija)
*Scaning electron microscope micrograph of a calcite crystal from the surface sediment from Jezero na Planini pri Jezeru (Photo: Zoran Samardžija)*

Določevanje aktivnosti ETS poteka *in vitro* in temelji na redukciji tetrazolijeve soli (INT), ki ima vlogo nadomestnega sprejemika elektronov. Do reakcije pride v prisotnosti homogenata organizmov in substratov ETS, ki so reakcijski zmesi dodani v prebitku. Količino rdečega formazana, ki je nastal z redukcijo brezbarvnega INT, določimo spektrofotometrično pri valovni dolžini 490 nm (G.–Tóth in sod., 1994; za podrobnosti glej Simčič in Brancelj, v tisku). Do redukcije INT pride v prisotnosti tako aerobnih kot tudi anaerobnih organizmov, kar pomeni, da s to metodo dejansko določimo celotno dihalno aktivnost mikroorganizmov v sedimentu (Songster – Alpin in Klotz, 1995). Za razliko od hitrosti porabe kisika, ki predstavlja dejansko intenziteto metabolizma in mineralizacije, nam aktivnost ETS poda kapaciteto biološke oksidacije in potencial mineralizacije. Metodo ETS so številni raziskovalci uporabljali v raziskavah sladkovodnih in morskih sedimentov (G.–Tóth in sod., 1994; Relexans, 1996 a, b).

Pri raziskavah kompleksnih mehanizmov, ki uravnavajo mineralizacijo organske snovi v sedimentu, določamo tudi koncentracije oksidantov in končnih produktov v pornih vodah. Porazdelitev raztopljenih zvrsti nato opišemo s primernimi matematičnimi modeli, izpeljanimi iz splošne diagenetske enačbe in tako določimo snovne tokove raztopljenih zvrsti na meji med vodo in sedimentom ter hitrost razgradnje organske snovi (Berner, 1980; Van Cappellen in sod., 1993; Furrer in Wehrli, 1996). V večini primerov je rešitev splošne diagenetske enačbe zaradi pomankanja podatkov o večdimenzijski porazdelitvi raztopljenih zvrsti v površinskem sedimentu zelo poenostavljena in podana v enodimenzionalni obliki.

system (ETS) makes a bridge between the oxidation of organic material and molecular $O_2$, an overall estimate of metabolism can be obtained by measuring the activity of the ETS. The *in vitro* measurement of ETS activity is based on the rate of reduction of the alternative electron acceptor of tetrazolium salt (INT) in the presence of the cell–free homogenate of the organisms and substrates of the ETS in surplus amounts. The reduction of the colourless INT to red formazan can be followed using a spectrophotometer at 490 nm (G.–Tóth *et al.*, 1994; for details of the method see Simčič & Brancelj, in press). Since INT can be reduced by both aerobes and anaerobes, the total microbial respiratory activity in the sediment is in fact measured (Songster – Alpin & Klotz, 1995). Therefore, ETS activity is a measure of the biological oxidation capacity and potential rate of mineralisation. This method has been widely used in investigations of freshwater and marine sediments (G.–Tóth *et al.*, 1994; Relexans, 1996 a, b).

In studies of the complex mechanisms that regulate mineralisation of organic matter in the sediment, oxidants and end product concentrations in pore waters must also be determined. The distribution of dissolved species can be described by appropriate mathematical models derived from the general diagenetic equation and enables us to determine the fluxes of dissolved species at the sediment–water interface and the rate of organic matter degradation (Berner, 1980; Van Cappellen *et al.*, 1993; Furrer & Wehrli, 1996). In most cases the solution of the general diagenetic equation is simplified to one-dimension (i.e. depth) due to the lack of dissolved species distribution data in other dimensions.

## IZVORI ORGANSKE SNOVI

Koncentracije organskega ogljika ($C_{org}$) in celotnega dušika ($N_{tot}$) kot tudi izotopsko sestavo sedimentiranega organskega ogljika ($\delta^{13}C_{org}$) smo določili v sedimentnih profilih štirih slovenskih visokogorskih jezer (Jezero na Planini pri Jezeru, Krnsko jezero, Jezero v Ledvicah in Zgornje Kriško jezero).

Koncentracije $C_{org}$ in $N_{tot}$ so v zgornjih nekaj centimetrih sedimenta visoke in znašajo za organski ogljik 5–19 % $C_{org}$ DW (DW = suha masa sedimenta) ter celotni dušik 0,4–2,4 % $N_{tot}$ DW (slika 1). Koncentracije $C_{org}$ in $N_{tot}$ se z globino sedimenta eksponentno znižajo na 1–9 % $C_{org}$ DW in 0,1–0,8 % $N_{tot}$ DW. Določene koncentracije $C_{org}$ in $N_{tot}$ v

## ORIGINS OF ORGANIC MATTER

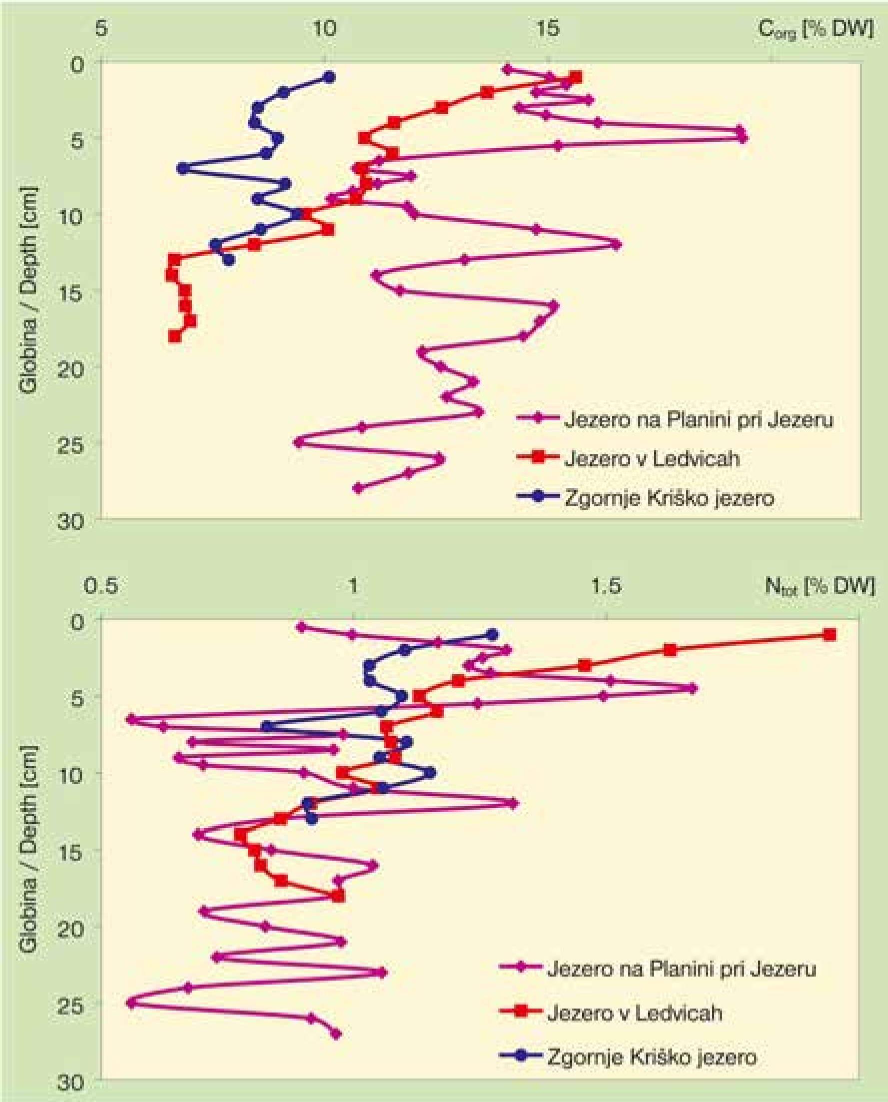
Concentrations of organic carbon ($C_{org}$), total nitrogen ($N_{tot}$) as well as the stable isotopic composition of sedimentary organic carbon ($\delta^{13}C_{org}$) were determined in the sediment profiles from four Slovenian high-mountain lakes (Jezero na Planini pri Jezeru, Krnsko jezero, Jezero v Ledvicah and Zgornje Kriško jezero).

Concentrations of $C_{org}$ and $N_{tot}$ in the upper few centimetres of the sediment are high, ranging from 5–19 % $C_{org}$ DW (DW = dry weight of the sediment) and 0.4–2.4 % $N_{tot}$ DW, respectively (Figure 1). Observed concentrations decrease exponentially with depth of the sediment to 1–9 % $C_{org}$ DW and sedimentu so mnogo višje kot v sedimentu predalpskega evtrofnega Blejskega jezera, kjer znašajo največ 6 % $C_{org}$ DW in 1,0 % $N_{tot}$ DW (Čermelj in sod., 1996; Muri in sod., 2002). Spreminjanje koncentracije $N_{tot}$ z globino sedimenta visokogorskih jezer je zelo podobno spreminjanju koncentracije $C_{org}$ (slika 1) in nakazuje, da je pretežni del $N_{tot}$ vezan na organsko snov.

Izotopska sestava sedimentirane organske snovi ($\delta^{13}C_{org}$) narašča z globino sedimenta v Jezeru na Planini pri Jezeru, Krnskem jezeru in Jezeru v Ledvicah, medtem ko se vrednosti $\delta^{13}C_{org}$ v Zgornjem Kriškem jezeru z globino znižajo. Razmerja $C_{org}/N_{tot}$ se z globino sedimenta zelo spreminjajo in kažejo na spreminjanje izvora sedimentirane organske snovi v posameznih jezerih. Odvisnost med vrednostmi $\delta^{13}C_{org}$ in razmerji $C_{org}/N_{tot}$, ki jasno pokaže

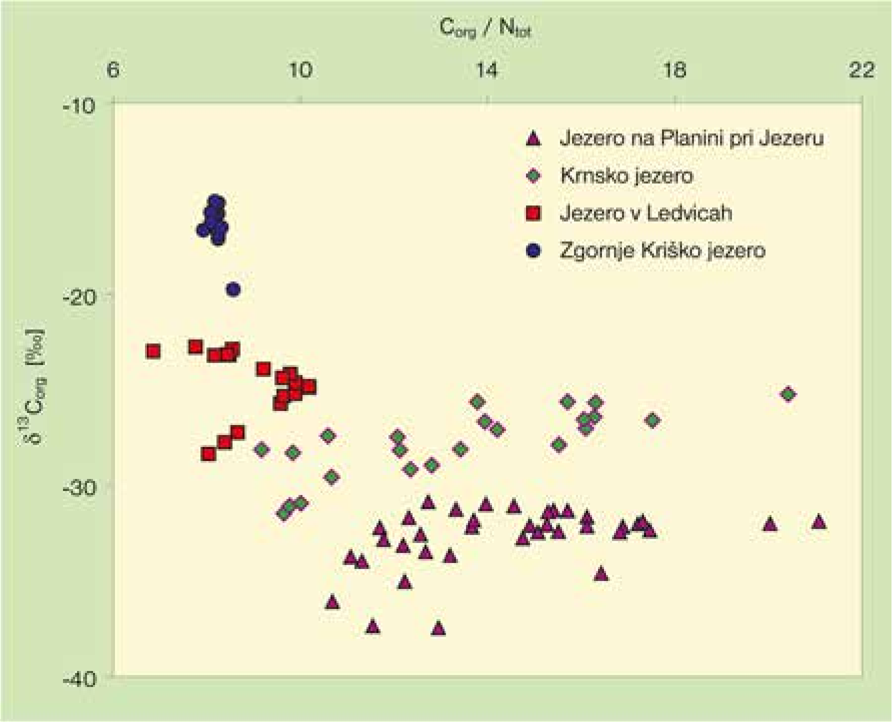
0.1–0.8 % $N_{tot}$ DW, respectively. For comparison, the maximum values in the sub-alpine eutrophic Lake Bled did not exceed 6 % $C_{org}$ DW and 1.0 % $N_{tot}$ DW (Čermelj *et al.*, 1996; Muri *et al.*, 2002). The $N_{tot}$ distribution closely follows the $C_{org}$ distribution, suggesting that most of the $N_{tot}$ in the sediments is associated with organic matter.

The isotopic composition of sedimentary organic matter ($\delta^{13}C_{org}$) increases with depth in the lakes Jezero na Planini pri Jezeru, Krnsko jezero and Jezero v Ledvicah, while in Zgornje Kriško jezero $\delta^{13}C_{org}$ values decrease with depth. The ratios $C_{org}/N_{tot}$ vary with the depth of the sediment considerably and thus indicate changes in sedimentary organic matter sources within the investigated lakes. The relationship between $\delta^{13}C_{org}$ values and $C_{org}/N_{tot}$ ratios is presented in Figure 2 and shows dis-




Slika 1: Globinski profili spreminjanja koncentracije organskega ogljika ($C_{org}$) in celotnega dušika ($N_{tot}$) v sedimentu Jezera na Planini pri Jezeru, Jezera v Ledvicah in Zgornjega Kriškega jezera (Triglavski narodni park, Slovenija)

*Figure 1: Depth profiles of organic carbon ($C_{org}$) and total nitrogen ($N_{tot}$) concentrations in sediments from lakes Jezero na Planini pri Jezeru, Jezero v Ledvicah and Zgornje Kriško jezero (Triglav National Park, Slovenia)*




Slika 2: Odvisnost med izotopsko sestavo sedimentirane organske snovi ($\delta^{13}C_{org}$) in razmerjem $C_{org}/N_{tot}$ v štirih visokogorskih jezerih (Triglavski narodni park, Slovenija)
*Figure 2: Relationship between isotopic composition of sedimentary organic matter ($\delta^{13}C_{org}$) and $C_{org}/N_{tot}$ ratios in four high-mountain lakes (Triglav National Park, Slovenia)*

različne izvore organske snovi v jezerih, je prikazana na sliki 2. Višje vrednosti $\delta^{13}C_{org}$ so povezane z nižjimi razmerji $C_{org}/N_{tot}$ in so značilne za oligotrofna jezera, medtem ko so nižje vrednosti $\delta^{13}C_{org}$ povezane z višjimi razmerji $C_{org}/N_{tot}$ in so značilne za evtrofna jezera. Ti rezultati kažejo razlike v trofičnih nivojih raziskanih štirih jezer.

Koncentracije $C_{org}$ in $N_{tot}$ so najvišje v visoko produktivnem, evtrofnem Jezeru na Planini pri Jezeru. Koncentracije $C_{org}$ in $N_{tot}$ najprej naraščajo od 14 % $C_{org}$ DW in 0,9 % $N_{tot}$ DW v površinskem sedimentu do 19 % $C_{org}$ DW in 1,7 % $N_{tot}$ DW na globini 5 cm, nato pa upadejo na 11 % $C_{org}$ DW in 0,5 % $N_{tot}$ DW na globini 27 cm (slika 1). Vrednosti $\delta^{13}C_{org}$ najprej upadajo od –31,3 ‰ v površinskem sedimentu do –37,5 ‰ na globini 5 cm, nato pa narastejo na –31,7 ‰ na globini 27 cm. Spremembe koncentracij $C_{org}$ in $N_{tot}$ ter izotopske sestave ogljika lahko pripišemo povišani primarni produkciji v jezeru zaradi vnosa hranil v zadnjih petdesetih letih. Izotopska sestava organskega ogljika kopenskih rastlin v okolici jezera znaša povprečno –26,5 ‰,

tinctly different sources of organic matter in the lakes. Higher $\delta^{13}C_{org}$ values are associated with lower $C_{org}/N_{tot}$ ratios that are characteristic of oligotrophic lakes, while lower $\delta^{13}C_{org}$ values are associated with higher $C_{org}/N_{tot}$ ratios that are characteristic of eutrophic lakes. The results obtained show trophic state changes in the four lakes investigated.

The highest concentrations of $C_{org}$ and $N_{tot}$ were observed in the highly productive, eutrophic lake Jezero na Planini pri Jezeru, with up to 14 % $C_{org}$ DW and 0.9 % $N_{tot}$ DW in the surface sediment. Concentrations of $C_{org}$ and $N_{tot}$ increased to 19 % $C_{org}$ DW and 1.7 % $N_{tot}$ DW at a depth of 5 cm and then decreased to 11 % $C_{org}$ DW and 0.5 % $N_{tot}$ DW at a depth of 27 cm (Figure 1). $\delta^{13}C_{org}$ values decrease from –31.3 ‰ in the surface sediment to –37.5 ‰ at a depth of 5 cm and then increase to –31.9 ‰ at a depth of 27 cm. These results can be explained by increased primary production in the lake due to the input of nutrients in the last fifty years causing an increase in organic carbon and total nitrogen concentrations in the sediment and a decrease in $\delta^{13}C_{org}$ values of sedimentary organic matter. The mean $\delta^{13}C_{org}$ values of terrestrial plants, plankton and particulate organic matter from the sediment traps were –26.5, –39.6 and –37.9 ‰ (Vreča, 2000). $\delta^{13}C_{org}$ values observed in the upper few centimetres of the sediment are very low and can be attributed to the presence of methanotrophic planktona –39,6‰ in organske snovi iz sedimentacijskih pasti –37,9‰ (Vreča, 2000) Zelo nizke vrednosti $\delta^{13}C_{org}$ v zgornjih centimetrih sedimenta (do –37,5 ‰) lahko pripišemo prisotnosti metanotrofnih združb. Takšne združbe porabljajo pri sintezi biomase izotopsko lahki metan, ki nastane med procesom mineralizacije sedimentirane organske snovi v anoksičnih okoljih (Hayes in sod., 1987). Razmerje $C_{org}/N_{tot}$ se spreminja od 10,7 do 21,1 (slika 2) in kaže, da je izvor sedimentirane organske snovi deloma terigen (alohton) deloma vodni (avtohton), vendar v recentnem sedimentu prevladuje avtohtona organska snov (Vreča, 2000). Podobne vrednosti $\delta^{13}C_{org}$ in razmerja $C_{org}/N_{tot}$ smo opazili tudi v evtrofnem Krnskem jezeru, kjer naraščajo vrednosti $\delta^{13}C_{org}$ od –31,5 ‰ v površinskem sedimentu do –25,3 ‰ na globini 23 cm. Razmerje $C_{org}/N_{tot}$ pa se spreminja od 9,2 do 20,4 (slika 2). Takšne vrednosti $\delta^{13}C_{org}$ in razmerja $C_{org}/N_{tot}$ kažejo, da predstavlja tudi v tem jezeru sedimentirana organska snov mešanico terigene in vodne organske snovi, vendar slednja prevladuje.

Čeprav uvrščamo Jezero v Ledvicah med oligotrofna jezera, so izmerjene koncentracije $C_{org}$ in $N_{tot}$ v površinskem sedimentu le malo nižje kot v Jezeru na Planini pri Jezeru in znašajo 16 % $C_{org}$ DW in 1,9 % $N_{tot}$ DW. Koncentracije z globino sedimenta naglo upadejo in znašajo na globini 18 cm 7 % $C_{org}$ DW in 1,0 % $N_{tot}$ DW (slika 1). Podobne koncentracije organskega ogljika v oddaljenih visokogorskih jezerih navaja tudi Fernandez s sodelavci (2000). Vrednosti $\delta^{13}C_{org}$ naraščajo od –28,4 ‰ v površin-skem sedimentu do –23,0 ‰ na globini 18 cm. Razmerje $C_{org}/N_{tot}$ pa se spreminja od 6,3 do 10,2 (slika 2). Takšne vrednosti kažejo, da predstavljajo v Jezeru v Ledvicah glavni izvor sedimentirane organske snovi vodni organizmi. Visoke koncentracije $C_{org}$ in $N_{tot}$ so v nasprotju z oligotrofnimi pogoji v jezeru. Deloma jih lahko pripišemo majhni globini jezera in s tem povezanim kratkim časom oksidacije odmrle organske snovi med tonjenjem na dno jezera, kjer proces oksidacije sedimentirane organske snovi znatno upočasnjuje tudi nizka temperatura (med 4 in 6 °C). Pomembno je tudi dejstvo, da je jezero pretežni del leta prekrito z ledom, ki znatno zmanjša izmenjavo med atmosfero in jezersko vodo. Posledica je znižanje koncentracije kisika v vodnem stolpcu ter zmanjšanje hitrosti oksidacije organske snovi.

Najnižjo vsebnost organske snovi smo določili v oligotrofnem Zgornjem Kriškem jezeru, kjer dosežejo v površinskem sedimentu koncentracije vrednosti 10 % $C_{org}$ DW in 1,3 % $N_{tot}$ DW. Koncentracije nato do globine 13 cm upadejo na 8 % $C_{org}$

bacterial communities that consume $^{13}C$ depleted methane produced during mineralisation of sedimentary organic matter in anoxic environments (Hayes *et al.*, 1987). $C_{org}/N_{tot}$ ratios range from 10.7 to 21.1 (Figure 2) and show that sedimentary organic matter is a mixture of terrestrial (alochtonous) and aquatic (autochtonous) sources, but in the recent sediment an aquatic origin prevails (Vreča, 2000). Similar $\delta^{13}C_{org}$ values and $C_{org}/N_{tot}$ ratios were observed in the sediment from the eutrophic lake Krnsko jezero where $\delta^{13}C_{org}$ values increase from –31.5 ‰ at the surface to –25.3 ‰ at a depth of 23 cm and $C_{org}/N_{tot}$ ratios from 9.2 to 20.4 (Figure 2). These $\delta^{13}C_{org}$ values and $C_{org}/N_{tot}$ ratios show that in this lake sedimentary organic matter is also a mixture of terrestrial and aquatic sources, but the aquatic origin prevails.

In contrast, Jezero v Ledvicah is an oligotrophic lake but the surface $C_{org}$ and $N_{tot}$ contents were only slightly lower than in Jezero na Planini pri Je-zeru, reaching 16 % $C_{org}$ DW and 1.9 % $N_{tot}$ DW in the surface sediment. Concentrations of $C_{org}$ and $N_{tot}$ decreased to 7 % $C_{org}$ DW and 1.0 % $N_{tot}$ DW at a depth of 18 cm (Figure 1). Similar $C_{org}$ contents were reported in the literature for remote high-mountain lakes (Fernandez *et al.*, 2000). $\delta^{13}C_{org}$ valu-es increase from –28.4 ‰ at the surface to –23.0 ‰ at the depth of 18 cm. The $C_{org}/N_{tot}$ ratios vary from 6.3 to 10.2 (Figure 2). These $\delta^{13}C_{org}$ values and $C_{org}/N_{tot}$ ratios show that the main source of sedimentary organic matter in Jezero v Ledvicah is of aquatic origin. The high $C_{org}$ and $N_{tot}$ concentrations are somehow in disagreement with the oligotrophic conditions in this lake. But it is important to keep in mind that high-mountain lakes usually have relativelly small water columns and subsequently short sinking times, when organic matter is exposed to oxidation. Also, bottom water temperature is generally low throughout the year (around 4–6 °C) and hence post-depositional oxidation processes are slow. Furthermore, such lake surfaces are covered by ice for a long period in the year. During the ice cover period, interaction between the atmosphere and the lake water is cut down. The oxygen content decreases down the water column and the capability for organic matter oxidation is further reduced.

The lowest organic matter content was observed in the oligotrophic lake Zgornje Kriško jezero where the surface concentrations amounted to 10 % $C_{org}$ DW and to 1.3 % $N_{tot}$ DW. These concentrations decrease to 8 % $C_{org}$ DW and 0.9 % $N_{tot}$ DW at a depth of 13 cm (Figure 1). $\delta^{13}C_{org}$ values de-

DW in 0,9 % $N_{tot}$ DW (slika 1). Vrednosti $\delta^{13}C_{org}$ upadajo od –16,7 ‰ v površinskem sedimentu do –19,8 ‰ na globini 13 cm. Razmerje $C_{org}/N_{tot}$ je zelo konstantno in se spreminja od 7,9 do 8,6 (slika 2). Takšne vrednosti $\delta^{13}C_{org}$ in razmerja $C_{org}/N_{tot}$ kažejo, da predstavljajo glavni izvor sedimentirane organske snovi vodni organizmi. Mnogo nižje koncentracije $C_{org}$ in $N_{tot}$ kot v ostalih visokogorskih jezerih so povezane z lego in trofičnim stanjem jezera. Zgornje Kriško jezero leži nad gozdno mejo in je najvišje ležeče slovensko visokogorsko jezero, zato je spiranje terigene organske snovi v jezero minimalno. Zaradi pomanjkanja hranil in dolgega obdobja prekritosti jezera z ledom (do 9 mesecev) pa je v jezeru primarna produkcija majhna.

crease from –16.7 ‰ at the surface to –19.8 ‰ at a depth of 13 cm. The $C_{org}/N_{tot}$ ratios are very consistant and vary from 7.9 to 8.6 (Figure 2). $\delta^{13}C_{org}$ values and $C_{org}/N_{tot}$ ratios obtained show that the source of sedimentary organic matter in this lake is also of aquatic origin. Lower $C_{org}$ and $N_{tot}$ concentration than in other high-mountain lakes are related to location and trophic status of the lake. The lake is the highest Slovenian high-mountain lake, situated above the tree line and therefore any surface input of organic material is more or less excluded. Besides, the lake surface is covered by ice for the longest period among all Slovenian high-mountain lakes (up to 8 months), meaning that primary production is minimal.

## INTENZITETA MINERALIZACIJSKIH PROCESOV V VISOKOGORSKIH JEZERIH

Poznavanje metabolnih procesov s fiziološkega vidika je bilo v sedimentih slovenskih jezer do nedavnega slabo. Prve tovrstne raziskave, ki so vključevale proučevanje metabolne aktivnosti mikrozoobentoške in mikrobne združbe, so bile narejene na sedimentih iz Blejskega in Bohinjskega jezera v letu 1995, v avgustu in septembru leta 2000 pa so raziskave potekale tudi na sedimentih iz 13 jezer, ki ležijo na področju vzhodnega dela Julijskih Alp (Simčič in Brancelj, v tisku). Z namenom, da določimo intenziteto potencialne oziroma dejanske mineralizacije, smo merili aktivnost ETS in hitrost porabe kisika na dveh globinah na vertikalnem profilu sedimentov iz posameznih jezer. Oba parametra smo merili v zgornji plasti sedimentov (0–1 cm debeline) ter v plasti, globlji od 15 cm. Rezultati teh meritev so prikazani na sliki 3. Na površini sedimenta je bila najvišja aktivnost določena v Rjavem jezeru, najnižji vrednosti pa sta bili dobljeni v mezotrofnem Dvojnem (Šestem) jezeru in oligotrofnem Srednjem Kriškem jezeru. Na splošno so bile višje aktivnosti ETS na površini sedimentov v bolj trofičnih jezerih. Statistično značilna korelacija med aktivnostjo ETS in celotnim fosforjem tudi kaže na povezanost med potencialno aktivnostjo bentoške združbe in trofičnim stanjem jezera. Presenetljiva pa je dokaj visoka aktivnost ETS v Rjavem jezeru, ki ga sicer prištevamo med oligotrofna jezera. Relexans (1996 a) je ugotovil, da razmerje ETS/POC odraža kvaliteto organske snovi v sedimentu. Visoka vrednost pomeni, da je velik delež od celotnega ogljika zaradi ustrezne kemijske zgradbe na voljo za vzdrževanje in/ali rast bentoške biomase. Po-

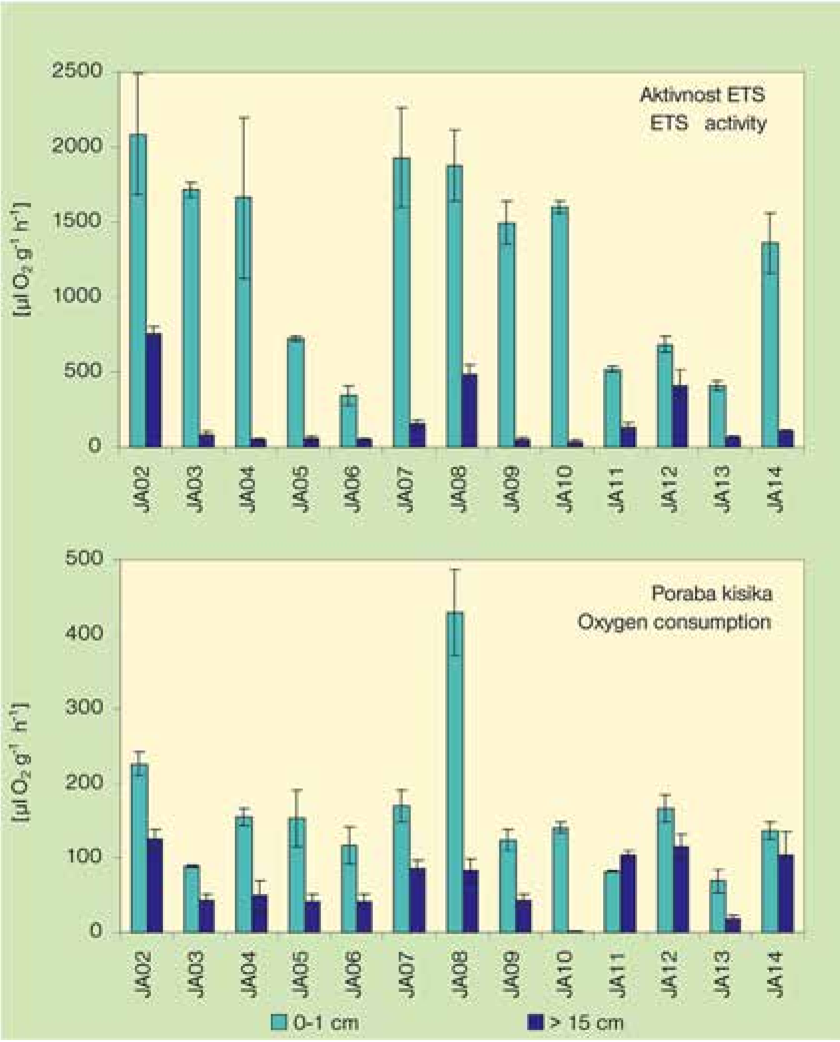
## INTENSITY OF MINERALISATION PROCESSES IN HIGH-MOUNTAIN LAKES

A knowledge of the physiological aspects of sedimentary metabolism in lakes in Slovenia was relatively lacking in the past. Therefore, the first investigations of the intensity of metabolic activity of microzoobenthos and microbial communities were made in the sediment in lakes Bled and Bohinj in 1995 and, later measurements in sediments in 13 lakes in the eastern part of the Julian Alps were performed in August and September 2000 (Simčič & Brancelj, in press). ETS activity and oxygen consumption rates were measured at two different depths in sediment profiles in order to evaluate the intensity of potential and actual mineralization. ETS activities and oxygen consumption rates in sediments were measured at the surface of the sediment (0–1 cm) and in layers deeper than 15 cm. Results are shown in Figure 3. The highest activity at the surface was in Rjavo jezero, and the lowest were in the mesotrophic lake Dvojno jezero (the south basin) and the oligotrophic lake Srednje Kriško jezero. In general, higher ETS activities in the surface sediment were observed in the lakes with higher trophic levels. A significant correlation between ETS activity and total phosphorus confirmed a transitory connection between the potential activity of the benthic community and the trophic state of a lake. An exception is high ETS activity in the oligotrophic lake Rjavo jezero, which cannot be explained by the trophic state. Relexans (1996 a) stated that ETS/POC ratios could reflect the quality of organic matter in sediment, with a high ratio associated with a greater proportion of total carbon available for maintenance and/or growth of bentemtakem je intenzivna in hitra mineralizacija v Rjavem jezeru posledica visokega deleža razpoložljive hitro razgradljive organske snovi. Kompaktnost sedimenta v tem jezeru še dodatno potrjuje hitro mineralizacijo snovi. Drugi vzrok za relativno visoko aktivnost ETS v visokogorskih oligotrofnih jezerih je nizka temperatura večji del leta, saj naj bi del aktivnosti ETS izhajal tudi iz biološko neaktivne frakcije ETS v mrtvih planktonskih in bentoških organizmih, ki se nabirajo na površini sedimenta. Mrtvi organizmi se zaradi izredno nizkih temperatur pozimi kopičijo, ne da bi prišlo do njihove razgradnje, nato pa v toplejšem delu leta potekajo intenzivni procesi razgradnje nakopičenega biološkega materiala, kar ima tudi za posledico visoko aktivnost ETS (G.–Tóth in sod., 1994).

Na intenziteto metabolnih procesov na površini sedimenta lahko vpliva tudi globina jezera. Naše raziskave so pokazale, da med aktivnostjo ETS in globino jezer obstaja statistično značilna pozitivna

Slika 3: Aktivnosti ETS in hitrosti porabe kisika na dveh globinah sedimenta: na površini (0–1 cm) in na globini >15 cm, merjeno pri standardni temperaturi 20 $^0$C. Standardni odkloni so prikazani z odklonskimi črticami. Oznake jezer: JA02 – Rjavo jezero, JA03 – Zeleno jezero, JA04 – Jezero v Ledvicah, JA05 – Dvojno (Peto) jezero, JA06 – Dvojno (Šesto) jezero, JA07 – Črno jezero, JA08 – Jezero na Planini pri Jezeru, JA09 – Dupeljsko jezero, JA10 – Krnsko jezero, JA11 – Jezero v Lužnici, JA12 – Zgornje Kriško jezero, JA13 – Srednje Kriško jezero, JA14 – Spodnje Kriško jezero. (Triglavski narodni park, Slovenija)

*Figure 3: ETS activities and oxygen consumption rates in sediments at two depths: surface (0–1 cm) and depth >15 cm; measured at standard temperature 20 $^0$C. Bars represent standard deviations. Lake labels: JA02 – Rjavo jezero, JA03 – Zeleno jezero, JA04 – Jezero v Ledvicah, JA05 – Dvojno jezero (the north basin), JA06 – Dvojno jezero (the south basin), JA07 – Črno jezero, JA08 – Jezero na Planini pri Jezeru, JA09 – Dupeljsko jezero, JA10 – Krnsko jezero, JA11 – Jezero v Lužnici, JA12 – Zgornje Kriško jezero, JA13 – Srednje Kriško jezero, JA14 – Spodnje Kriško jezero. (Triglav National Park, Slovenia)*



Zgodaj spomladi se po močnem vetru lahko tudi na nekaterih čistih jezerih pojavijo pene. To je naravni pojav, ki je posledica propadanja rastlinske biomase v mehki vodi (snežnici). Iz rastlinskega materiala se izločajo saponini, ki zaradi vetrov oz. valov na površini vode naredijo peno. Fotografija je bila posneta na Jezeru v Ledvicah junija 1996. (Foto: Anton Brancelj)
*Early in spring we can observe foam after strong winds, even in some clear lakes. This is a natural phenomena and is the result of decay of dead plant material in soft water (snow-water). Chemicals, called saponins are released from plants, and form a foam on the water surface in a presence of strong wind. The picture was taken on Jezero v Ledvicah in June 1996. (Photo: Anton Brancelj)*

korelacija. Vsa jezera, razen Krnskega in Jezera na Planini pri Jezeru, so prosojna do dna in biomasa fito- ter zooplanktona je bila višja v globokih kot pa plitvejših jezerih. Vosjan in Olanczuk – Neyman (1977) sta ugotovila, da v večini plitvih vodnih sistemov največji del mineralizacije poteka v sedimentu, Christensen (1983) pa je izmeril za približno dva reda velikosti višjo aktivnost ETS v sedimentu iz plitvega dela morja kot pa v globokomorskem sedimentu. Ker so vsa jezera, vključena v našo raziskavo plitva (< 10 m), v njih z naraščajočo globino ne pride do zmanjševanja aktivnosti ETS v sedimentu, ko naj bi se v globljih jezerih večji del organske snovi mineraliziral že v vodnem stolpcu.

Rezultati so tudi pokazali, da so bile aktivnosti ETS višje na površini kot pa v globljih plasteh sedimentov. Na globini, večji kot 15 cm, so bile najvišje vrednosti izmerjene v Rjavem jezeru, ki mu sledita Zgornje Kriško jezero in Jezero na Planini pri Jezeru. Nizke aktivnosti pa so bile ugotovljene v Krnskem jezeru, Jezeru v Ledvicah in Dupeljskem jezeru. Znižanje aktivnosti ETS v globini je povezano s kompaktnostjo in utrjenostjo sedimenta ter delno tudi s prenehanjem aerobnega metabolizma

thic biomass. Based on this assumption, the proportion of available (labile) organic matter in Rjavo jezero is high, and mineralisation is intensive and rapid. Consolidation of the sediment in this lake confirms these findings. The second reason for a relatively high ETS activity in high-mountain oligotrophic lakes is the low temperature during most of the year. Part of the ETS activity in sediment derives from inactive ETS fractions from dead organisms in the plankton and benthic deposit. Dead organisms can be accumulated in the cold sediment in winter without being mineralised. This accumulated biological matter indicated that the high ETS-activity peaks of the sediment during the warming period in spring are due to this latent activity (G.–Tóth *et al.*, 1994).

Lake depth is another factor that can influence sedimentary metabolism in the surface of sediment. We found a significant correlation between ETS activity and lake depth. All the lakes studied, except Krnsko jezero and Jezero na Planini pri Jezeru, are transparent to the bottom and the biomass of phyto- and zooplankton was greater in deep lakes than in shallow ones. Vosjan & Olanczuk – Neyman (1977) found that in shallow–water systems most of mineralisation takes place in the sediment. Christensen (1983) observed that ETS activities in marine shallow–water sediment were about two orders of magnitude greater than those in deep–sea sediments. The lakes we investigated are shallow (< 10 m), so no decrease in ETS activity with depth was observed as a result of mineralisation in the water column.

These results show that ETS activities are higher in the surface than in the deeper layers of sediment in freshwater lakes. In layers deeper than 15 cm the highest value was found in Rjavo jezero, followed by Zgornje Kriško jezero and Jezero na Planini pri Jezeru. Low values were observed in Krnsko

(Songster – Alpin in Klotz, 1995). Na znižanje aktivnosti ETS v globini vpliva tudi zmanjševanje števila bakterij v globljih plasteh sedimenta (Hayes in Anthony, 1959). Eden od dejavnikov, ki vplivajo na višjo aktivnost v zgornji plasti sedimenta, so tudi bentoške alge. Na izmerjeno aktivnost ETS namreč ne vpliva le dihalni ETS, temveč tudi ETS, ki sodeluje v fotosintetskih procesih, saj je metoda ETS občutljiva za aktivnost obeh sistemov (del Giorgio, 1992).

Hitrost porabe kisika je bila najvišja v evtrofnem Jezeru na Planini pri Jezeru. To kaže na intenzivno mineralizacijo kot posledico metabolizma bentoških organizmov. Visoka korelacija med hitrostjo porabe kisika na površini sedimenta in celotnim fosforjem tudi kaže na vpliv primarne produkcije v vodnem stolpcu na metabolno dogajanje v sedimentu. Tako kot pri aktivnosti ETS sta bili najvišji hitrosti porabe kisika v plasti sedimenta, globlji od 15 cm, izmerjeni v Zgornjem Kriškem in Rjavem jezeru, v katerih je v prvem v preteklosti prišlo do mešanja sedimenta.

Negativna korelacija med obema merjenima parametroma, aktivnostjo ETS in hitrostjo porabe kisika ter deležem suhe snovi v sedimentu potrjuje vpliv kompaktnosti sedimenta na intenziteto metabolnih procesev v sedimentu. Odsotnost korelacije med obema parametroma in LOI pa pomeni, da je intenziteta metabolnih procesov pri bentoških organizmih odvisna od kvalitete organske snovi (Relaxans, 1996 b).

V štirih jezerih, ki se nahajajo v različnem trofičnem stanju, pa smo proučevali razlike v aktivnosti ETS in hitrosti porabe kisika po profilu sedimenta z intervalnim razmikom 1 cm. Kot evtrofni jezeri smo izbrali Jezero na Planini pri Jezeru in Krnsko jezero, kot oligotrofni jezeri pa Jezero v Ledvicah in Zgornje Kriško jezero. Ugotovili smo, da se tako aktivnost ETS kot tudi hitrost porabe kisika po profilu med jezeri razlikujeta. V zgornjih plasteh sedimenta je bila najvišja aktivnost ETS izmerjena v Jezeru na Planini pri Jezeru in Krnskemu jezeru na globini od 0 do 3 cm, medtem ko je bila v Jezeru v Ledvicah in Zgornjem Kriškem jezeru najbolj intenzivna aktivnost ETS na globini 4 in 5 cm. Zaradi višje produkcije v vodnem stolpcu hiperevtrofnih in evtrofnih jezer se velika količina hitrorazgradljivih organskih snovi kopiči na sami površini sedimenta, kar se nato odrazi tudi v visoki aktivnosti. V oligotrofnih jezerih pa je bila izmerjena najvišja aktivnost globlje v sedimentu, kar kaže na intenzivnejšo razgradnjo težje razgradljivih snovi, ki za razkroj in mineralizacijo potrebujejo daljši čas.

Intenziteta aktivnosti ETS v globini in globina

jezero, Jezero v Ledvicah and Dupeljsko jezero. Decrease in ETS activity with depth partly depends on the consolidation and stabilisation of the sediment and partly on the termination of aerobic metabolism (Songster – Alpin & Klotz, 1995). As bacterial numbers decline with depth in lake sediments (Hayes & Anthony, 1959), so ETS activity also declines. Secondly, benthic algae are the probable source of the observed high ETS activity in the surface sediment. It is also likely that a considerable part of this activity originates not only from substrate–induced ETS but also from the photosynthetic ETS of algae, because the ETS-assay is sensitive to the activity of both systems (del Giorgio, 1992).

Oxygen consumption rates in surface sediment were the highest in eutrophic lake Jezero na Planini pri Jezeru. This indicates intensive mineralisation through benthic metabolism. The high correlation between the oxygen consumption rate in the surface sediment and total phosphorus confirmed the effect of primary production in the water column on sedimentary metabolism. As for ETS activity, the highest oxygen consumption at depths below 15 cm was observed in Zgornje Kriško jezero with mixed sediment and Rjavo jezero.

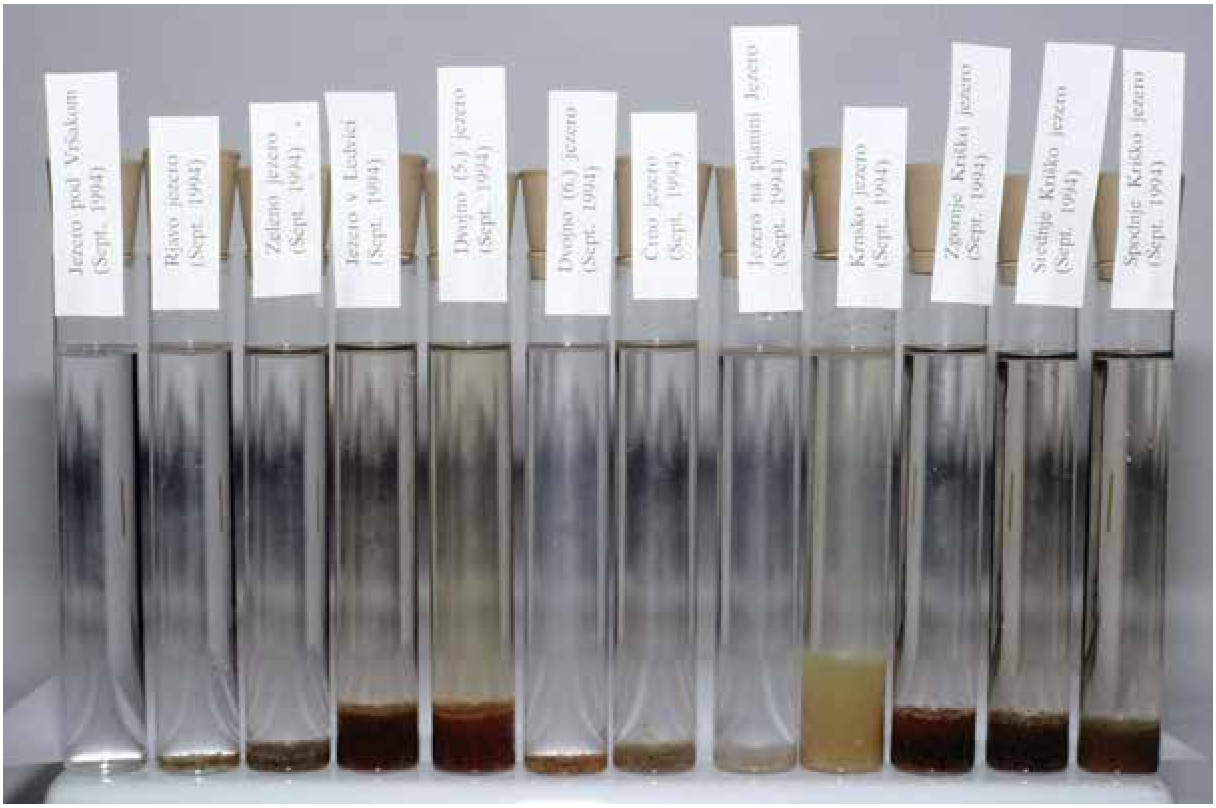
The negative correlation between both the ETS activity and oxygen consumption rate, and the proportion of dry weight in sediment confirmed the effect of compactness of the sediment on the sedimentary metabolism. The lack of correlation between the two parameters and LOI could indicate that the intensity of mineralisation through benthic metabolism depends on the quality of organic matter (Relaxans, 1996 b).

Additionally we investigated differences in ETS activity and oxygen consumption rate in sediment profiles at 1 cm intervals in four lakes of different trophic status. Jezero na Planini pri Jezeru and Krnsko jezero were selected as eutrophic lakes, while Jezero v Ledvicah and Zgornje Kriško jezero were selected as oligotrophic sites. ETS activity and oxygen consumption rate in vertical sediment profiles differed between the lakes. The highest ETS activity at the surface sediment was observed in Jezero na Planini pri Jezeru and Krnsko jezero at depths from 0 to 3 cm, while in Jezero v Ledvicah and Zgornje Kriško jezero ETS activity was the most intense at 4 and 5 cm. Because of higher production in the water column in hypereutrophic and eutrophic lakes, a large amount of labile organic matter accumulates at the surface of the sediment, and that is reflected in more intense activity in the upper layers of the sediment profile. In contrast, in sedimenta, do katere aktivnost lahko izmerimo, sta odvisni od trofičnega stanja jezera. G.–Tóth (1992) je ugotovil, da je v Blatnem jezeru (Balaton, Madžarska) v hipertrofnem delu Keszthely in mezotrofnem delu Siófok prišlo do različnega zmanjševanja aktivnosti ETS v globino sedimenta, in sicer v prvem delu jezera za 10 % na cm, v drugem pa 25 % na cm. Relaxans (1996 a) pa je ugotovil, da v morskih sedimentih z oligotrofnega področja ni bilo mogoče izmeriti aktivnosti ETS globlje od 10 do 15 cm, v sedimentih z obalnega področja pa je bila aktivnost prisotna tudi globlje, v anoksičnih plasteh (globlje od 30 cm). V naših visokogorskih jezerih je bila največja aktivnost ETS na globini večji od 15 cm, izmerjena v oligotrofnem Zgornjem Kriškem jezeru,

oligotrophic lakes the highest activity was obtained deeper in the sediment. This indicates that organic matter less available as a food for organisms needs a longer time to decay and mineralise (Relaxans 1996 b).

The intensity of ETS activity and the depth of the sediment at which it is observed depend on the trophic status of the lake. G.–Tóth (1992) reported that in the hypereutrophic Keszthely–basin and the meso-eutrophic Siófok–basin of Lake Balaton in Hungary, the decreases in the sediment ETS activity per cm of increasing depth were 10 % and 25 % of the surface values, respectively. Relaxans (1996 a) found that in marine sediments from oligotrophic areas, ETS becomes undetectable deeper than 10 to 15 cm, but that in coastal zones ETS activity is still present in deep, anoxic layers (more than 30 cm). The results of the present study are not in accord with those of G.–Tóth (1992) and Relaxans (1996 a). The highest ETS activity at depths greater than 15 cm was found in the oligotrophic lake Zgornje Kriško jezero. To a certain extent this was expected because in this lake the sediment was mixed as a result of landslides caused by the earthquake in 1979 (Brancelj *et al.*, 2000 a).

The ETS activity is a measure of the respiratory capacity of organisms since it shows the $V_{max}$ of



Odmrli zooplankton je v nekaterih jezerih pomemben vir organske snovi, ki potone na dno. Slika prikazuje količino zooplanktona v posameznih jezerih v Julijskih Alpah v vodnem stolpcu z osnovo 0,1 m$^2$. Vzorci so bili pobrani s planktonsko mrežo sredi jezera v septembru leta 1994. (Foto: Anton Brancelj)

*In some lakes dead zooplankton is an important source of organic material deposited on the bottom. In the picture is a collection of zooplankton, collected in the lakes of the Julian Alps in a water column with a base of 0.1 m$^2$. Samples were collected with a tow net in the middle of the lakes in September 1994. (Photo: Anton Brancelj)* kar ni v skladu z ugotovitvama predhodnih raziskav. To je bilo tudi pričakovati, saj je bil v tem jezeru sediment premešan zaradi plazov, ki jih je povzročil potres v letu 1979 (Brancelj in sod., 2000 a).

Aktivnost ETS predstavlja dihalno kapaciteto organizmov, saj merimo $V_{max}$ v multiencimskem kompleksu ETS. Za izračun dejanske porabe kisika na osnovi izmerjene aktivnosti ETS pa moramo empirično določiti razmerje med njima. Pretvorbeni faktor lahko določimo sami ali pa uporabimo vrednosti iz literature. Veliko tovrstnih raziskav je bilo narejenih na jezerskem planktonu (glej del Giorgio, 1992), malo podatkov pa najdemo v literaturi v zvezi z razmerjem R/ETS v jezerskih sedimentih.

Raziskava v slovenskih alpskih jezerih je pokazala, da se je razmerje R/ETS razlikovalo tako med jezeri kot tudi med obema globinama. Najnižje razmerje R/ETS je bilo v Zelenem jezeru, najvišje pa v Dvojnem (Šestem) jezeru. Razmerja R/ETS so bila v večini jezer višja v globini sedimenta, razen v Jezeru na Planini pri Jezeru in Krnskem jezeru. Tako je bila na površini sedimenta povprečna vrednost razmerja nižja (0,15 ± 0,08; N = 13) kot pa pri globini, večji od 15 cm (0,58 ± 0,35; N = 13). Eden od razlogov za nižje razmerje R/ETS na površini je v obstojnosti aktivnosti ETS v mrtvih organizmih še tedne po smrti, ki pride v mrzlih visokogorskih jezerih močno do izraza (G.–Tóth, 1992). Inkubacija homogenata bakterij iz sedimenta je namreč pokazala, da je pri nizki temperaturi ETS ostal aktiven še dneve po smrti organizmov (G.–Tóth in sod., 1994). Na ta način detrit prispeva k višji aktivnosti ETS, ne pa k hitrosti porabe kisika. Drugi razlog so bentoške alge, ki na površini sedimenta s svojim fotosintetskim ETS dodatno zvišujejo izmerjeni ETS (del Giorgio, 1992). K aktivnosti ETS na površini sedimenta prispevajo predvsem prisotne alge in praživali, ki imajo nizko razmerje R/ETS, v globjih plasteh sedimenta pa večji del aktivnosti izhaja iz bakterij, ki imajo višje razmerje. Na izračun aktivnosti ETS in hitrosti porabe kisika do neke mere vpliva tudi količina hitinskih ostankov živali, ki se razlikuje tako med jezeri kot tudi po globini (Brancelj in sod., 2000 a).

Razlike v razmerju R/ETS v zgornjih plasteh sedimenta obstajajo tudi med jezeri, ki se nahajajo v različnem trofičnem stanju. Tako je bilo povprečno razmerje R/ETS na površini sedimenta (0–3 cm) nižje v evtrofnih (0,16 ± 0,07; N = 12) kot pa v oligotrofnih jezerih (0,27 ± 0,16; N = 12).

Zaključimo lahko, da sta tako aktivnost ETS kot tudi poraba kisika dobra pokazatelja intenzitete metabolnih procesov in mineralizacije v alpskih jezer-

the ETS multienzyme complex. It is necessary, therefore, to determine empirically the relation between this potential respiration and oxygen consumption in order to obtain the latter from the former. Researchers using ETS to estimate organism respiration have either determined an empirical conversion factor themselves, or have used one of several published R/ETS ratios. R/ETS ratios for lake plankton have been reported in many studies (see del Giorgio, 1992), but there are not many published data on the R/ETS ratio in lake sediments.

The R/ETS ratio differs significantly between lakes and between depths. The lowest R/ETS ratio in surface sediment was found in Zeleno jezero and the highest in Dvojno jezero (the south basin). R/ETS ratios were higher in the deeper layer of sediment in most lakes, except in Jezero na Planini pri Jezeru and Krnsko jezero. For surface sediment the average value was lower (0.15 ± 0.08; N = 13) than for the deeper layers below 15 cm (0.58 ± 0.35; N = 13). The reason for lower average R/ETS ratios in surface than in deeper layers of sediment is the persistence of ETS activity in dead organisms at the sediment surface for weeks after their death, especially in the cold water of high-mountain lakes (G.–Tóth, 1992). Incubation of cell-free homogenates of sediment bacteria showed that ETS remains active days after the death of organisms at low temperature (G.–Tóth *et al.*, 1994). Detrital material contributes to ETS activity measurements but not to oxygen consumption rates. Benthic algae on the sediment surface, with their photosynthetic ETS, additionally increase measured ETS activity (del Giorgio, 1992). Thus, ETS activity at the sediment surface originates from algae and protozoa, which have low R/ETS ratios, but in deeper layers of sediment the majority of the activity originates from bacteria, which have higher R/ETS ratios. Calculations of ETS activity and oxygen consumption rates are also affected by the number of chitinous particles, which varies from lake to lake and with depth (Brancelj *et al.*, 2000a).

As was expected the differences in the R/ETS ratio in surface sediment were observed between lakes of different trophic status. The average R/ETS ratio was lower at the surface of sediment (0–3 cm) in eutrophic lakes (0.16 ± 0.07; N = 12) than in oligotrophic ones (0.27 ± 0.16; N = 12).

It is concluded that ETS activity and oxygen consumption are good indicators of the intensity of metabolic activity and mineralisation in alpine lake sediments. It was shown that the major factors affecting mineralisation processes in the sediments skih sedimentih. Rezultati so tudi pokazali, da na mineralizacijske procese v sedimentih teh jezer v veliki meri vplivata trofično stanje in globina jezer.

## MINERALIZACIJA ORGANSKE SNOVI V JEZERU NA PLANINI PRI JEZERU

Podrobnejše raziskave biogeokemijskih procesov, povezanih z mineralizacijo organske snovi v visoko evtrofnem Jezeru na Planini pri Jezeru, so bile opravljene s pomočjo kombinacije meritev izotopske sestave ogljika in kemijskih analiz vodnega stolpca, sedimenta in pornih vod (Vreča, 2000). Nagla evtrofikacija v tem visokogorskem jezeru je bila v veliki meri pospešena v zadnjih petdeset letih in je povezana z vnosom rib leta 1951, planšarsko tradicijo in intenzivnim vnosom hranil med leti 1985 in 1992, ko planinska koča nad jezerom ni imela urejene kanalizacije (Povž, 1997; Brancelj in sod., 2000 b). Zaradi visokih koncentracij hranil v Jezeru na Planini pri Jezeru je v poletnih mesecih primarna produkcija v epilimniju zelo intenzivna. Poleg tega se precejšnja količina organske snovi spere v jezero s površinsko erozijo tudi s planinskega pašnika. V globljih delih vodnega stolpca je koncentracija kisika pretežni del leta zelo nizka, do prezračenja pa pride le v kratkem obdobju pomladne in jesenske homotermije. Ker anoksični pogoji, ki vladajo na dnu jezera, upočasnjujejo razgradnjo sedimentirane organske snovi, se le-ta v jezeru kopiči hitreje kot v ostalih slovenskih visokogorskih jezerih.

Stratifikacija vodnega stolpca je izrazita poleti in pozimi, vmes pa nastopi kratko obdobje premešanja. S stratifikacijo vodnega stolpca so povezane sezonske spremembe koncentracije raztopljenega anorganskega ogljika (DIC) in njegove izotopske sestave ($\delta^{13}C_{DIC}$), ki kažejo na vpliv fotosinteze, respiracije in razgradnje organske snovi med padanjem skozi vodni stolpec na anoksično dno jezera. Izotopska sestava raztopljenega anorganskega ogljika, $\delta^{13}C_{DIC}$, se s časom zelo spreminja in upada od –8,9 ± 1,8 ‰ na površini jezera do –12,2 ± 1,2 ‰ na dnu jezera. V času jesenskega premešanja se vrednosti $\delta^{13}C_{DIC}$ ne spreminjajo znatno. V nasprotju z jesensko izotermijo pa smo poleti opazili v epilimniju obogatitev DIC s $^{13}C$, v hipolimniju pa osimromašitev (Vreča, 2000). Višje vrednosti $\delta^{13}C_{DIC}$ v epilimniju lahko pripišemo primarni produkciji, med katero alge prednostno odstranjujejo lažji ogljikov izotop ($^{12}C$) iz raztopljenega anorganskega ogljika (Quay in sod., 1986). V nasprotju s fotosintezo

in high-mountain lakes are the trophic state of the lake and its depth.

## MINERALISATION OF ORGANIC MATTER IN THE LAKE JEZERO NA PLANINI PRI JEZERU

Biogeochemical processes related to mineralisation of organic matter were studied in more detail in the highly eutrophic lake Jezero na Planini pri Jezeru using measurements of the stable isotopic composition of carbon as well as chemical analyses of the water column, sediment and pore waters (Vreča, 2000). Eutrophication of the lake has increased greately in the past 50 years and is associated with the introduction of fish in 1951, alpine dairying and an intensive input of nutrients from the inappropriate sewage system of the alpine hut above the lake during 1985–1992 (Povž, 1997; Brancelj *et al.*, 2000 b). Due to high nutrient concentrations in Jezero na Planini pri Jezeru primary production is very intense in the epilimnium in the summer months. In addition, a substantial amount of organic–rich material enters the lake from high-mountain pasture via surface run-off. Consequently, there is a strong depletion of oxygen in the deeper layers of the water column almost throughout the year, except for a short period during the spring and autumn over-turn. Anoxic conditions at the bottom of the lake reduce the mineralisation rate of sedimented organic matter and therefore organic matter is better preserved in the sediment than in other Slovenian high-mountain lakes.

Stratification of the water column is distinct in summer and winter, while in the intermediate periods mixing occurs. Seasonal changes in concentrations of dissolved inorganic carbon (DIC) and its stable isotopic composition ($\delta^{13}C_{DIC}$) are related to stratification of the water column and indicate the influence of photosynthesis, respiration and decomposition of organic matter during sinking to the anoxic lake bottom. The isotopic composition of dissolved inorganic carbon, $\delta^{13}C_{DIC}$, is highly variable and decreases on average from –8,9 ± 1,8 ‰ at the lake surface to –12,2 ± 1.2 ‰ at the bottom of the lake. During the autumn overturn the $\delta^{13}C_{DIC}$ values are very constant. In contrast an apparent enrichment of $^{13}C$ in the epilimnium and depletion in the hypolimnium was observed in summer (Vreča, 2000). The higher $\delta^{13}C_{DIC}$ values in the epilimnium are attributed to *insitu* photosynthesis during which algae preferentially remove light car-pa respiracija in razgradnja organske snovi med tonjenjem na anoksično dno jezera povzročita znižanje razmerja $^{13}C/^{12}C$ v nastalem $CO_2$ (Quay in sod., 1986).

Na dnu jezera se kopiči organsko bogati karbonatni mulj, ki vsebuje več kot 10 % organskega ogljika (slika 1). Ugotovili smo, da je izvor sedimentirane organske snovi v površinskem sedimentu pretežno avtohton (Vreča, 2000). Povečanje primarne produkcije, povezano z vnosom hranil v zadnjih petdesetih letih, je povzročilo zvišanje koncentracije organskega ogljika in znižanje izotopske sestave sedimentirane organske snovi. Z ureditvijo kanalizacije planinske koče in zmanjšanjem izpusta odpadnih vod v jezero so se leta 1992 razmere v jezeru nekoliko izboljšale.

Med razgradnjo organske snovi nastaja v porni vodi sedimenta raztopljeni anorganski ogljik (DIC), ki predstavlja v jezerih pomembno hranilo. V karbonatnih sedimentih vpliva poleg oksidacije organske snovi na nastanek in koncentracijo DIC tudi raztapljanje in izločanje karbonatnih mineralov (McNichol in sod., 1991). Poleg koncentracije raztopljenih zvrsti je pomemben indikator omenjenih dveh procesov izotopska sestava DIC v porni vodi sedimenta, ki ima podobno izotopsko sestavo ogljika kot izvorni material (sedimentirana organska snov ali karbonatni minerali). V anoksičnih sedimentih ima pomemben vpliv tudi metanogeneza, med katero nastaja izotopsko ($^{13}C$) osiromašeni metan ($CH_4$), izotopska sestava DIC v porni vodi pa pri tem zaradi obogatitve s $^{13}C$ z globino sedimenta narašča (LaZerte, 1981).

Koncentracije raztopljenih spojin v porni vodi sedimenta Jezera na Planini pri Jezeru se spreminjajo z globino in časom (Vreča, 2000). Koncentracije DIC kot tudi njegove izotopske sestave ($\delta^{13}C_{DIC}$) pričnejo naraščati že v porni vodi površinske plasti sedimenta. Koncentracija DIC narašča z globino od 3,7 ± 0,4 na meji med vodo in sedimentom do 6,3 ± 0,8 mmol $l^{-1}$ na globini > 30 cm. Sočasno naraščajo tudi vrednosti $\delta^{13}C_{DIC}$, in sicer od –9,2 ± 1,4 na meji med vodo in sedimentom do +4,7 ± 1,0 ‰ na globini > 30 cm. Velik pozitiven gradient $\delta^{13}C_{DIC}$ (11–16 ‰ na 30 cm sedimenta) lahko pripišemo razgradnji organske snovi in metanogenezi. Spreminjanje koncentracije DIC z globino smo ob upoštevanju stacionarnega stanja opisali s pomočjo enodimenzionalnega difuzijsko-reakcijskega modela, izpeljanega iz splošne diagenetske enačbe (Berner, 1980):

$$\frac{\partial C}{\partial t} = 0 = D_s \frac{\partial^2 C}{\partial z^2} + R_c(z)$$

bon ($^{12}C$) from the DIC pool (Quay *et al.*, 1986). In contrast to photosynthesis, respiration and decomposition of organic matter during sinking to the anoxic lake bottom result in lowering of the $^{13}C/^{12}C$ ratios in the $CO_2$ generated (Quay *et al.*, 1986).

At the bottom of the lake, organic–rich carbonate silt with more than 10 % organic carbon is accumulated (Figure 1). The source of sedimentary organic matter in the surface sediment is predominantly autochthonous (Vreča, 2000). The increased primary production in the lake due to the input of nutrients in the last 50 years has caused an increase in organic carbon concentration in the sediment and a decrease in the isotopic composition of the sedimentary organic matter. The situation was improved when discharge of untreated sewage effluent and wastewater from the alpine hut stopped in 1992.

Dissolved inorganic carbon (DIC), representing an important aquatic nutrient, is produced in sediment pore waters during decomposition of organic matter. In carbonate sediments, in addition to oxidation of organic matter, dissolution or precipitation of carbonate minerals also affects DIC concentrations (McNichol *et al.*, 1991). Besides concentrations of individual compounds, a sensitive indicator of these two processes is the isotopic composition of DIC released to the pore water of the sediment that has a carbon isotopic composition similar to the source (sedimentary organic matter or carbonate minerals). Furthermore, in anoxic sediments significant enrichment of $^{13}C$ in pore water DIC with depth was observed. This increase is related to the production of highly $^{13}C$-depleted $CH_4$ during methanogenesis in anoxic sediments (LaZerte, 1981).

Concentrations of dissolved species in the sediment pore waters of Jezero na Planini pri Jezeru change with depth and time (Vreča, 2000). Concentrations of DIC as well as their isotopic composition ($\delta^{13}C_{DIC}$) in pore water profiles start to increase immediately below the sediment–water interface from 3.7 ± 0.4 to 6.3 ± 0.8 mmol $l^{-1}$ at a depth of >30 cm, and from –9,2 ± 1.4 to +4.7 ± 1.0 ‰, respectively. A positive $\delta^{13}C_{DIC}$ gradient (11–16 ‰ in 30 cm of sediment), indicating the influence of decomposition of organic matter and methanogenesis was observed. Changes in concentrations of DIC with depth were described by applying a one-dimensional diffusion-reaction model derived from the general diagenetic equation given by Berner (1980) and assuming steady state conditions:

$$\frac{\partial C}{\partial t} = 0 = D_s \frac{\partial^2 C}{\partial z^2} + R_c(z)$$

kjer je C koncentracija raztopljene zvrsti [mmol $dm^{-3}$], t čas [s], $D_s$ koeficient difuzije [$cm^2 s^{-1}$], ustrezno korigiran zaradi poroznosti sedimenta in temperature pri vzorčenju ter z globina [cm]. $R_c$ je hitrost produkcije DIC v porni vodi sedimenta [mmol $dm^{-3} s^{-1}$] in jo opišemo z enačbo:

$$R_c(z) = R_0 \cdot e^{-\beta z}$$

kjer je $R_0$ hitrost produkcije DIC na meji med vodo in sedimentom [mmol $dm^{-3} s^{-1}$] in parameter $\beta$ koeficient oslabitve [$cm^{-1}$]. Vrednosti parametrov $R_0$ in $\beta$ smo določili s prileganjem modela eksperimentalnim podatkom (Vreča, 2000). Hitrosti produkcije DIC na meji med vodo in sedimentom ($R_{DIC,0}$) so zbrane v preglednici 1.

Hitrost produkcije DIC ($R_c$) je odvisna od koncentracije kisika na dnu jezera in je najhitrejša v času jesenskega premešanja vodnega stolpca. Najvišje vrednosti $R_c$ smo določili novembra 1999, ko je bil vodni stolpec dobro premešan, koncentracija $O_2$ na dnu jezera pa je znašala 7,9 mg $l^{-1}$. Junija 1998 in maja 1999 so bile vrednosti $R_c$ nekoliko nižje, nižja pa je bila tudi koncentracija $O_2$, ki je znašala 1,9 in 0,6 mg $l^{-1}$. V času anoksičnih razmer na dnu jezera (oktober 1998, junij in avgust 1999) je bila hitrost produkcije DIC znatno upočasnjena. Ti rezultati kažejo, da produkcijo DIC v Jezeru na Planini pri Jezeru v veliki meri določa oskrba s kisikom.

Vendar pa je v parametru $R_c$ poleg oksidacije organske snovi ($R_{org}$) zajet tudi vpliv raztapljanja oziroma izločanja kalcita ($R_{Ca}$), kar lahko zapišemo z enačbo:

$$R_c = R_{org} + R_{Ca}$$

| Datum vzorčenja<br>Sampling date | $R_{DIC,0}$<br>[mmol $dm^{-3} s^{-1}$] |
|---|---|
| Junij, 1998<br>June, 1998 | $2.4 \cdot 10^{-6}$ |
| Oktober, 1998<br>October, 1998 | $9.9 \cdot 10^{-8}$ |
| Maj, 1999<br>May, 1999 | $2.0 \cdot 10^{-6}$ |
| Junij, 1999<br>June, 1999 | $2.6 \cdot 10^{-7}$ |
| Avgust, 1999<br>August, 1999 | $1.9 \cdot 10^{-7}$ |
| November, 1999<br>November, 1999 | $4.2 \cdot 10^{-6}$ |

where C is the concentration of dissolved species [mmol $dm^{-3}$], t is time [s], $D_s$ is the diffusion coefficient [$cm^2 s^{-1}$] corrected for sediment porosity and in-situ temperature and z is depth [cm]. $R_c$ is the rate of production of DIC in the sediment pore water [mmol $dm^{-3} s^{-1}$] defined by the equation:

$$R_c(z) = R_0 \cdot e^{-\beta z}$$

where $R_0$ is the rate of production of DIC at the sediment–water interface [mmol $dm^{-3} s^{-1}$] and $\beta$ is the so-called attenuation coefficient [$cm^{-1}$]. Values of the parameters $R_0$ and $\beta$ were obtained by fitting the pore water data to the model (Vreča, 2000). Rates of DIC production at the sediment–water interface ($R_{DIC,0}$) are summarised in Table 1.

It was found that $R_c$ depends on the concentration of oxygen at the bottom of the lake and is most rapid during autumn mixing of the water column. The highest $R_c$ was observed during the autumn overturn in November 1999 when the bottom concentration of $O_2$ reached 7.9 mg $l^{-1}$. $R_c$ was somewhat lower in June 1998 and May 1999 when the concentration of $O_2$ was 1.9 and 0.6 mg $l^{-1}$, respectively. During completely anoxic conditions at the bottom of the lake (October 1998, June and August 1999) the $R_c$ was one to two orders of magnitude lower. The results obtained indicate that in Jezero na Planini pri Jezeru production of DIC is greatly limited by the supply of $O_2$.

The rate of DIC production, $R_c$, is a combination of two processes – the net production of DIC from the oxidation of organic matter ($R_{org}$) and from the dissolution or precipitation of calcite ($R_{Ca}$):

$$R_c = R_{org} + R_{Ca}$$

Preglednica 1: Hitrost produkcije DIC na meji med vodo in sedimentom v Jezeru na Planini pri Jezeru (Slovenija)

*Table 1: Rate of DIC production at the sediment-water interface in the lake Jezero na Planini pri Jezeru (Slovenia)*

Vrednosti parametra $R_{Ca}$ smo ocenili s pomočjo prileganja difuzijsko-reakcijskega modela globinskim profilom koncentracije $Ca^{2+}$ v pornih vodah sedimenta. Ugotovili smo, da prispeva raztapljanje kalcita k nastalemu DIC 3–16 % in na produkcijo DIC ne vpliva znatno.

Izrazito pozitiven gradient $\delta^{13}C_{DIC}$ v porni vodi sedimenta Jezera na Planini pri Jezeru kaže na vpliv metanogeneze. Prispevek tega procesa k nastanku DIC smo določili s pomočjo izotopske masne bilance (Vreča, 2000). Ugotovili smo, da je vpliv metanogeneze na nastanek DIC velik in znaša povprečno 76 %, prispevek razgradnje organske snovi, ki vključuje druge akceptorje elektronov, pa je znatno manjši in znaša povprečno le 17 %.

Fitting the pore water concentrations of $Ca^{2+}$ to the model allowed the determination of the contribution of $R_{Ca}$. The contribution of calcite dissolution to the production of DIC varies through the year from 3–16 % but does not influence DIC production appreciably (Vreča, 2000).

The distinctive positive $\delta^{13}C_{DIC}$ gradient in pore water of the sediment from Jezero na Planini pri Jezeru indicates the influence of methanogenesis. The isotopic mass balance was used to calculate the contribution of this process to the production of DIC (Vreča, 2000). It was found that the major contribution to DIC derives from methanogenesis (76 %) and much less from decomposition of the sedimentary organic carbon with other electron acceptors (17 %).

## ZAKLJUČKI

Razmerja $C_{org}/N_{tot}$ in izotopska sestava sedimentiranega organskega ogljika ($\delta^{13}C_{org}$) predstavljajo pomemben indikator izvora organske snovi, akumulirane v jezerskih sedimentih. Raziskave sedimentov štirih gorskih jezer (Jezero na Planini pri Jezeru, Krnsko jezero, Jezero v Ledvicah in Zgornje Kriško jezero) so pokazale, da se na jezerskem dnu akumulira vedno več organske snovi, katere izvor je v evtrofnih jezerih (Jezero na Planini pri Jezeru in Krnsko jezero) deloma iz okolice (alohtoni material) deloma pa izvira iz samih jezer (avtohtoni material). V oligotrofnih jezerih (Jezero v Ledvicah in Zgornje Kriško jezero) ves material izvira iz samih jezer.

Intenziteto potencialne oziroma dejanske mineralizacije smo merili z intenziteto aktivnosti dihalne verige (ETS) in hitrostjo porabe kisika (R) na dveh globinah na vertikalnem profilu sedimentov iz 13 gorskih jezer. Na splošno so bile višje aktivnosti ETS in hitrosti porabe kisika na površini sedimentov v bolj trofičnih jezerih. Oba parametra sta bila v vseh jezerih višja na površini kot v globljih plasteh sedimentov. Aktivnost ETS in hitrost porabe kisika sta se po verikalnem profilu sedimenta razlikovali med jezeri z različnim trofičnim nivojem. V zgornjih plasteh sedimenta je bila najvišja aktivnost ETS izmerjena v Jezeru na Planini pri Jezeru in Krnskemu jezeru na globini od 0 do 3 cm, medtem ko je bila v Jezeru v Ledvicah in Zgornjem Kriškem jezeru najbolj intenzivna aktivnost ETS na globini 4 in 5 cm. Povprečno razmerje R/ETS je bilo na površini sedimenta nižje v evtrofnih kot pa v oligotrofnih jezerih. Na mineralizacijske procese v sedi-

## CONCLUSIONS

$C_{org}/N_{tot}$ ratios and isotopic composition of sedimentary organic carbon ($\delta^{13}C_{org}$) represent important tracers of sources of organic matter accumulated in the lake sediments. Investigations of sediments from four Slovenian mountain lakes (Jezero na Planini pri Jezeru, Krnsko jezero, Jezero v Ledvicah and Zgornje Kriško jezero) show increased accumulation of organic matter at the bottom of the lakes origin of which in eutrophic lakes (Jezero na Planini pri Jezeru and Krnsko jezero) is a mixture of alochthonous and autochthonous sources and in oligotrophic lakes (Jezero v Ledvicah and Zgornje Kriško jezero) only of autochthonous origin.

Intensity of potential respiratory activity (ETS) and oxygen consumption rates (R) were measured at two different depths in sediment profiles from 13 lakes in order to evaluate the intensity of potential and actual mineralisation. In general, higher ETS activities and oxygen consumption rates in the surface of sediment were observed in the lakes with higher trophic status. Both parameters were higher in the surface than in the deeper layers in all the lakes. ETS activity and oxygen consumption rate in vertical sediment profiles differed between the lakes of different trophic status. The highest ETS activity at the surface sediment was observed in lakes Jezero na Planini pri Jezeru and Krnsko jezero at depths from 0 to 3 cm, while in lakes Jezero v Ledvicah and Zgornje Kriško jezero ETS activity was the most intense at 4 and 5 cm. The average R/ETS ratio was lower at the surface of sediment in eutrophic lakes than in oligotrophic ones. It is concluded that mentih teh jezer v veliki meri vplivata trofično stanje in globina jezer.

Hitrost razgradnje organske snovi oziroma produkcije raztopljenega anorganskega ogljika ($R_c$), ki nastaja med razgradnjo organske snovi, smo v Jezeru na Planini pri Jezeru ocenili tudi s pomočjo difuzijsko-reakcijskega modela, izpeljanega iz splošne diagenetske enačbe. Ugotovili smo, da je vrednost $R_c$ odvisna predvsem od vsebnosti kisika na meji med vodo in sedimentom in je v času jesenske izotermije najvišja. Znatno počasnejša je razgradnja organske snovi v času pomanjkanja kisika na dnu jezera.

factors affecting mineralisation processes in the sediments in mountain lakes are the trophic state of the lake and its depth.

The rate of organic matter degradation or production of dissolved inorganic carbon ($R_c$) that is produced during organic matter degradation in Jezero na Planini pri Jezeru was determined by applying a diffusion-reaction model derived from the general diagenetic equation. It was found that $R_c$ depends on the concentration of oxygen at the sediment–water interface and is highest during autumn overturn. During anoxic conditions at the bottom of the lake $R_c$ is much lower.

# *Poglavje* 12 *Chapter*

# *Rastlinski in živalski ostanki v jezerskih sedimentih*

# *Plant and Animal Remains in Lake Sediments*

Anton BRANCELJ* & Milijan ŠIŠKO*

## UVOD

Rastline in živali, ki živijo v jezerih, pustijo v jezerskih sedimentih sledove svojega bivanja še dolgo po smrti. Nekatere imajo namreč trdne skelete, ki po njihovi smrti ne razpadejo, temveč potonejo na dno. Odlagajo se skupaj z materialom, ki izvira iz samega jezera, ali pa ga vode in vetrovi prinesejo od drugod (t. i. alohtoni material). Vse se nalaga v kronološkem zaporedju v obliki različnih plasti, podobno kot listi v knjigi. V nekaterih jezerih so plasti zaradi živali, ki živijo na dnu (predvsem polžev, školjk in različnih "črvov"), premešane (bioperturbacija). Pojav je v gorskih jezerih redek, saj tam takih živali navadno ni ali pa so vsaj redke, tako da je njihov vpliv zanemarljiv.

Debelina plasti, njihova barva, zgradba, vsebnost organskih in anorganskih spojin ter ostanki rastlin in živali v njih so odsev zgodovine jezera, ki sega nazaj za nekaj stoletij ali celo tisočletij. Naravni okoljski dejavniki (npr. sprememba temperature ali vodnega režima, priselitev nove vrste) ali pa človekova dejavnost (raba prostora, turizem, vnos tujerodnih vrst ipd.) imajo lahko velik vpliv tako na vodni živelj kot tudi na fizikalne in kemijske latnosti jezerske vode. Kvalitativne in kvantitativne spremembe v okolju in življu se lahko z uporabo primernih metod ugotavljajo za nekaj stoletij ali tisočletij v preteklost.

Kar nekaj skupin rastlin in živali se lahko uporablja za ugotavljanje zgodovine jezer iz njihovih sedimentov. Med rastlinami so za to najbolj znane in uporabne kremenaste alge (Bacyllariophyta). Njihove lupinice (valve) so zgrajene iz silikata, ki je

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## INTRODUCTION

Animals and plants that live in lakes, leave information about their existence over long periods in the sediments. Some of the plants and animals have hard parts of their bodies, which are not destroyed or decayed after death but sink to the bottom of the lakes. They are deposited on the bottom, together with material, originating from the lakes themselves or transported by water or wind from nearby or distant sources (i.e. allochthonous material). They are deposited in chronological order in layers, like pages in a book. In some lakes, the layers can be disturbed by animals, particularly snails, clams or worms, living in the sediment (bioperturbation). This phenomenon is normally absent in high–mountain lakes, because only on rare occasions do such animals live there or because their populations are not big enough to have such an effect.

The thickness of layers, their colour, consistency and especially mineral particle content, organic compounds and remains of plants and animals, are a reflection of the history of the lake for several hundreds or even thousands of years. Natural environmental factors (for example change of temperature or of water regime, invasion of new species), or human activities (land–use, tourism, introduction of new species, etc.) can have a considerable influence on aquatic biota and the physical and chemical characteristics of lake water. Qualitative and quantitative changes in the biota and environment can be discerned from the sediment over long periods, spanning centuries and even millennia, using appropriate methods.

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po zgradbi in odpornosti proti koroziji podoben steklu. Kremenaste alge (imenovane tudi diatomeje) rastejo v večini vod, in to od zelo kislih do zelo bazičnih oziroma od nižin do visokogorja. Nekatere vrste diatomej lahko preživijo le pri zelo specifičnih vrednostih okoljskih dejavnikov (npr. temperatura, pH, količina hranil).

Druga skupina alg, katerih ostanki se dobro ohranijo v sedimentu, so rumene alge (Chrysophyceae). So bližnje sorodnice kremenastih alg, vendar v nasprotju z njimi proizvajajo ciste (mirujoča oblika celic), ki se lahko zelo dolgo obdržijo v sedimentu (Smol in Cumming, 2000). Ciste so vrstno značilne, vendar obstaja precej oblik, pri katerih še niso ugotovili, kateri vegetativni obliki alg pripadajo.

Poleg kremenastih in rumenih alg puščajo sledi o svoji prisotnosti v sedimentu tudi druge skupine alg, in sicer v obliki različnih pigmentov. Nekateri med njimi so bolj splošno razširjeni med algami, drugi pa so značilni le za eno skupino (Lami in sod., 2000). Z ustreznimi biokemičnimi metodami se da te spojine analizirati. Na podlagi kvalitativnih in kvantitativnih rezultatov se potem lahko sklepa o vrstni sestavi združb alg v preteklosti.

V jezerskih sedimentih je pogost tudi pelod. Vendar ta ne nastaja v jezerih (izjema so le vodne rastline – makrofiti – glej poglavje 8), zato ga težko uporabimo za razlago jezerske zgodovine. Pelod namreč večinoma izvira od cvetočih rastlin, ki rastejo v okolici jezer. V nekaterih primerih pa ga veter lahko prinese iz krajev, ki so od jezera oddaljeni več deset ali celo sto kilometrov. Rezultati pelodnih analiz zato lahko dajo koriste podatke o širši okolici jezer, še zlasti o klimi in rabi prostora.

Od živali so v sedimentu najbolj pogosti, in tudi najbolj uporabni, ostanki vodnih bolh (Cladocera) in ličink trzač (Chironomidae) (komarjem podobne živali) (Löffler, 1984). Osebki obeh skupin so med najbolj pogostimi prebivalci najrazličnejših vodnih teles. Nekatere vrste imajo zelo specifične zahteve do okoljskih dejavnikov in jih zato lahko uporabimo kot pokazatelje paleookolja. Med vodnimi bolhami živi nekaj vrst v vodnem stolpcu (zooplankton), medtem ko živijo druge na dnu (zoobentos). V nižinskih jezerih zmernih klimatov lahko najdemo do pet planktonskih vrst in več kot dvajset bentoških vrst vodnih bolh. V gorskih jezerih je število vrst nižje. Le redko najdemo v jezeru več kot eno ali dve planktonski vrsti ter pet bentoških (Brancelj in sod., 1997). Pri vodnih bolhah ločimo dva tipa ostankov. V prvi skupini so hitinski deli oklepa (eksoskeleta). Najpogostejši deli so glavini ščiti, koš (valva) ter "noga" (postabdomen). Iz teh ostankov

There are several groups of plants and animals whose study in lake (i.e. lacustrine) sediments can reveal their history. Among plants, the best known and most studied group are the diatoms (Bacyllariophyta). Their frustules (valves) are made from pure silica, in consistency and resistance to chemicals similar to glass. Diatoms can be found in most waterbodies from the very acid to very alkaline, and from lowland to high altitudes. Some species are able to survive only in a narrow range of environmental conditions, such as temperature, pH, concentration of nutrients.

Another class of algae, which leaves remains in the sediment, are Chrysophyceae, a close relative of diatoms. Unlike their relatives, they produce cysts (resting stage) which can stay in the sediment for a long time (Smol & Cumming, 2000). Cysts are species specific but there are several types, which are not yet related to the vegetative form of algae.

Beside diatoms and chrysophytes, other algae also leave information in the sediment, this time in the form of different pigments. Some of them are common to several groups while some are specific for a particular group (Lami *et al.*, 2000). With specific bio-chemical analyses, the compounds can be determined and quite a lot of qualitative and quantitative information can be reconstructed on algae assemblages in the past.

Pollen has frequently been studied in the sediment from lakes. Since pollen is not produced in lakes (except in the case of macrophytes – see chapter 8) it cannot be used to interpret the history of the lake itself. The origin of the pollen is from flowering plants, which grow around the lakes or, in some cases, in locations several tens or even hundreds of kilometres away. Thus, pollen analyses may provide useful information on the surrounding of a lake, particularly on climate and land–use.

Of the lake fauna, the most frequent and useful remains originate from Cladocera (water flies) and Chironomidae (mosquito–like midges) (Löffler, 1984). These groups are the most common inhabitants of different types of waterbodies. Some of the species have specific environmental requirements and can be used as indicators of the paleo–environment. Among Cladocera, several species are inhabitants of the water column – i.e. open water (zooplankton) and some of them are bottom–dwellers (benthos). Up to five planktonic and more than twenty benthic cladoceran species may be found in lowland lakes in temperate zones. In high–mountain lakes, their number is lower and rarely exceeds one or two planktonic species and five benthic species per lake (Brancelj *et al.*, 1997). Two different se da določiti vrsto, včasih pa tudi spol in starost živali. Po vsaki levitvi (pet do osem v času življenja – odvisno od vrste) in po smrti osebkov ti hitinski ostanki, ki so odporni tudi proti bakterijski razgradnji, potonejo na dno. Drugi vir ostankov so trajna jajca oz. njihovi ovoji, imenovani tudi sedelca (glej tudi poglavje 9). Sedelca so posebne oblike jajc, ki se oblikujejo v določenih pogojih (običajno so to nizke temperature). Deli izleglih kot tudi neizleglih sedelc se prav tako nabirajo na dnu jezer. Večino med njimi se da, podobno kot dele oklepa, določiti do vrste in tako lahko prispevajo dodatne podatke o združbi vodnih bolh v preteklosti.

Pri skupini trzač so najpogostejši telesni deli v sedimentu glavine kapsule ličink, ki so vrstno specifične. V gorskem jezeru je lahko prisotnih celo več kot deset vrst trzač in številne med njimi imajo specifične zahteve do okolja.

V jezerskih sedimentih lahko najdemo še ostanke nekaterih drugih živalskih skupin, vendar so ti navadno redki. Kljub temu pa lahko prispevajo dodatne informacije o paleookolju, kajti za veliko vrst rastlin oz. živali so znane njihove zahteve do okolja. Tako najdemo v sedimentu ostanke, zgrajene iz drobnih zrnc peska, ki so podobni majhnim stekleničkam in pripadajo praživalim iz skupine Theckamoebae, ostanke jajčnih lupin vrtinčarjev (Turbellaria), oklepe rakov dvoklopnikov (Ostracoda), lupine školjk in polžev (Bivalvia in Gastropoda), ostanke glavinih členov ličink žuželk (skupina dvokrilcev: Diptera – Chaoboridae) in stato-

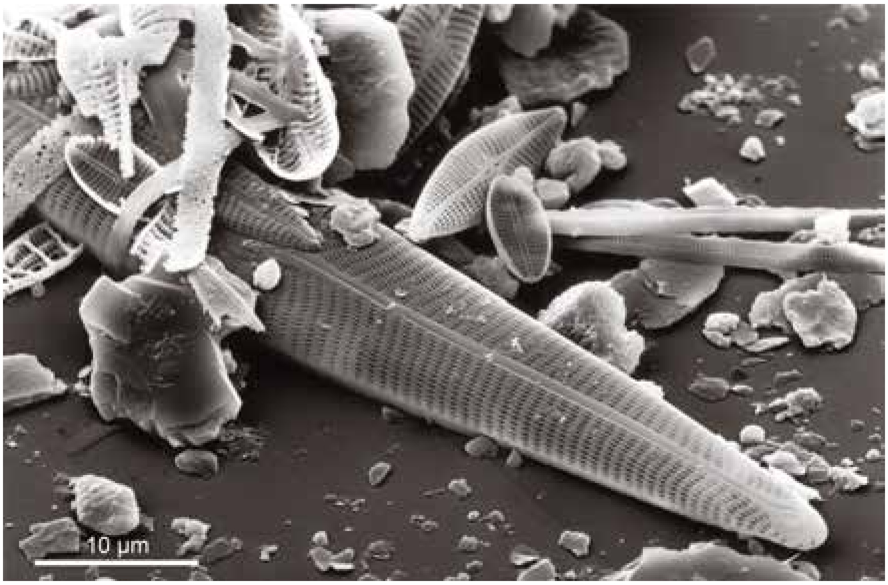
types of remains can be identified from Cladocera. In the first group are the chitinous parts of the exoskeleton – the most common are head capsules, valves and post–abdomens. These parts are species–specific and even sex and age specific. After each moult of the animal (usually between five and eight during a lifetime, depending on species) and after death, the chitinous remains, which are very resistant to bacterial decomposition, sink to the bottom. The second source comes from ephippia (for details see chapter 9). They are a special form produced by adult females under certain environmental conditions, usually at low or high temperatures. Parts of hatched ephippia as well as non–hatched ones are also deposited in the sediment. They are species–specific and they can provide additional information on cladoceran populations in the past.

In Chironomidae, head capsules of larvae are the most common body part found in the sediment, and they are species specific. More than ten different species have been found in a particular mountain lake and some of the taxa have specific environmental requirements.

Remains of some other groups of animals can be found in the sediment, but usually in rather low numbers. Despite this, they can provide additional information on the paleo–environment as most of them have well-known and specific requirements. The most frequently found are the remains of exoskeletons of protozoa, in the shape of small bottles composed of tiny grains of sand (group Theckamoebae), egg–shells of flat–worms (group Turbellaria), valves of crustaceans (group Ostracoda), shells of molluscs (groups Gastropoda and Bivalvia), parts of

Kremenaste alge iz sedimenta Jezera v Ledvicah, posnete z vrstičnim elektronskim mikroskopom. Največja lupinica pripada vrsti *Navicula radiosa* Kützing. Poleg nje so še lupinice oziroma ostanki manjših vrst, kot so *Navicula cryptotenella* Lange-Bertalot, *Achnanthes minutissima* Kützing, *Denticula tenuis* Kützing in druge. (Foto: Kazimir Drašlar)

*Scaning electron microscope micrograph of diatoms in a sediment sample from Jezeo v Ledvicah. The biggest valve is of Navicula radiosa Kützing. There are some valves or their remains of smaller species like Navicula cryptotenella Lange-Bertalot, Achnanthes minutissima Kützing, Denticula tenuis Kützing and others. (Photo: Kazimir Drašlar)*



blaste mahovnjakov (Bryozoa). Hitinski ostanki živali iz teh skupin se v sedimentu navadno prav tako dobro ohranijo kot ostanki kremenastih alg ali vodnih bolh. Do neke mere so izjema le lupinice dvoklopnikov, polžev in školjk z visoko vsebnostjo apnenca, ki se v kislem okolju (nizke vrednosti pH) delno ali povsem raztopijo (Löffler, 1984).

V preteklosti je bilo le malo del posvečenih paleolimnologiji sodobnih slovenskih jezer. Pravzaprav sta le dva članka obravnavala to temo. Eden od njiju se je nanašal na paleolimnologijo Blejskega jezera (Löffler, 1984). Drugi pa je novejšega datuma in obravnava spremembe okolja v šotnih jezercih na Pohorju, natančneje v Lovrenškem jezeru (Brancelj in sod., 1999). Večina drugih člankov je bila osredotočena bolj na pelodne analize v jezerskih sedimentih in je obravnavala spremembe okolja v širšem zaledju takratnih jezer in ne zgolj v samih jezerih.

heads of insects (group Diptera – Chaoboridae) and cysts of moss–animals (group Bryozoa). The remains of these groups are usually as persistent as those of diatoms or Cladocera. To some extent, the valves of Ostracoda, Gastropoda and Bivalvia are an exception, as they can dissolve in an environment with low pH (acidic water) (Löffler, 1984).

In the past, few papers have dealt with the palaeolimnology (science, dealing with lake history) of Slovenian lakes; in fact, only two papers have dealt with the topic directly. One paper studied the palaeolimnology of Blejsko jezero (Löffler, 1984). Another was published recently on environmental changes in the peat bog lake Lovrenško jezero (Brancelj *et al.*, 1999). Other papers were oriented to palynological analyses of some lacustrine (= lake) sediments, and focused on the environmental changes in the entire lake catchment and not specifically in the lakes.

## MATERIAL IN METODE

Na območju Triglavskega narodnega parka smo jemali vzorce sedimenta za analizo ostankov rastlin in živali v trinajstih jezerih (od skupno štirinajstih). V Jezeru pod Vršacem je sediment zelo tanek, kar je verjetno posledica dolgotrajnega ledenega pokrova, zato ga s standardnimi metodami nismo mogli odvzeti. Iz ostalih jezer smo z najglobje točke na dnu s težnostnim vzorčevalnikom s premerom 6 cm odvzeli od 15 do 60 cm dolge vzorce sedimenta (jedra). Jedra iz Zgornjega Kriškega jezera, Krnskega jezera, Jezera v Ledvicah ter Jezera na Planini pri Jezeru smo še posebej natančno analizirali. Zgornjih 30 cm jedra iz Jezera v Ledvicah smo razrezali na 2 mm debele rezine. Iz ostalih jezer smo zgornjih 10 centimetrov narezali na 5 mm, preostali del jedra pa na en centimeter debele rezine.

Vsaka rezina je predstavljala določeno časovno obdobje, od dveh pa do več kot deset let, odvisno od debeline rezine ter njenega položaja v jedru. Tanjše rezine na zgornjem delu jedra so obsegale obdobje okoli 2 do 5 let, medtem ko so debelejše rezine bolj proti dnu jedra obsegale časovno obdobje, ki je bilo navadno daljše od 10 let. Starost posameznih plasti sedimenta je bila določena s pomočjo aktivnosti izotopa $Pb^{210}$, ki omogoča zanesljivo ugotavljanje starosti za obdobje zadnjih 150 let (glej tudi poglavje 10). Iz vsake rezine je bila odvzeta točno določena količina sedimenta za kvalitativne in kvantitativne analize ostankov vodnih bolh, kremenastih alg ter rastlinskih barvil (slednje le za

## MATERIAL AND METHODS

In the Triglav National Park, we sampled thirteen out of the fourteen lakes for analyses of biota remains. In Jezero pod Vršacem the sediment is very thin, as a result of long–lasting ice cover over the lake and it cannot be collected by standard sampling techniques. Sediment cores, between 15 and 60 cm long and 6 cm in diameter, were collected from the rest of the lakes, at the deepest point of each lake.

From four lakes, Zgornje Kriško jezero, Krnsko jezero, Jezero v Ledvicah and Jezero na Planini pri Jezeru, sediment cores were studied in detail. From Jezero v Ledvicah, the sediment core was sliced into 2 mm thick layers from the top of the core to a depth of 30 cm. From the other three lakes, the top-most 10 centimetres of the cores were sliced into 5 mm thick layers and, below 10 cm, into layers of 1 cm each. Each layer represents a time–period from about two to more than ten years, depending on the thickness of the layer and its relative position. Thinner layers in the upper part of the core give much better time resolution (about 2 – 5 years) than thicker layers lower down (usually more than ten years). The age of layers in the cores is determined by measuring the decay of the radioactivity of the isotope of lead $Pb^{210}$, covering a period of the past 150 years approximately (see also chapter 10). From each layer a known amount of the sediment is analysed for qualitative and quantitative data on the remains of Cladocera, diatoms and

Jezero v Ledvicah). Za analizo barvil in ostankov vodnih bolh je bilo potrebne okoli 1 g sveže mase sedimenta (= 1 g ww), za kremenaste alge pa je bilo dovolj že 0,1 g.

Iz preostalih devetih jezer smo analizirali sediment le s površine jedra ter iz plasti pod globino 15 cm. Predpostavljali smo, da sedimet pod to globino izvira iz predindustrijskega obdobja (pred letom 1850) in da je zato zapis o vplivu človekove dejavnosti minimalen, še zlasti z vidika onesnaževanja okolja.

## PODROBNJEŠI REZULTATI ANALIZ SEDIMENTA IZ ŠTIRIH IZBRANIH JEZER

### Zgornje Kriško jezero

Natačnejša analiza 24 cm dolgega jedra, pobranega junija 1994, je dala le nekaj omejenih rezultatov. Z datacijo je bilo ugotovljeno, da je sediment na globini 24 cm star le okoli 40 let. To je kazalo na zelo hitro nalaganje sedimenta na dno jezera. Ostanki dveh vrst vodnih bolh ter nekaj vrst kremenastih alg so bili zelo enakomerno razporejeni vzdolž vertikalnega profila. Oboje, enakomerna razporeditev ostankov in hiter prirast sedimenta, je nakazovalo, da je sedanje stanje v sedimentu rezultat nekega dogodka, najverjetneje plazu, ki ga je sprožil potres. Nekaj let kasneje smo to predpostavko potrdili z rezultati analiz iz Jezera v Ledvicah. Od kremenastih alg so bili najpogostejši ostanki lupinic vrst *Achnanthes minutissima* Kützing, *Cymbella minuta* Hilse, *Fragilaria pinnata* Ehrenberg in *Denticula tenuis* Kützing, ki so tipične predstavnice epilitičnih alg in ki obenem odsevajo tipično sedanje stanje v jezeru. Od vodnih bolh smo našli le ostanke osebkov bentoške vrste *Chydorus sphaericus* (O. F. Müller, 1785) in planktonske vrste *Daphnia pulicaria* Forbes, 1893.

### Krnsko jezero

Jezero je na meji med mezotrofnim in evtrofnim stanjem, leži pod gozdno mejo in je pod močnim vplivom človeka. Pod globino 10 m je redno pomanjkanje kisika, kar lahko traja več mesecev. V jezero so pred okoli 80 leti naselili ribe (za podrobnosti glej poglavje 9).

Sediment iz Krnskega jezera je plastovit, z razločnimi različno debelimi plastmi. Sediment ima razmeroma nizko vsebnost vode, v povprečju le oko-

pigments, the latter only for Jezero v Ledvicah. Normally about 1 g of wet weight of the sediment is used for pigments and Cladocera and about 0.1 g for diatoms.

Sediment slices from the remining nine lakes were analysed from the top of each core and from a depth of 15 cm only. Sediment below 15 cm was considered as a record of the pre–industrial period (i.e. before 1850), when limited influence of human activities was expected, particularly from the point of view of pollution.

## DETAILS ON SEDIMENT CORES FROM THE FOUR LAKES SELECTED

### Zgornje Kriško jezero

Detailed analyses of a 24 cm long sediment core, collected in June 1994 from Zgornje Kriško jezero gave very limited information. Dating of the sediment at the bottom of the core gives its age as about 40 years. This indicates very fast sedimentation of material within the lake. Remains of two cladoceran species and several diatom taxa were distributed quite evenly along the sediment profile. The combination of even distribution of remains with fast sedimentation suggests that the present constituition of the sediment is the result of a specific event, probably a slump, induced by earthquake. This hypothesis was later confirmed by data from Jezero v Ledvicah. The most common diatom taxa in the sediment are *Achnanthes minutissima* Kützing, *Cymbella minuta* Hilse, *Fragilaria pinnata* Ehrenberg and *Denticula tenuis* Kützing, typical epilithic diatoms reflecting population distribution identical to those existing today. In the sediment from Zgornje Kriško jezero only remains of bottom dwelling *Chydorus sphaericus* (O. F. Müller, 1785) and planktonic *Daphnia pulicaria* Forbes, 1893 were found.

### Krnsko jezero

The lake is mesotrophic/eutrophic, situated below the tree line, and has been subjected to high human impact. Below a depth of 10 m in the water column there is regular oxygen depletion for several month of the year. Approximately 80 years ago the lake was populated by two fish species (for details see chapter 9).

Sediment from Krnsko jezero is composed of li 50 % sveže mase, in tudi nizko vsebnost organske snovi; v povprečju le okoli 12 % (izražena kot LOI – loss on ignition = izguba po sežigu). Izjema je le zgornja plast v debelini 6 cm, z visoko vsebnostjo vode (60–80 %) in višjimi vrednostmi LOI (18–20 %). Datacija je pokazala, da je sediment na globini 17,5 cm star okoli 73 let. Oboje: razločna plastovitost, povezana z visokim deležem mineralnih delcev, ter hiter prirast sedimenta, v povprečju okoli 2,4 mm na leto, kaže, da je jezero prizadela v zadnjih nekaj desetletjih vrsta nenadnih dogodkov. Material so v jezero prinašali občasni hudourniki, ki imajo zaledje okoli jezera. Izvor tega materiala je lahko dvojen. Prvi je rezultat intenzivne erozije apnenca, ki se kopiči pod strmimi pobočji okoli jezera. Plazovi, ki jih prožijo močna deževja, sneg ali potresi, prispevajo fine delce, ki jih voda in veter odložita v jezero. Več potresov v prejšnjem stoletju je prizadelo okolico Krna, vključno s tistim iz 60. let (Brancelj in sod., 2000 b). Drugi vir je antropogenega izvora. Med prvo svetovno vojno (1914–1918) je bilo v okolici jezera veliko vojaških dejavnosti, vključno z gradnjo utrdb, jarkov in tudi granatiranja. Rezultat vseh teh aktivnosti je bil tudi fin material, ki sta ga veter in voda nosila v jezero.

V celoti so bili v sedimentu Krnskega jezera določeni ostanki 48 vrst kremenastih alg. Iz njihovega profila se lahko razberejo tri glavna obdobja v novejši zgodovini jezera. Najstarejše obdobje je iz 19. stoletja in se zaključi okoli leta 1880. Za to so

distinct laminae of different thickness. The sediment in general has a relatively low water content, on average about 50 % of wet weight, and a low content of organic material, on average of about 12 % (expressed as LOI – loss-on-ignition). The exception is the upper 6 cm of the sediment, with a higher content of water (60–80 %) and higher LOI (18–20 %). Dating showed that sediment at a depth of 17.5 cm is about 73 years old. The distinct lamination with high content of mineral particles, and fast sedimentation rate, on average 2.4 mm per year, indicates that several events have influenced the lake in the last few decades. Material was transported into the lake by transient torrents, which have a catchment around the lake. There are two potential origins of the material that has been transported into the lake. The first is material that results from intensive weathering of limestone, which has accumulated beneath the high cliffs around the lake. Slumps, triggered by heavy rains, snow or earthquakes, could result in the transport of the fine particles into the lake. Several earthquakes hit the area of Krn in the last century, including one in 1960s (Brancelj *et al.*, 2000 b). Another source has an anthropogenic origin. During the First World War (1914–1918) there was a lot of military activity around the lake, including the building of fortifications and trenches, and shelling. All these activities produced a lot of fine material, which could be transported into the lake by water.

In total, the remains of 48 diatom species were found in the sediment core. Three main periods can be distinguished in the profile of these remains. The oldest is the 19$^{th}$ century up to around 1880, and contains abundant diatom remains (10 valves per microgram dry weight (µg $DW^{-1}$), with peaks in

Grbasta oblika vodne bolhe vrste *Chydorus sphaericus* (O. F. Müller, 1785) ima tudi značilno oblikovan del zunanjega skeleta, ki pokriva glavo (čelada) (levo). Na desni je normalna oblika čelade. Podologovata oblika čelade se pojavi samo pri majhnem odstotku odraslih samic v pozni jeseni.
(Foto: Anton Brancelj)
*The hump-backed form of the oceran species* Cladocerau sphaericus *(O. F. Müller, 1785) has also a characteristic form of exoskeleton, covering the head (helmet) (left). On the right side is a normal shaped helmet. The elongated form of the helmet appears only in some adult females late in autumn.*
*(Photo: Anton Brancelj)*

značilni razmeroma pogosti ostanki (10 valv µg $DW^{-1}$; DW = suha masa sedimenta) z dvema vrhovoma v 60. in 70. letih. Naslednje obdobje traja do 60. let 20. stoletja, kjer je rezmeroma malo ostankov (2,3 valve µg $DW^{-1}$) toda z dvema vrhovoma, eden okoli leta 1916, drugi okoli 1945. Po vsej verjetnosti sta posledica potresov v letih 1915 in 1942 (za podrobnosti glej spodaj; Brancelj in sod., 2000 b). Zadnje obdobje, ki se začne v 70. letih 20. stoletja, je najbolj bogato z ostanki kremenastih alg in ima tri vrhove, prvi okoli leta 1968. Drugi vrh, iz obdobja okoli 1976 do 1981, je verjetno rezultat povišanih vrednosti hranilnih snovi, ki so se sprostile ob potresu leta 1976. Tretji vrh sovpada s sedanjostjo, kjer največji del lupinic pripada dvema planktonskima vrstama, *Cyclotella radiosa* (Grun.) Lemm. in *Stephanodiscus parvus* Stoermer in Håkansson, ki imata bolj krhke lupinice (64 valv µg $DW^{-1}$). Tik pod površjem so bolj pogoste lupinice nekaterih drugih vrst, npr. *Amphora libyca* Ehrenberg, *Amphora pedicelus* (Kützing) Grunow and *Fragilaria pinnata* Ehrenberg. Njihove lupinice so nekoliko debelejše in so zato tudi bolj odporne.

V sedimentu Krnskega jezera smo našli ostanke osebkov devetih vrst vodnih bolh. Najbolj številni so bili ostanki osebkov vrst *Chydorus sphaericus, Alona affinis* (Leydig, 1860) in *Acroperus harpae* (Baird, 1836), in sicer je bila vsaka vrsta zastopana z okoli 500 ostanki na 1 $cm^3$. Izjema je bil interval med 12 in 22 cm globine, kjer so vrednosti padle pod 50 ostankov na 1 $cm^3$. Ostanki osebkov naslednjih dveh vrst, *Alona costata* G. O. Sars, 1862, in *Alonella excisa* (S. Fischer, 1854), so bili precej bolj redki, nekako med 5 in 10 ostankov na 1 $cm^3$. Ostanki osebkov štirih vrst, *Alona quadrangula* (O. F. Müller, 1785), *Daphnia longispina* O. F. Müller, 1785, *Simocephalus expisnosus* (DeGeer, 1778) in *Pleuroxus truncatus* (O. F. Müller, 1785), so bili še bolj redki in so se pojavljali le na določenih globinah. Profil ostankov vodnih bolh v jezeru ni pokazal nobenega določenega vzorca. Izjema je le jasen padec števila njihovih ostankov v intervalu med 12 in 22 cm globine, kar ustreza obdobju med letom 1960 in začetkom 20. stoletja.

the 1960s and 1970s. Then follows a period till the late 1960s, with relatively low abundance (2.3 valves µg $DW^{-1}$) but with two minor peaks, one in 1916 and the other in 1945. These are presumed to correspond to earthquakes in 1915 and 1942 (for details see below; Brancelj *et al.*, 2000 b). The last period, beginning in the 1970s, is the most abundant for diatom remains and has three peaks, the first being in 1968. The second strong peak, from 1976 to 1981, is probably due to an increase in nutrients as a result of the earthquake in 1976. The third peak corresponds to recent times, in which the main proportion of the diatom record is composed of two planktonic species, *Cyclotella radiosa* (Grun.) Lemm and *Stephanodiscus parvus* Stoermer & Håkansson with more fragile valves (64 valves µg $DW^{-1}$). Below this top-most part of the sediment, the most abundant remains are those of other species, *Amphora libyca* Ehrenberg, *Amphora pedicelus* (Kützing) Grunow and *Fragilaria pinnata* Ehrenberg, because their valves are somewhat more robust and thus resistant.

From the sediment of Krnsko jezero, remains of nine different Cladocera species were determined. *Chydorus sphaericus, Alona affinis* (Leydig, 1860) and *Acroperus harpae* (Baird, 1836) were the most abundant, with about 500 remains per $cm^3$ each. An exception was found in the interval from a depth of 12 to 22 cm, where the number of remains dropped to less than 50 per $cm^3$. An additional two species, *Alona costata* G. O. Sars, 1862 and *Alonella excisa* (S. Fischer, 1854) were much more rare, between 5 and 10 remains per $cm^3$. Four species, *Alona quadrangula* (O. F. Müller, 1785), *Daphnia longispina* O. F. Müller, 1785, *Simocephalus expisnosus* (DeGeer, 1778) and *Pleuroxus truncatus* (O. F. Müller, 1785), were also present in the sediment at very low frequencies and only in certain depths. The profile of Cladocera remains in the sediment showed no particular pattern, except for a very distinct decrease in the number of their remains in the depth between 12 and 22 cm, corresponding to the period between 1960 and the beginning of the $20^{th}$ century.

### Jezero v Ledvicah

Jedro, ki je bilo iz tega jezera odvzeto avgusta 1996 (merilo je 30 cm v dolžino), smo razrezali na 2 mm debele rezine (Brancelj in sod., 2000 b). Jezero je oligotrofno, leži tik nad drevesno mejo in vpliv človeka nanj je minimalen (Brancelj in sod.,

### Jezero v Ledvicah

The sediment core, 30 cm in length and collected in August 1996 from Jezero v Ledvicah, was sliced into 2 mm thick sections (Brancelj *et al.*, 2000 b). The lake is oligotrophic, i.e. poor in nutrients, situated above the tree line, and has experienced

2000 b). V primerjavi s Krnskim jezerom je sediment iz tega jezera manj plastovit in vsebuje več vode. Zgornjih 17 cm sedimenta vsebuje okoli 93 % vode. Na globini 17 cm pa je izrazit preskok v povečanju suhe mase (DW) in sicer na okoli 15 % sveže mase; in ta vrednost je precej enaka vse do konca jedra, to je do globine 30 cm. Količina organske snovi v sedimentu, izražena kot izguba po sežigu (LOI), je med 30 % na površini sedimenta in pade na okoli 20 % na globini 17 cm in ostane na tej vrednosti vse do konca jedra. Datacija, temelječa na izotopu $Pb^{210}$,je pokazala, da je sediment na globini 17,4 cm star okoli 171 let (± 25 let), oziroma da je nastajal okoli leta 1825 ± 25 let. Na podlagi linearne ekstrapolacije tako lahko ocenimo, da je sediment na globini 30 cm star okoli 600 let. Zgornje plasti sedimenta, ki vključujejo obdobje zadnjih 160 let, kažejo na podlagi povečanih hitrosti prirasti sedimenta, da so bile te vrednosti povečane trikrat. Obdobja povečanih vrednosti sovpadajo z letnicami potresov, ki so prizadeli območje v zadnjih 100 letih (leta 1895 – globina okoli 13 cm; leta 1942 – globina okoli 9 cm in v letih 1975/76 – globina okoli 2,8 cm). Potres v letu 1997 ni vključen, saj je bil vzorec sedimenta pobran v avgustu leta 1996. Rjava barva sedimenta vzdolž celega jedra kaže, da jezero ni bilo nikoli resno prizadeto zaradi pomanjkanja kisika.

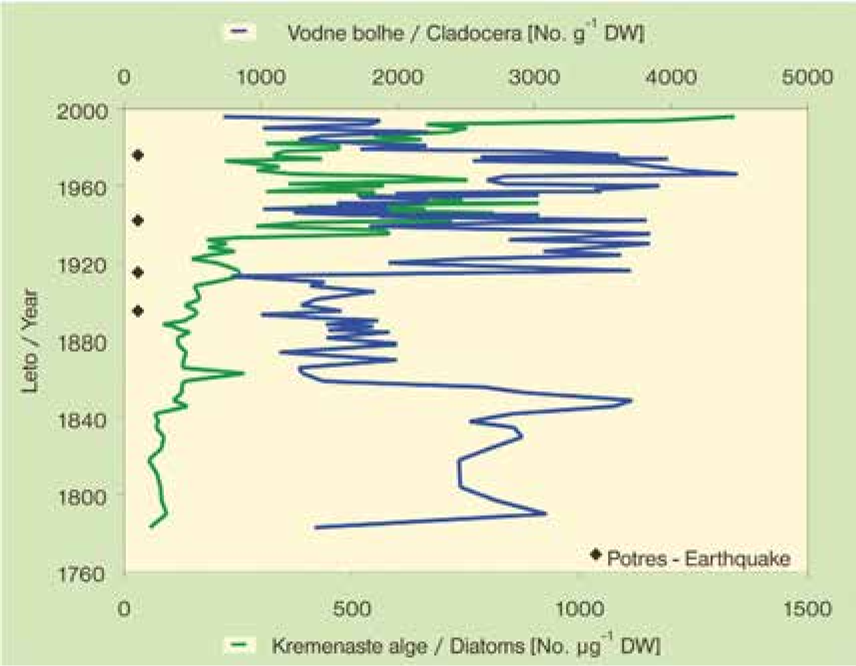
V celoti so bili iz sedimenta Jezera v Ledvicah prepoznani ostanki 50 vrst kremenastih alg. Med njimi je 13 vrst, vse pripadajo bentoškim vrstam, ki so bile označene kot pogoste. Najpogostejši pa so bili ostanki vrst *Denticula tenuis* Kützing in *Navicula cryptotenella* Lange – Bertalot. Ostanki kremenstih alg so vzdolž jedra razporejeni zelo neenakomerno (slika 1). Na odseku med površino in globino 11–12 cm (okoli leta 1910) je število lupinic relativno visoko, a z očitnimi nihanji v abundanci (min. 200 in max. 1200 valv μg $DW^{-1}$). Pod globino 12 cm povprečno število lupinic pade na 100–150 valv μg $DW^{-1}$. Temu sledi rahel dvig na okoli 200 valv μg $DW^{-1}$ na globini med 27 in 30 cm. Povečanje števila lupinic na μg suhe $mase^{-1}$ (od globine 12 cm navzgor) se je začelo kmalu po močnem potresu leta 1895.

Boljše rezultate dajejo izračuni intenzivnosti sedimentacije (izraženi v številu lupinic $cm^{-2}$ $leto^{-1}$) (slika 1) in jo lahko do neke mere primerjamo s primarno produkcijo kremenastih alg. Intenzivnost sedimentacije se je le malo povečala v obdobju od 1780 do 1890/95 (globina med 19 in 13,2 cm) in se je močno povečala okoli leta 1895 (13,2 cm) in nato ponovno po letu 1913 (12 cm). Najbolj očitna povečanja pa so bila leta 1942 ± 4 leta in okoli 1955 ± 4 leta. Naslednje povečanje (a nekoliko manj pou-

minimal human impact (Brancelj *et al.*, 2000 b). Compared with Krnsko jezero, the sediment is less laminated and contains more water. The upper 17 cm of the sediment contains about 93 % of water. At a depth of 17 cm, there is a very sharp increase of DW, on average to about 15 % of wet weight, and the value is fairly constant down to the bottom of the core at 30 cm. The amount of organic material in the sediment is about 30 % of DW at the top of the sediment, drops to less than 20 % of DW at 17 cm, and stays quite constant to the bottom of the core. Dating, based on the concentration of $Pb^{210}$, indicates that the sediment at the depth of 17.4 cm is about 171 years old (± 25 years), corresponding to 1825 ± 25 years. Assuming a linear extrapolation, we can estimate that the sediment at the depth of 30 cm is about 600 years old. The upper part of the sediment, encompassing a time span of about 160 years, was disturbed at least three times, resulting in increased sedimentation rates. Disturbances coincide with three earthquakes known to have occurred in the area in 1895 – at a depth of about 13 cm; in 1942 – at a depth of about 9 cm and in 1975/76 – at a depth of about 2.8 cm. (The earthquake in 1997 is not included, because the sediment core was collected in August 1996). The brown colour of the sediment throughout the core indicates that there was no serious oxygen depletion at the bottom of the lake.

In total, 50 diatom taxa were identified from the sediment of the lake. Among them, 13 belong to benthic forms recognised to be common, with *Denticula tenuis* Kützing and *Navicula cryptotenella* Lange – Bertalot occurring most frequently. The distribution of diatom assemblages is very uneven (Figure 1). In the section between the surface and a depth of 11–12 cm (around 1910), the number of valves is relatively high with an obvious fluctuation in concentration (minimum 200 and maximum 1200 valves μg $DW^{-1}$). Below 12 cm, the average number of valves drops to 100–150 μg $DW^{-1}$ but there is a slight increase to about 200 μg $DW^{-1}$ in the section between 27 and 30 cm. An increase of number of valves per μg $DW^{-1}$ (at a depth of 12 cm and upwards) started soon after the strong earthquake in 1895.

Good quality results allow an accumulation rate to be calculated for the number of valves per cross section per year ($cm^{-2}$ $y^{-1}$) (Figure 1) and could be interpreted as the rate of primary production of diatoms. Diatom accumulation rates increased only slightly in the period 1780 to 1890/95 but more sharply around 1895 and again after 1913. The most




Slika 1: Skupno število ostankov vodnih bolh (Cladocera) in kremenastih alg (Bacyllariophyta) v vertikalnem profilu sedimenta iz Jezera v Ledvicah (Triglavski narodni park, Slovenija). Posebej so označeni tudi močnejši potresi.

*Figure 1: Total number of remains of cladocerans (Cladocera) and diatoms (Bacyllariophyta) in the vertical profile of the sediment from the lake Jezero v Ledvicah (Triglav National Park, Slovenia). Four strong earthquakes are also indicated.*

darjeno) ustreza obdobju od leta 1976 ± 2 leti do 1982 ± 2 leti. Vsa navedena povečanja intenzivnosti sedimentacije sovpadajo s potresi in kratkimi obdobji po njih. Izjema je le dogodek okoli leta 1913 (globina 12 cm). Za to povečanje predpostavljamo, da je bil vzrok sicer šibak potres ali plaz, ki pa je sprožil razmeroma velik zdrs materiala v jezero. Ob navedenih dogodkih naj bi prišlo do intenzivnega premešanja sedimenta, s tem pa do ponovnega sproščanja hranil nazaj v vodni stolpec, kar je povzročilo začasno povečano rast alg, vključno s kremenastimi algami.

Analize pigmentov, značilnih za alge (celokupni karotenoidi – TC in klorofilni ostanki – CD), dajo nekoliko drugačen vzorec razporeditve. Od globine 30 do 12 cm so vrednosti za CD in TC zelo nizke (0,1 g oz. 1 mg g LOI$^{-1}$) (Lami in sod., 2000). Na globini 12 cm (okoli leta 1910) vrednosti obeh parametrov narasteta na okoli 0,5 g oz. 5 mg g LOI$^{-1}$ in ostaneta tako visoki do okoli leta 1945. Sledi hiter padec vrednosti za obdobje okoli 10 let, nato pa začno vrednosti ponovno naraščati in ostanejo enako visoke vse do danes (glej tudi Brancelj in sod., 2000 b).

V sedimentu jezera smo našli ostanke štirih vrst vodnih bolh, med katerimi so tri bentoške. Vse štiri vrste so prisotne vzdolž celotnega analiziranega profila, vendar število njihovih ostankov niha med 3000 in 13.000 g DW$^{-1}$ . Ločimo tri obdobja, ko so bile izrazito povečane vrednosti števila ostankov vodnih bolh. Prvo je bilo okoli leta 1840, drugo okoli leta 1930 in tretje okoli leta 1970. Dandanes (t. j. leta 1996) je število ostankov na g suhe mase najnižje

pronounced increases were in 1942 ± 4 yr and 1955 ± 4 yr. The next, but less pronounced, peak rate corresponds to the period 1976 ± 2 yr to 1982 ± 2 yr. All increases coincide with earthquakes and short periods thereafter. An exception is around 1913. There is a hypothesis that, in that period, a weak earthquake or an avalanche triggered a big slump. This event induced an intensive re-suspension of the sediment, releasing nutrients back into the water column, and triggering an intensive growth of algae, including diatoms.

Analyses of pigments, associated with algae (total carotenoids – TC and chlorophyll derivatives – CD), give a slightly different pattern. From 30 cm to 12 cm the values of DC and TC are very low (0,1 g and 1 mg g LOI$^{-1}$ respectively) (Lami *et al.*, 2000). At a depth of 12 cm (around 1910) their values increase to about 0.5 g and 5 mg g LOI$^{-1}$ respectively and stay high until about 1945. The sharp decrease, with low values for the next 10 years, is followed by a further increase, remaining high to the present day (see also Brancelj *et al.*, 2000 b).

In the sediment of the lake we found remains of four Cladocera, three of them being benthic. The same taxa are present in all sections of the core, but their numbers oscillate between 3000 and 13000 g DW$^{-1}$. Three distinct maxima in Cladocera assemblage could be distinguished. The first was around 1840, the second around 1930 and the third around 1970. In 1996, the number of Cladocera remains g DW$^{-1}$ was at a minimum (< 3000 g DW$^{-1}$). In the sed-

(> 3000 g $DW^{-1}$). Najpogostejši so ostanki osebkov vrst *Chydorus sphaericus* in *Alona affinis*, medtem ko so ostanki vrst *Daphnia longispina* in *Alona rectangula* G. O. Sars, 1862 redki (~ 10 % celotne združbe). V starejših plasteh sedimenta (pod 15,8 cm oz. pred letom 1863 ± 16 let) so bili ostanki rodu *Chydorus* najpogostejši (~ 80 % vseh ostankov), medtem ko je v mlajših plasteh (nad 7,0 cm oz. po letu 1950 ± 5 let) število ostankov vrste *C. spahericus* le še dvakrat bolj pogosto, kot so ostanki vrste *A. affinis*.

Rezultati, pridobljeni z izračuni intenzivnosti sedimentacije ostankov vodnih bolh (izraženi v številu ostankov $cm^{-2} leto^{-1}$) (slika 1), sledijo splošnemu vzorcu, opisanem pri kremenastih algah. Število ostankov naraste po vsakem potresu. Izjema je obdobje po potresu leta 1975, ko začne združba vodnih bolh upadati, narašča pa združba kremenastih alg. Predvidevamo, da obstaja določena povezava med naraščanjem povprečne letne temperature zraka v zadnjih treh desetletjih v Alpah, in s tem posledično tudi naraščanje temperature vode, in upadanjem populacije vodnih bolh (glej tudi Brancelj in sod., 2000 b).

iment, remains of *Chydorus sphaericus* and *Alona affinis* are the most common, whilst those of *Daphnia longispina* and *Alona rectangula* G. O. Sars 1862 are rare (~ 10 % of the total assemblage). In the lower part of the sediment core (before 1863 ± 16 yr) remains of *Chydorus* were dominant (~ 80 % of all remains) whilst in the upper–most part (after 1950 ± 5 yr) remains of *C. sphaericus* are only twice as common as those of *A. affinis*.

The calculated accumulation rates for the number of cladoceran remains ($cm^{-2} yr^{1}$) (Figure 1) follow a similar pattern to that for the diatoms. They increase after each earthquake. An exception was a period following the earthquake in 1975, when the cladoceran community decreased, although that of the diatoms increased. We can speculate that increased mean annual air–temperature, and consequently lake–water temperature, in the last three decades has had a negative effect on community growth of benthic Cladocera (see also Brancelj *et al.*, 2000 b).

### Jezero na Planini pri Jezeru

Vzorec sedimenta iz Jezera na Planini pri Jezeru (pobran aprila leta 1996, dolžina jedra 40 cm) je bil razrezan na 5 mm debele rezine (zgornjih 10 cm), preostali del pa na 1 cm debele rezine. Jezero je močno evtrofno in leži sredi iglastega gozda. V zadnjih stoletjih je bil vpliv človeka na jezero zelo močan (planšarstvo, oglarjenje, turizem, vnos rib) (Brancelj in sod., 2000 a). Sediment sicer nima izrazitih plastnic (tanke plasti z izmenjajočimi se svetlimi in temnimi plastmi), vendar lahko ločimo pet odsekov, ki imajo različne barvne odtenke (slika 2). Zgornjih 16 cm sedimenta je temnorjavih/črnih, kar kaže na pomanjkanje kisika na dnu v času nastajanja sedimenta. Ta del je močno prepojen z vodo. Na globini 31 cm je v sedimentu okoli 80 % vode in njena količina precej enakomerno narašča proti površini, kjer predstavlja kar okoli 95 % sveže mase sedimenta. Tudi del jedra med 31 in 40 cm globine vsebuje še vedno veliko vode (od 80 % naraste na preko 90 %). Delež organske snovi v sedimentu (izražene kot izguba po sežigu – LOI) je visok. Na površini sedimenta je njena vsebnost okoli 40 % suhe mase in pada do vrednosti okoli 20 % na globini 31 cm ter ponovno naraste na preko 40 % na globini 40 cm (slika 2). Ugotavljanje starosti sedimenta na osnovi koncentracij izotopa $Pb^{210}$ je pokazala, da je sediment na globini 21,5 cm star okoli

### Jezero na Planini pri Jezeru

A sediment core from Jezero na Planini pri Jezeru (collected in April 1996; 40 cm in length) was sliced into 5 mm thick layers (top 10 cm) and the rest into 1 cm thick layers. The lake is at present highly eutrophic (rich in nutrients), and situated in the middle of dense coniferous forest. In the last few centuries it was heavily influenced by human activities (alpine diary pasturing, forges, tourism, fish stocking) (see Chapter 13; Brancelj *et al.*, 2000 a). The sediment has no varves (thin layers, with dark and light parts) but five segments with distinct colours could be recognised (Figure 2). The topmost 16 cm of the sediment is dark brown / black indicating oxygen depletion during deposition of the sediment. The sediment has a high water content. At a depth of 31 cm there is about 80 % of water in the fresh sediment and this increases evenly to the top of the sediment (about 95 % of wet weight). The section between 31 and 40 cm also contains a lot of water (from 80 % it increases to over 90 %). Organic matter in the sediment is high. At the top, there is about 40 % of DW, decreasing to about 20 % at 31 cm and increasing again to over 40 % at a depth of 40 cm (Figure 2). Dating, based on concentration of $Pb^{210}$, indicates that the sediment at 21.5 cm is about 110 years old, corresponding to around 1885. By linear extrapolation, we can

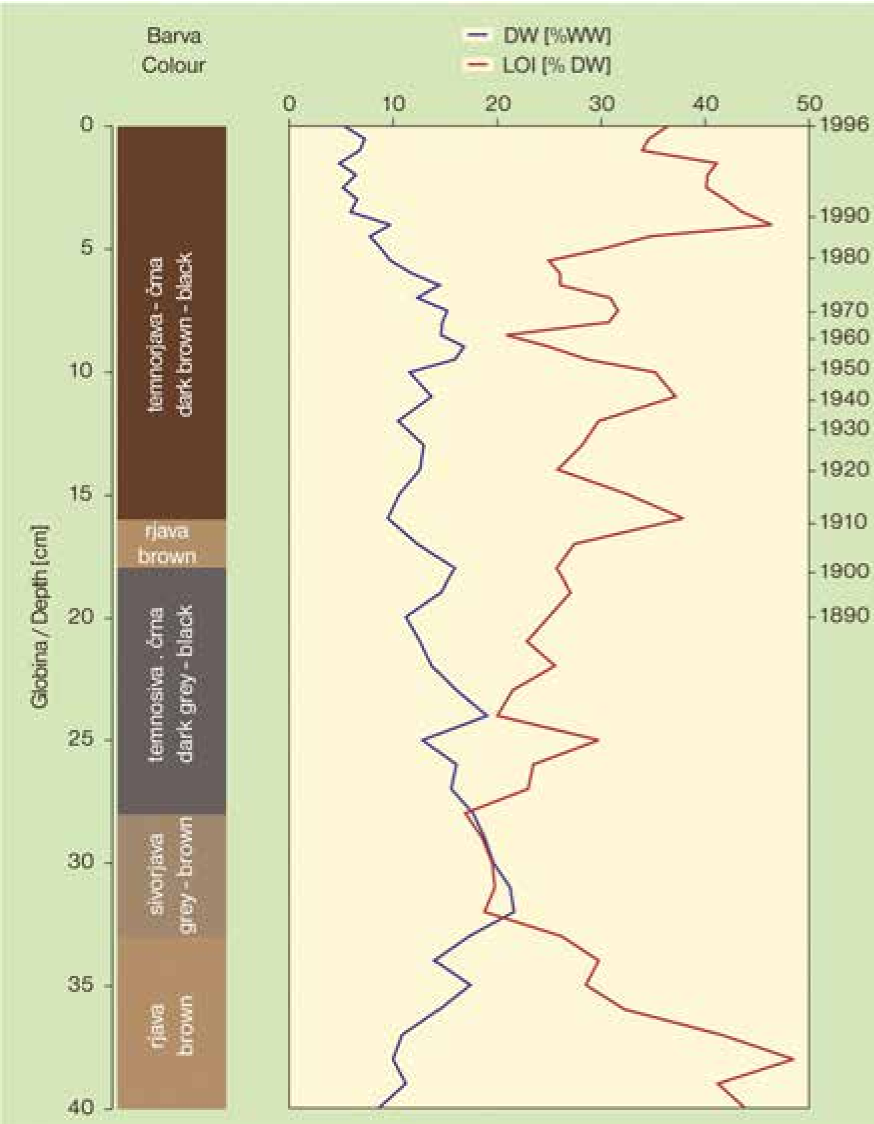
110 let oziroma da je nastal okoli leta 1885. Na podlagi linearne ekstrapolacije lahko ocenimo, da je sediment na globini 40 cm star okoli 240 let. Hitrost prirastka sedimenta je enakomerno upadala z vrednostmi okoli 0,04 g DW $cm^{-2}$ $leto^{-1}$ (okoli leta 1880) na okoli 0,015 g DW $cm^{-2}$ $leto^{-1}$ (okoli leta 1970). Izrazito, a kratkotrajno povečanje prirastka okoli leta 1976 sovpada z močnim potresom (glej tudi Jezero v Ledvicah). Povečana hitrost prirasta sedimenta se ponovno začne v zgodnjih 80. letih.

V sedimentu smo sicer našli ostanke 47 vrst kremenastih alg, a le tri vrste (*Fragilaria pinnata* Ehrenberg, *F. construens* (Ehrenberg) Hustedt, *Stephanodiscus parvus* Szoermer in Haåkansson) so bile relativno pogoste (50–100 valv µg $DW^{-1}$). Naslednje tri taksone smo označili kot pogoste (*Amphora libyca* Ehrenberg, *Achnanthes minutissima* Kützing, *Fra-*

estimate that sediment at the depth of 40 cm is about 240 years old. The sedimentation rate decreased evenly from 0.04 g DW $cm^{-2}y^{-1}$ around 1880 to about 0.015 g DW $cm^{-2}y^{-1}$ around 1970. A sharp but short–lasting increase in 1976 coincides with a strong earthquake (see Jezero v Ledvicah). A sharp increase of the sedimentation rate started again in the early 1980s.

Forty–seven diatom taxa were identified in the sediment, but only three (*Fragilaria pinnata* Ehrenberg, *F. construens* (Ehrenberg) Hustedt, *Stephanodiscus parvus* Szoermer & Haåkansson), are present at relatively high frequencies (50–100 valves µg $DW^{-1}$). A further three species are common (*Amphora libyca* Ehrenberg, *Achnanthes minutissima* Kützing, *Fragilaria ulna acus* (Kützing) Lange – Bertalot) and the remaining taxa are scarce (> 20 valves µg $DW^{-1}$). Four species (*A. minutissima, F. pinnata, F. construens, S. parvus*) have been present throught the 240 years, although their abundance changes along the core. The number of valves of *F. ulna acus*, which are very rare in the lower part of the core, probably because of fragile valves, increases significantly in the top two centimetres, i.e. after 1990 (Figure 3).

Cladocera are represented in the sediment by thirteen species. Two of them (*Alona affinis* and

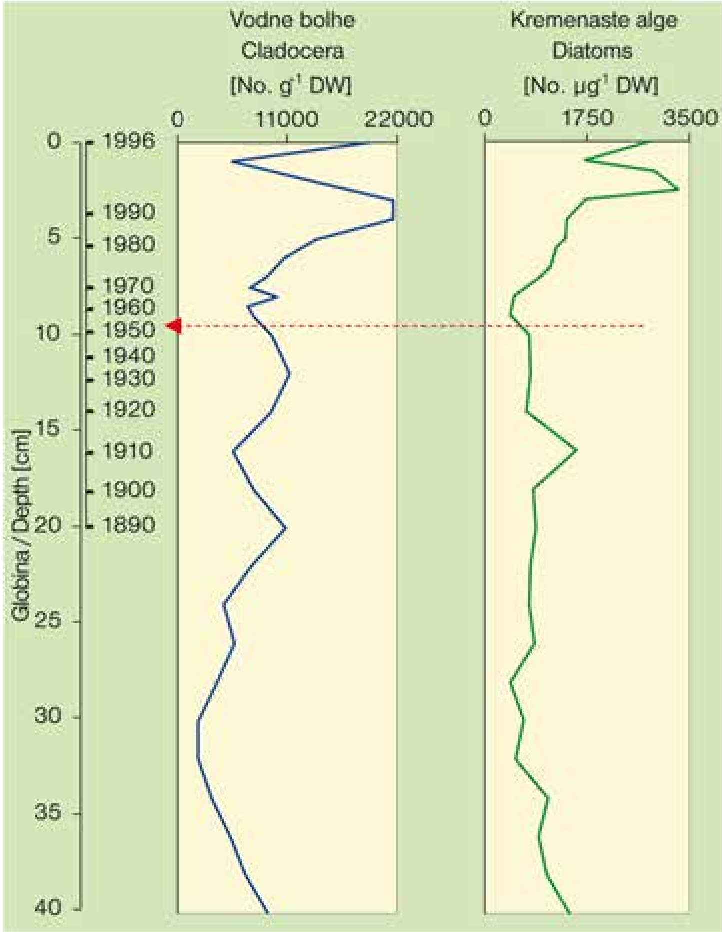



Slika 2: Masa suhega sedimenta (DW) in njegov žarilni ostanek (LOI) vzdolž vertikalnega profila jedra iz Jezera na Planini pri Jezeru (Triglavski narodni park, Slovenija) Označena je tudi barva sedimenta na posameznem segmentu.
*Figure 2: Dry weight (DW) and loss-on-ignition (LOI) of the sediment along the vertical profile of the core from the lake Jezero na Planini pri Jezeru (Triglav National Park, Slovenia). Colour of different sediment segments along the core is indicated.*

*gilaria ulna acus* (Kützing) Lange – Bertalot), medtem ko so bile ostale vrste redke (> 20 valv µg $DW^{-1}$). Štiri vrste (*A. minutissima, F. pinnata, F. construens, S. parvus*) so bile prisotne vzdolž celega profila sedimenta, vendar se je njihova pogostost spreminjala. Tako se je število lupinic taksona *F. ulna acus,* ki so bile zelo redke v spodnjem delu jedra (deloma verjetno tudi na račun krhkosti lupinic), močno povečalo v zgornjih dveh centimetrih, t. j. po letu 1990 (slika 3).

Vodne bolhe so zastopane v sedimentu z ostanki osebkov trinajstih vrst. Ostanki osebkov dveh vrst (*Alona affinis* in *Eurycercus lamellatus* (O. F. Müller, 1776)) so bili najdeni le v sedimentu, medtem ko živih osebkov (še) nismo našli. V zgornjih 10 cm sedimenta je skupno število ostankov vodnih bolh precej nihalo – med 5000 and 22.000 g $DW^{-1}$ (slika 3). Njihovo število pa je upadlo v intervalu med 10 cm (od 10000 ostankov g $DW^{-1}$) in 30 cm globine (na 2000 ostankov g $DW^{-1}$). Na globini med 30 and 40 cm je število ostankov ponovno naraslo (na okoli 9000 ostankov g $DW^{-1}$). Ostanki osebkov treh vrst (*Chydorus sphaericus, Daphnia longispina, Eubosmina Eurycercus lamellatus* (O. F. Müller, 1776)) have been found only in the sediment and not (yet) in the living community. In the upper 10 cm of the sediment, the total number of cladoceran remains oscillates considerably – between 5000 and 22,000 g $DW^{-1}$ (Figure 3). Their number decreases overall in the section between 10 cm (10,000 remains g $DW^{-1}$) and 30 cm (2000 remains g $DW^{-1}$). In the section between 30 and 40 cm, the number of remains increases again, up to 9000 remains g $DW^{-1}$. Three of the Cladocera, *Chydorus sphaericus, Daphnia longispina, Eubosmina longispina* (Leydig, 1860) are common throughout the whole length of the core and constitute 65–93 % of cladoceran remains. In the section between 10 and 32 cm their numbers were quite similar (1000–3000 remains of each species), with *Daphnia* predominating. In the sections between 0 and 8 cm and below a depth of 32 cm, there is a clear predominance of *Eubosmina* remains (with a maximum of 22,000 remains g $DW^{-1}$ at a depth of 3.5 to 4.0 cm).

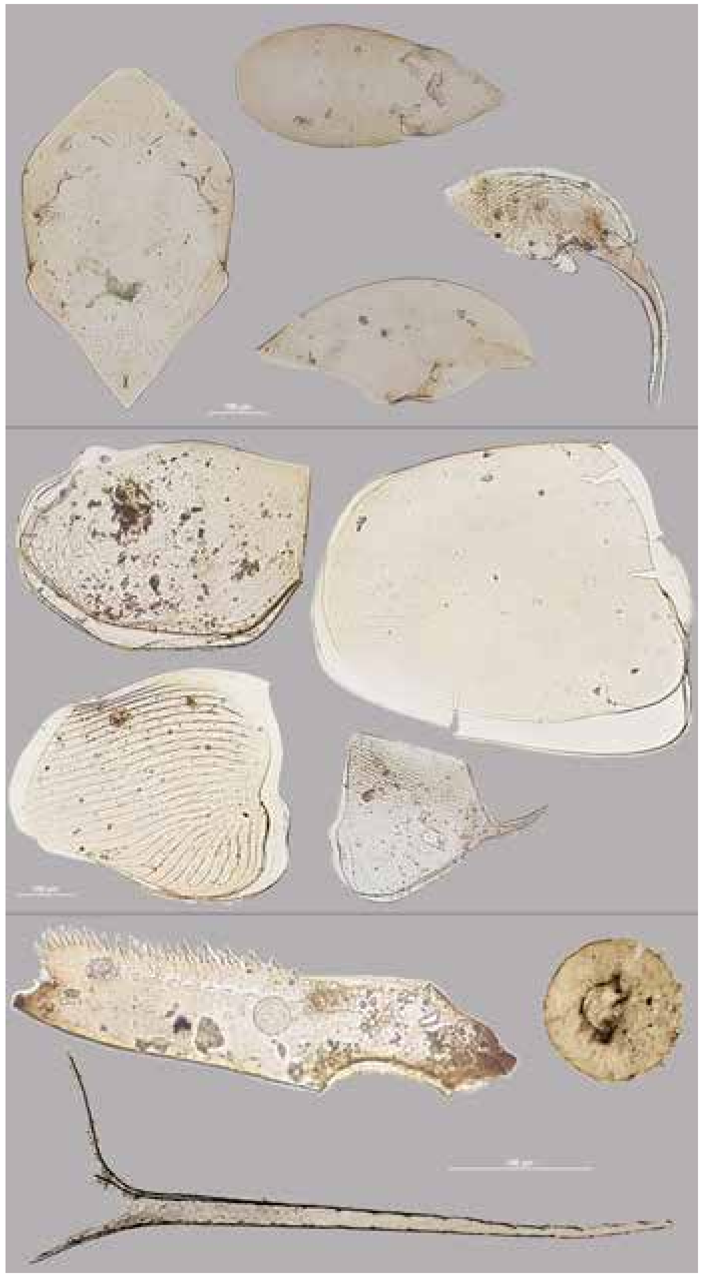
Sediment analyses show that, within the last 250 years, several periods in the lake history can be distinguished. The oldest part of the sediment core, between 1750 and 1800, is characterised by a sharp increase of mineral component in the sediment. From pollen analyses (Culiberg, pers. com.) this period is characterised by very low values of non–arboreal pollen (NAP). An increase of mineral component in the sediment indicates the start of intensive wood cutting in the drainage basin of the lake which resulted in increased soil erosion. From about 1800 onward, pollen grains of NAP (Graminaceae, Umbeliferae, Urticaceae, Compositae, Selaginellaceae and some other herbs) increased as a result of deforestation and associat-




Slika 3: Skupno število ostankov vodnih bolh (Cladocera) in kremenastih alg (Bacyllariophyta) v vertikalnem profilu sedimenta iz Jezera na Planini pri Jezeru (Triglavski narodni park, Slovenija). S puščico je označeno leto naselitve rib v jezero.
*Figure 3: Total number of remains of cladocerans (Cladocera) and diatoms (Bacyllariophyta) in the vertical profile of the sediment from the lake Jezero na Planini pri Jezeru (Triglav National Park, Slovenia). Arrow indicates year of fish introduction in the lake.*

*longispina* (Leydig, 1860)) so bili pogosti v celotnem profilu sedimenta in so predstavljali 65–93 % vseh ostankov. Na globini med 10 in 32 cm je bilo število ostankov osebkov vseh treh vrst precej podobno (1000–3000 ostankov na vsako vrsto), vendar so nekoliko izstopali ostanki iz rodu *Daphnia*. Na globini med 0 in 8 cm ter pod globino 32 cm je očitna prevlada ostankov osebkov iz rodu *Eubosmina* (z največjo vrednsotjo 22.000 ostankov g $DW^{-1}$ na globini med 3,5 in 4,0 cm).

Analize sedimenta kažejo, da lahko v zadnjih 250 letih ločimo več obdobij v zgodovini jezera. Za najstarejši del sedimenta (obdobje od leta 1750 do 1800 = globina med 40 in 33 cm) je značilen hiter porast mineralnih delcev. Iz rezultatov pelodnih analiz (Culiberg, osebno poročilo) je za to obdobje značilna še nizka vrednost nedrevesnega (NAP) oz. zeliščnega peloda. Povišane vrednosti mineralnih delcev v jezeru pa že kažejo na intenzivno sečnjo v pojezerju, kar se odraža v povečani eroziji. Od okoli leta 1800 naprej (globina 33 cm) se poveča delež pelodnih zrn zelišč (NAP: Graminaceae, Umbeliferae, Urticaceae, Compositae, Selaginellaceae in nekatere druge skupine) kot rezultat sečnje gozda in z njo povezane erozije. Združba vodnih bolh v jezeru je reagirala na povečan vnos hranil od zunaj, predvsem kot rezultat erozije, vendar z določenim časovnim zamikom. Za obdobje med leti 1800 in 1910 je značilno rahlo nihanje v trofičnem nivoju jezera kot posledica sečnje gozda in erozije prsti. Nihanja so bila razmeroma majhna, kar lahko pripisujemo homeostatskim procesom znotraj jezera, ki so lahko po do-



Hitinasti ostanki nekaterih živali se v jezerskih sedimentih dobro ohranijo. Zgoraj: glavini ščiti različnih vrst vodnih bolh - levo: *Alona affinis* (Leydig, 1860); zgoraj: *Chydorus sphaericus* (O. F. Müller, 1785); desno: *Eubosmina longispina* (Leydig, 1860); spodaj: *Acroperus harpae* (Baird, 1836). Sredina: koši (valve) različnih vrst vodnih bolh - levo zgoraj: *Chydorus sphaericus* (O. F. Müller, 1785); levo spodaj: *Acroperus harpae* (Baird, 1836); desno zgoraj: *Alona affinis* (Leydig, 1860); desno spodaj: *Eubosmina longispina* (Leydig, 1860). Spodaj: levo zgoraj: 'noga' (postabdomen) vrste *Acroperus harpae* (Baird, 1836); levo spodaj: repna bodica vrste *Daphnia longispina* O.F. Müller, 1785; desno zoraj: ostanek lupinice tekamebe. (Foto: Nataša Gorjanc)

*Chitinous remains of some animals are well preserved in the sediment. Top: head capsules of different species of Cladocera - left:* Alona affinis *(Leydig, 1860); top:* Chydorus sphaericus *(O. F. Müller, 1785); right:* Eubosmina longispina (*Leydig, 1860); bottom:* Acroperus harpae *(Baird, 1836). Middle: valves of different species of Cladocera - upper left:* Chydorus sphaericus *(O. F. Müller, 1785); lower left:* Acroperus harpae *(Baird, 1836); upper right:* Alona affinis *(Leydig, 1860); lower right: Eubosmina longispina (Leydig, 1860). Bottom: upper left: postabdomen of* Acroperus harpae *(Baird, 1836); lower left: tail spine of* Daphnia longispina *O.F. Müller, 1785; upper right: exoskeleton of protozoan (Theckamoebae). (Photo: Nataša Gorjanc)* ločenem času dokaj uspešno nevtralizirali negativne vplive erozije prsti.

Od okoli leta 1910 naprej (globina 16 cm) se je začelo povečevati število ostankov osebkov iz rodu *Daphnia*, njim pa je sledil porast ostankov iz rodu *Eubosmina*. Istočasno se je začelo dolgoročno upadanje ostankov osebkov iz rodu *Chydorus*, ki so skoraj popolnoma izginili iz sedimenta okoli leta 1985. Po letu 1900 se je v okolikci jezera pričelo razmeroma intenzivno planšarstvo. Za obdobje med začetkom 20. stoletja ter 60. leti je značilno rahlo povečanje trofičnega stanja jezera.

Leta 1951 so v jezero naselili ribe (Povž, 1997) (slika 3). Prva reakcija na vnos rib se lahko zazna na zgradbi sedimenta, in sicer kot znižanje suhe snovi (DW; kot % od ww) in povečanje izgube po sežigu (LOI) okoli leta 1955 (globina 9,0 cm). Istočasno se je povečala hitrost prirastka sedimenta. Temu je okoli leta 1960 sledila sprememba v zgradbi združbe vodnih bolh (globina 8,0 cm). Kremenaste alge so vnosu rib sledile počasneje. Ribe so na jezero vplivale po dveh poteh – plenjenje zooplanktona in intenzivno mešanje sedimenta v obrežnem pasu. Plenjenje osebkov planktonskih vrst vodnih bolh je razmeroma hitro pripeljalo do popolnega iztrebljenja relativno velikih osebkov rodu *Daphnia*. V nasprotju z njimi pa so bili relativno majhni osebki rodu *Eubosmina* precej manj zanimiv plen za ribe. Zato je njihova populacija močno narasla in dosegla največjo gostoto sredi 80. let, zatem pa je nekoliko upadla.

Posledica prehranjevanja koresljev (*Carassius carassius* (Linnaeus, 1758)) z bentoškimi organizmi je intenzivno mešanje sedimenta v obrežnem pasu, s čemer je prišlo do ponovnega vračanja hranil iz sedimenta v vodni stolpec, s tem pa se je povečevala primarna produkcija. Tovrstna evtrofikacija je imela za posledico pojav pomanjkanja kisika v globjih plasteh vodnega stolpca (hipoksija oz. anoksija).

Naslednja motnja jezerskega ekosistema se je začela po letu 1983, ko je pogorela planinska koča nad jezerom. Obnovitvena dela so se začela v letu 1985 in se nadaljevala v naslednjih letih. Med samo gradnjo je bilo na pobočja nad jezerom odloženega veliko gradbenega materiala. To je vključevalo tudi vodo, pomešano z apnom in cementom, ki je odtekala tudi neposredno v jezero. Temu so bila dodana tudi nekatera zemeljska dela na pobočju. Zaradi vseh teh aktivnosti je bil živelj v jezeru za kratek čas močno prizadet (zmanjšanje biotske raznovrstnosti, visok LOI, odsotnost ostankov vodnih bolh). Po tem času (od globine 3,5 cm navzgor) se je začela

ed soil erosion. The cladoceran community in the lake reacted to the increased external input of nutrients, resulting mainly from erosion, but the reaction had a certain time–delay. The period from about 1800 to 1910 is characterised by slight oscillations of the lake's trophic status, as a result of deforestation and soil erosion. Oscillations were moderate, because of homeostatic forces within the lake, able to neutralise the negative effects of soil erosion for some period of time.

From about 1910 onward, *Daphnia* remains started to increase, followed by *Eubosmina*. At the same time a long–term decrease in *Chydorus* started, resulting in its almost complete disappearance from the lake by 1985. After 1900, relatively intensive alpine pasturing was practised in the catchment. The period between the beginning of the 20$^{th}$ century and the 1960s was characterised by a slight increase in the trophic level of the lake.

In 1951 fish were introduced into the lake (Povž, 1997) (Figure 3). The first response can be observed in the structure of the sediment, with decreasing DW (as % of wet weight) and increasing LOI around 1955. At the same time, the sedimentation rate increased. This was followed by change in the Cladocera community around 1960. Diatoms react much more slowly to fish introduction. Fish affected the lake in two ways – predation on zooplankton and intensive re-suspension of the sediment in the littoral. Predation on planktonic Cladocera very quickly eliminated the large–bodied *Daphnia*. Conversely, the small–bodied *Eubosmina* was less exposed to fish predation and its population increased dramatically, reaching maximum abundance in the mid-1980s, then decreasing slightly.

*Carassius carassius* (Linnaeus, 1758) feed on benthic animals, resulting in an increased re-suspension of sediment and release of nutrients, leading to increased primary production in the following period. Eutrophication resulted in the onset of hypoxia, with anoxia in the deeper part of the water column.

An additional disturbance of the lake started after 1983, when the hostal on the shore of the lake accidentally burnt down. Reconstruction started in 1985 and continued through the following year. During construction, much debris was deposited onto the slopes above the lake, into which water, mixed with cement or lime, flowed directly. Some earth–works were carried out on the slopes. Because of these activities, biota in the lake were severely affected for a short period (low diversity indices, high LOI values, lack of cladoceran remains). Afsituacija nekoliko izboljševati, kar kaže povečevanje ostankov osebkov vodnih bolh ter rahlo znižanje vsebnosti organske snovi (LOI).

**Primerjava ostankov kremenastih alg in vodnih bolh danes in v predindustrijski dobi**

V vsakem od trinajstih jezer smo primerjali ostanke življa v površinski plasti ter tisti na globini 15 cm. V vseh jezerih skupaj smo našli ostanke 16 vrst vodnih bolh in v večini primerov smo našli ostanke istih vrst v obeh plasteh. Izjema sta bili le obe jezeri v Dvojnem jezeru, kjer so v predindustrijski plasti (globina 15 cm) ostanki osebkov vrste *Acroperus harpae*, ki jih ni v površinski plasti. Podobno je tudi v Jezeru na Planini pri Jezeru, kjer smo našli ostanki vrste *Pleuroxus aduncus* le v predindustrijski plasti. V Dupeljskem jezeru so bili ostanki osebkov vrste *Simocephalus vetulus* le v površinski plasti, ne pa tudi v starejših. Ostanki osebkov obeh vrst pa so bili v obeh primerih zelo redki. Število vrst, katerih ostanke smo našli v posameznih jezerih, je bilo od ene (Rjavo jezero) pa vse do desetih (Jezero na Planini pri Jezeru), vendar je bilo normalno število med dvema in petimi vrstami. Najpogostejši so bili ostanki osebkov vrst *Chydorus sphaericus, Alona affinis* in *Daphnia longispina* oz. *D. pulicaria*.

Število ostankov v obeh plasteh (izraženo kot število ostankov na g $DW^{-1}$; upoštevani so bili le najbolj pogosti telesni deli – običajno koši) je močno nihalo – od nekaj do nekaj 10.000 ostankov ali celo več (preglednica 1). Najbolj številni so bili ostanki osebkov vrste *C. sphaericus* (26.500 ostankov g $DW^{-1}$ v Zgornjem Kriškem jezeru; 17.000 ostankov g $DW^{-1}$ v Rjavem jezeru in 12.000 ostankov g $DW^{-1}$ v Dupeljskem jezeru). Sledili so ostanki osebkov vrste *Eubosmina longispina* (12.000 ostankov g $DW^{-1}$ v Jezeru na Planini pri Jezeru), osebkov vrste *A. harpae* (8800 ostankov g $DW^{-1}$ v Črnem jezeru) in vrste *A. affinis* (8600 ostankov g $DW^{-1}$ v Spodnjem Kriškem jezeru) (preglednica 1).

Od skupno 54 parov taksonov (površina sedimenta: globina 15 cm, 13 jezer) so bili v 20 parih ostanki bolj pogosti v spodnjih plasteh sedimenta. V treh jezerih so bili ostanki 13 parov (od skupno 19) bolj pogosti v spodnjih plasteh (v Jezeru na Planini pri Jezeru 6 od 10; v Črnem jezeru 3 od 5 in v Dvojnem (Šestem) jezeru 4 od 4). To kaže, da so bile populacije vodnih bolh v preteklosti bolj pogoste kot sedaj. Za Dvojno jezero in Jezero na Planini pri Jezeru potrjujejo to hipotezo tudi drugi podatki pridobljeni iz analiz celotnega jedra ter več-

ter that time (depth from 3.5 cm upward), the situation recovered, as indicated by increased numbers of cladoceran remains and a slight drop of LOI.

**Remains of diatoms and Cladocera from the top of the sediment vs. those from a depth of 15 cm**

From each of the 13 lakes, the top of the sediment was compared with that from a depth of 15 cm. Remains of 16 Cladocera taxa were identified in the sediments and, in most of the lakes, the same Cladocera species were found in both layers. The exceptions are the two lakes of Dvojno jezero, where the supposed pre–industrial sediment (depth of 15 cm) contains remains of *Acroperus harpae*, not found in recent samples. The same situation is found in Jezero na Planini pri Jezeru, where remains of *Pleuroxus aduncus* were found in pre–industrial samples. In Dupeljsko jezero, remains of *Simocephalus vetulus* were found in recent layers, but not in old ones. Remains of both *P. aduncus* and *S. vetulus* were found in very low numbers. The number of species found in a particular lake varied from one (Rjavo jezero) to up to ten (Jezero na Planini pri Jezeru) but, on average, there were two to five. The most common taxa in the sediment were *Chydorus sphaericus, Alona affinis* and *Daphnia longispina* or *D. pulicaria*.

The number of remains in the two layers, expressed as the number of remains g $DW^{-1}$ – only the most abundant body part of Cladocera , normally the valves – varied considerably – from a few to about 10,000 remains and even more. The most numerous were remains of *C. sphaericus* (26,500 remains g $DW^{-1}$ in Zgornje Kriško jezero; 17,000 remains g $DW^{-1}$ in Rjavo jezero and 12,000 remains g $DW^{-1}$ in Dupeljsko jezero), of *Eubosmina longispina* (12,000 remains g $DW^{-1}$ in Jezero na Planini pri Jezeru), of *A. harpae* (8800 remains g $DW^{-1}$ in Črno jezero) and of *A. affinis* (8600 remains g $DW^{-1}$ in Spodnje Kriško jezero) (Table 1).

Out of 54 pairs of taxa, determined at the top of the sediment and at a depth of 15 cm in 13 lakes, remains were more numerous in lower part of the core for 20 pairs of taxa. In three lakes, remains of 13 pairs, out of a total of 19, were more common in the lower part (in Jezero na Planini pri Jezeru 6 out of 10; in Črno jezero 3 out of 5 and Dvojno jezero (southern basin) 4 out of 4). This suggests that populations of Cladocera were more numerous in the past than at the present day. For Dvojno jezero and Jezero na Planini pri Jezeru some additional infor-

| Jezero / Lake | Globina / Depth [cm] | *Acroperus harpae* | *Alona affinis* | *Alona costata* | *Alona quadrangula* | *Alona rectangular* | *Alonella excisa* | *Alonella nana* | *Chydorus piger* | *Chydorus sphaericus* | *Daphnia longispina* | *Daphnia pulicaria* | *Eubosmina longispina* | *Graptoleberis testudinaria* | *Pleuroxus aduncus* | *Simocephalus vetulus* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rjavo jezero | 0 | | | | | | | | | 370 | | | | | | |
| | 15 | | | | | | | | | 440 | | | | | | |
| Zeleno jezero | 0 | 1400 | 6000 | | | | 5300 | | | 17 | 70 | | | | | |
| | 15 | 80 | 2100 | | | | 1100 | | | 7800 | 210 | | | | | |
| Jezero v Ledvicah | 0 | | 5400 | | 80 | | | | | 3600 | 380 | | | | | |
| | 15 | | 1100 | | 63 | | | | | 4200 | 100 | | | | | |
| Dvojno (5.) jezero | 0 | | 240 | | 970 | | | | | 3200 | | | | | | |
| | 15 | 40 | 70 | | | | | | | 1600 | | | | | | |
| Dvojno (6.) jezero | 0 | | 1000 | | 480 | | | | | 2600 | | | | | | |
| | 15 | 100 | 1400 | | 340 | | | | | 6800 | | | | | | |
| Črno jezero | 0 | 5300 | 300 | | | | | | | 2800 | 480 | | | | | |
| | 15 | 8800 | 280 | | 80 | | | | | 1100 | 520 | | | | | |
| Jezero na Planini pri Jezeru | 0 | 230 | 150 | 1200 | | | | 770 | 230 | 1600 | 1000 | | 12 | 460 | | |
| | 15 | 2200 | 200 | 680 | | | | 550 | 550 | 5000 | 1400 | | 6500 | 70 | 340 | |
| Zgornje Kriško jezero | 0 | | | | | | | | | 27 | | 650 | | | | |
| | 15 | | | | | | | | | 18 | | 840 | | | | |
| Srednje Kriško jezero | 0 | | 5000 | | | | | | | 10 | | 310 | | | | |
| | 15 | | 4000 | | | | | | | 3300 | | 80 | | | | |
| Spodnje Kriško jezero | 0 | | 8600 | | | | | | | 1200 | 420 | | | | | |
| | 15 | | 1600 | | | | | | | 10 | 110 | | | | | |
| Krnsko jezero | 0 | 470 | 40 | | | 470 | 820 | | | 1400 | | | | | | |
| | 15 | 200 | 50 | | | 40 | 30 | | | 150 | | | | | | |
| Dupeljsko jezero | 0 | 7500 | 160 | | | 320 | | 400 | | 12 | | | | | | 40 |
| | 15 | 380 | 90 | | | | | 40 | | 1400 | | | | | | |
| Jezero v Lužnici | 0 | 3500 | | | | | | | | 6700 | | | | | | |
| | 15 | 2100 | | | | | | | | 9200 | | | | | | |

Preglednica 1: Ostanki vodnih bolh (število ostankov na gram suhe mase) v površinski plasti sedimenta in v globini 15 cm iz 13 jezer Julijskih Alp (Slovenija). V preglednici so upoštevani samo najbolj pogosti ostanki za vsako vrsto.
*Table 1: Cladocera remains (number of remains per one gram of dry weight) in the surface of the sediment and from the depth of 15 cm of 13 lakes from the Julian Alps (Slovenia). Only the most abundant part of each taxon is indicated in the table.*

letna redna vzorčenja bentosa in planktona. Te spremembe so posledica človekove dejavnosti, še zlasti vnosa rib v jezera.

V preostalih 10 jezerih nakazuje visoko število ostankov vodnih bolh v površinski plasti rahlo evtrofikacijo jezer, kar je verjetno povezano tudi z nekoliko povišano temperaturo zraka oz. vode. Nekaj razlik oz. napak v številu ostankov lahko izvi-

mation, obtained from whole core analyses or long term sampling of benthos and plankton, confirms this suggestion. These changes were induced by human activities, predominantly by the introduction of fish to the lakes.

In the remaining 10 lakes, the higher number of Cladocera remains in the upper part of the sediment core indicates slight eutrophication, probara tudi iz same tehnike vzorčenja, saj so zgornji deli sedimenta manj mineralizirani in je zato specifična masa manjša, kar je rezultat večje količine organske snovi na gram suhe snovi.

Lupinice 102 vrst kremenastih alg smo našli v trinajstih jezerih v zgornji in spodnji plasti sedimenta. V sedmih jezerih je bilo v površinski plasti več ostankov kremenastih alg kot v plasteh pod 15 cm globine (preglednica 2). Vrstna sestava in pogostost osebkov posameznih vrst sta bili zelo različni od jezera do jezera. Dvanajst vrst lahko označimo kot dominantne ali sodominantne v zgornjih in/ali spodnjih plasteh trinajstih jezer (t. j. 26 vzorcev), le ostanki štirih vrst pa so prisotni v več kot petih vzorcih (*Achnanthes minutissima* – 10 vzorcev, *Fragilaria pinnata* – 9, *Fragilaria construens venter* – 7 in *Denticula tenuis* – 6). Preostalih osem taksonov je prevladujočih (ali vsaj sodominantnih) v treh ali manj vzorcih (preglednica 3). To kaže na veliko raznolikost jezer glede ekoloških pogojev tako v preteklosti kot tudi danes.

V obeh plasteh v Rjavem jezeru predstavljajo lupinice podvrste *Fragilaria construens venter* več kot

bly induced by the slight temperature rise. Some error originates from the sampling technique, because the upper part of the sediment is less mineralised and the specific weight is thus lower, resulting in more organic material per gram of DW.

Remains of 102 diatom species were found in the top and lower layers of sediments in 13 lakes. In seven lakes, the top layers of sediments contain more diatom remains than layers deeper than 15 cm (Table 2). Species composition and abundance is very different from one lake to another. Twelve diatom taxa were designated as dominant or co-dominant taxa in top and/or bottom sections of 13 lakes (i.e. 26 samples), but only four of them appear in more than five samples (*Achnanthes minutissima* – 10 samples, *Fragilaria pinnata* – 9, *Fragilaria construens venter* – 7 and *Denticula tenuis* – 6). The remaining eight taxa were dominant (or co-dominant) in three or less samples (Table 3). This reflects a high diversity among the lakes reflecting ecological parameters in the past and present.

In both layers in Rjavo jezero, *Fragilaria construens venter* constitute more than 80 % of the valves

| Jezero Lake | Skupno število taksonov Total No. of taxa | Zgornja plast Top layer | | Globina 15 cm Depth of 15 cm | |
|---|---|---|---|---|---|
| | | Število lupinic No. of valves [µg WW] | Število taksonov No. of taxa | Število lupinic No. of valves [µg WW] | Število taksonov No. of taxa |
| Rjavo jezero | 25 | 66.0 | 24 | 28.1 | 21 |
| Zeleno jezero | 31 | 19.1 | 23 | 2.8 | 17 |
| Jezero v Ledvicah | 49 | 46.5 | 37 | 12.9 | 45 |
| Dvojno (Peto) jezero | 42 | 40.8 | 41 | 44.2 | 25 |
| Dvojno (Šesto) jezero | 46 | 20.2 | 44 | 0.1 | 7 |
| Črno jezero | 30 | 41.2 | 29 | 62.1 | 24 |
| Jezero na Planini pri Jezeru | 52 | 56.2 | 45 | 61.4 | 40 |
| Krnsko jezero | 46 | 262.9 | 43 | 20.8 | 35 |
| Dupeljsko jezero | 42 | 60.5 | 35 | 42.1 | 31 |
| Jezero v Lužnici | 38 | 188.3 | 37 | 219.2 | 36 |
| Zgornje Kriško jezero | 31 | 64.5 | 29 | 100.9 | 30 |
| Srednje Kriško jezero | 34 | 38.9 | 33 | 39.4 | 31 |
| Spodnje Kriško jezero | 35 | 38.0 | 34 | 29.1 | 25 |

Preglednica 2: Ostanki kremenastih alg v površinski plasti sedimenta in v globini 15 cm iz 13 jezer Julijskih Alp (Slovenija). 2. kolona: skupno število vrst v obeh plasteh; 3. in 5. kolona: število lupinic v površinski oz. globinski plasti; 4. in 6. kolona: število vrst, najdenih v posamezni plasti, (ww = sveža masa)

*Table 2: Diatom remains in the surface of the sediment and from the depth of 15 cm of 13 lakes from the Julian Alps (Slovenia). 2nd column: total number of taxa recorded in both layers of particular lake; 3rd & 5th column: number of valves in the top and bottom layer respectively; 4th & 6th column: total number of taxa found in particular layer. Dvojno (5.) jezero: Dvojno jezero (the north basin); Dvojno (6.) jezero: Dvojno jezero (the south basin) (ww = wet weight)*

Preglednica 3: Dvanajst najpogostejših taksonov kremenastih alg (od skupno 102 taksonov) v površinski plasti sedimenta in/ali v globini 15 cm v trinajstih jezerih Triglavskega narodnega parka (Slovenija). Številka označuje frekvenco pojavljanja v vzorcih sedimenta (maximum: 26).

*Table 3: Twelve of the most abundant diatom taxa (out of 102) in the top of the sediment and/or at the depth of 15 cm of 13 lakes from Triglav National Park (Slovenia). Number indicates frequency of appearance in the sediment (maximum: 26).*

| | Frekvenca pojavljanja Frequency of appearance |
|---|---|
| *Achnanthes minutissima* | 10 |
| *Fragilaria pinnata* | 9 |
| *Fragilaria construens venter* | 7 |
| *Denticula tenuis* | 6 |
| *Amphora libyca* | 3 |
| *Navicula cryptotenella* | 3 |
| *Cyclotella radiosa* | 2 |
| *Fragilaria construens construens* | 2 |
| *Stephanodiscus parvus* | 2 |
| *Cymbella caespitosa* | 1 |
| *Fragilaria nanana* | 1 |
| *Navicula disjuncta* | 1 |

80 % ostankov. V Zelenem jezeru lupinice vrste *Denticula tenuis* predstavljajo okoli polovico ostankov v površinski plasti in lupinice podvrste *F. construens venter* 58 % v spodnji plasti. Lupinice vrst *D. tenuis* (34 %) in *Navicula disjuncta* (23 %) so prevladujoče v površinski plasti, medtem ko so lupinice vrst *Amphora libyca* (28 %) in *Fragilaria pinnata* (23 %) prevladujoče v spodnji plasti v Jezeru v Ledvicah. V obeh jezerih Dvojnega jezera prevladujejo lupinice vrste *F. pinnata* v obeh plasteh (na površini 36 % v Petem jezeru in 26 % v Šestem jezeru, medtem ko je v spodnji plasti Petega jezera delež te vrste 54 %). Na površini sedimenta se pojavlja skupaj z vrsto *Achnanthes minutissima* (26 % in 27 %). V globlji plasti sedimenta v Šestem jezeru so ostanki le sedmih vrst kremenastih alg, in še to v zelo nizkih koncentracijah (0,1 valve μg $ww^{-1}$). V Črnem jezeru prevladujejo lupinice vrst *D. tenuis* (35 %) in *Amphora libyca* (20 %) na površini, medtem ko so lupinice vrst *F. pinnata* (62 %) in *F. construens venter* (20 %) pogoste v globlji plasti. V Jezeru na Planini pri Jezeru so ostanki celic treh vrste dominantni v obeh plasteh sedimenta (*F. pinnata* – 33 % na površini, 17 % v globini), *Stephanodiscus parvus* (18 % oz. 30 %) in *F. construens construens* (14 % v obeh primerih). V Krnskem jezeru so najpogostejše lupinice vrste *Cyclotella radiosa* v obeh plasteh (48 % oz. 27 %), ki se jim na površini pridružijo še lupinice vrste *Fragilaria nanana* (21 %) in vrst *A. minutissima* (15 %) ter *Navicula cryptotenella* (14 %) v globlji plasti. Podobno je tudi v Dupeljskem jezeru, kjer so lupinice vrste *F. pinnata* (57 %) dominantne na površini, medtem ko so vrste *A. minutissima* (28 %), *N. cryptotenella* (11 %) in *Cymbella caespitosa* (10 %) sodominantne v globlji plasti. Precej bolj monotone so razmere v Jezeru v Lužnici, kjer je vrsta *F. construens venter* (30 % oz. 53 %) dominantna v obeh plasteh, a se ji na površini pridruži še vrsta *D. tenuis*

present. In Zeleno jezero *Denticula tenuis* form half of the diatom remains in the top layer and *F. construens venter* 58 % in the deeper layer. *D. tenuis* (34 %) and *Navicula disjuncta* (23 %) dominate in the top layer, *Amphora libyca* (28 %) and *Fragilaria pinnata* (23 %) in the deeper layer in Jezero v Ledvicah. In both basins of Dvojno jezero, *F. pinnata* is the main species in both layers (on the top 36 % in the north basin and 26 % in the south basin, and 54 % in the deeper layer of the north basin). At the sediment surface, it is accompanied by *Achnanthes minutissima* (26 % and 27 %). The deeper layer of the south basin contains just seven species in very low abundance (0.1 valve $\mu g^{-1}$ wet weight). In Črno jezero *D. tenuis* (35 %) and *Amphora libyca* (20 %) dominate on the top and *F. pinnata* (62 %) and *F. construens venter* (20 %) in the deeper layer. In Jezero na Planini pri Jezeru three species dominate in both layers of the sediment (*F. pinnata* – 33 % at top, 17 % at the bottom), *Stephanodiscus parvus* (18 % and 30 %) and *F. construens construens* (14 % both). In Krnsko jezero *Cyclotella radiosa* is the main species in both layers (48 % and 27 % respectively), accompanied by *Fragilaria nanna* (21 %) in the top layer and by *A. minutissima* (15 %) and *Navicula cryptotenella* (14 %) in the deeper layer. A similar situation was recorded in Dupeljsko jezero, where *F. pinnata* is the main species in the top layer (57 %) and *A. minutissima* (28 %), *N. cryptotenella* (11 %) and *Cymbella caespitosa* (10 %) are dominant in the deeper layer. There is a less diversified situation in Jezero v Lužnici, where *F. construens venter* is

(35 %). V Zgornjem Kriškem jezeru prevladujejo ostanki vrste *A. minutissima* v obeh plasteh (49 % oz. 56 %). Ista vrsta prevladuje tudi na površini sedimenata v Srednjem Kriškem jezeru (51 %), medtem ko so v spodnji plasti pogoste lupinice kar štirih taksonov: *F. pinnata* (28 %), *A. minutissima* (19 %), *F. construens venter* (19 %) in *Amphora libyca* (14 %). V Spodnjem Kriškem jezeru so na površini sedimenta pogoste lupinice vrst *N. cryptotenella* (29 %), *D. tenuis* (25 %) in *A. minutissima* (20 %). Slednji dve sta s 15-odstotnim oz. 45-odstotnim deležem lupinic tudi najpogostejši vrsti v spodnji plasti sedimenta.

## ZAKLJUČKI

V jezerih Julijskih Alp so štiri skupine organizmov, katerih ostanki so v sedimentu dovolj dobro ohranjeni in tudi dovolj številčni, da omogočajo razlago dogajanj v preteklosti. Med algami so to kremenaste alge (Bacyllariophita) in njihove sorodnice rumene alge (Chrysophyceae), med živalmi pa vodne bolhe (Cladocera) in ličinke trzač (Chironomidae).

Število vrst, ki smo jih za obdobje zadnjih nekaj stoletij ugotovili za omenjene skupine po njihovih ostankih v sedimentu, je podobno kot v vzorcih flore in favne, pobranih v zadnjih letih. Le malo je vrst, ki bi iz posameznih jezer popolnoma izginile ali se vanje nanovo naselile. Se pa od plasti do plasti močno spreminja število ostankov posameznih vrst, kar kaže na velike spremembe, ki so jih doživela jezera.

Na podlagi podrobnejših analiz vzorcev sedimenta iz štirih jezer, ki časovno segajo od 40 do približno 600 let v preteklost, lahko ugotovimo tri sklope dejavnikov, ki so vplivali na dogajanja in življenje v jezerih. Močna potresna aktivnost v Julijskih Alpah je povzročala občasne motnje, ki so se odražale predvsem v začasnem povečanem vnosu hranil v vodni stolpec. To se je dogajalo bodisi s prožitvijo posameznih plazov s pobočij nad jezeri ali pa s premeščanjem grušča in sedimenta v samih jezerih. V obeh primerih je prišlo do premešanja sedimenta in s tem vračanja hranil v vodni stolpec. Posledica je bila začasna povečana rast nekaterih vrst alg, vpliv na živalstvo pa je bil manjši. Večji vpliv na favno in floro ima splošno naraščanje temperature, kar se odraža v povečanem številu ostankov nekaterih toploljubnih organizmov v zgornjih plasteh sedimenta.

Daleč največji vpliv na jezera pa je že v prete-

dominant in both layers (30 % and 53 %) but accompanied by *D. tenuis* (35 %) in the top layer. In Zgornje Kriško jezero *A. minutissima* prevails in both layers (49 % and 56 % respectively). The top layer in Srednje Kriško jezero is dominated by the same species (51 %) while in the deeper layer the main part represent four species: *F. pinnata* (28 %), *A. minutissima* (19 %), *F. construens venter* (19 %) and *Amphora libyca* (14 %). In Spodnje Kriško jezero *N. cryptotenella* (29 %), *D. tenuis* (25 %) and *A. minutissima* (20 %) prevail in the top layer. The last two species with 15 % and 45 % respectively make up the main part of the deeper layer.

## CONCLUSIONS

In the lakes of the Julian Alps there are four groups of organism, whiche produce remains that are well preserved in the sediment and numerous enough to be used for reconstruction of the lakes' history. Diatoms (Bacyllariophyta) and their relatives, chrysophyta (Chrysophyceae) are the groups among the algae, and cladocerans (Cladocera) and mosquito–like midge larvae (Chironomidae) among the animals.

The number of species, identified from the remains of the above mentioned groups from the sediment for the last few centuries, is similar to the number of species from flora and fauna collected in the same lakes in the last decade. Only a few species have completely disappeared from the lakes or colonized them. On the other hand, the number of the remains of a particular species can oscillate significantly from one layer of sediment to another. This indicates that the lakes experienced big changes in the past.

Based on the results of detailed analyses of the sediment from four lakes, covering a time span from 40 to about 600 years from the present, we identify some of these influences. Strong earthquakes in the Julian Alps induced some events, resulting in increased concentration of nutrients in the water column of the lakes. This resulted either by slumps from the slopes above the lakes or of internal replacement of gravel and sediment within the lakes. In both cases, there was intensive re-suspension of the sediment, and nutrients were released back to the water column. Increased concentrations of nutrients promoted temporary increase in the growth of algae, whilst fauna were less affected. Bigger effects on flora and fauna were realised by an overall increaseof temperature. This is reflected in an inklosti imel človek. Začelo se je že v prejšnjih stoletjih, ko je z izsekavanjem gozda pospešil erozijo. To je po eni strani povzročilo hitrejši prirast sedimenta, po drugi strani pa se je v jezera povečal vnos hranil za alge, kar je vodilo do sprememb v razmerju med posameznimi vrstami. Daleč največji vpliv na dogajanja v jezerih pa ima naseljevanje rib v visokogorska jezera v zadnjih desetetjih, kar povzroča velike spremembe tako v flori in favni, kot tudi v kvaliteti vode.

creased number of the remains of thermophilic organisms in the top layer of the sediment.

Even in the past, human activities have had bigt influence on the lakes. Anthropogenic impacts started a few centuries ago, when clearing–cutings the forest accelerated erosion. A consequence was increase amount of sediment accumulationg in the lakes. Another effect of erosion was an the increased amount of nutrients available for algae, resulting in a changed ratios between some species. Introduction of fish in some high–mountain lakes in the last decades induced big changes in fauna and flora as well as in water quality.

# *Poglavje* 13 *Chapter*

# *Človekov vpliv na območju Triglavskega narodnega parka*

# *Human Impacts in the Area of Triglav National Park*

Irena REJEC BRANCELJ* & Aleš SMREKAR*

## UVOD

Obravnavano območje se nahaja v severozahodnem delu Slovenije, v regiji, ki jo imenujemo Julijske Alpe in obsega 154.200 ha. Osrednji del s 83.807 ha je bil v sedanjem obsegu leta 1981 zavarovan kot Triglavski narodni park (TNP). Zanj je značilna velika reliefna razgibanost, ki jo stopnjujejo višinske razlike, saj sega od nadmorske višine 180 m pri koritih Tolminke do najvišjega vrha države, Triglava, na višini 2864 m. Večji del površja je sestavljen iz karbonatnih kamnin, med katerimi prevladuje apnenec. Tektonski premiki, ledeniško preoblikovanje in močno zakrasevanje so bili na tem območju pomembni geomorfološki procesi. Če bi imele ledeniško-kraške kotanje nepropustno podlago, bi bilo na tem območju še več visokogorskih jezer. Takšno podlago dajejo le jurski ali kredni laporji in peščenjaki v Dolini Triglavskih jezer in na območju Krna ter zbito morensko gradivo na Kriških podih in na planini Jezero (Kunaver, 1998). Na obravnavanem območju je 14 visokogorskih jezer in rezultati raziskovanj v zadnjem desetletju so pokazali, da so nekatera od njih podvržena evtrofizaciji. Analize sedimentov so opozorile na to, da je pomemben preoblikovalec tega območja tudi človek (Brancelj in sod., 2000).

V preteklosti so na obravnavanem območju imeli največjo gospodarsko vlogo fužinarstvo, planšarstvo in gozdarstvo. Z njimi so bili povezani tudi človekovi vplivi. V drugi polovici 20. stoletja so se jim pridružili še vplivi zaradi turizma in rekreacije: zlasti planinski domovi, počitniške hiše, smučišča in omrežje prometnic. Posegi, ki jih vse te dejav-

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## INTRODUCTION

The area discussed lies in the north-west part of Slovenia, i.e. in the Julian Alps region, which extends over 154,200 hectares. In 1981, the central part of the Julian Alps, 83,807 hectares was protected as the Triglav National Park (hereafter: the TNP). It is renowned for its great diversity of landforms and large vertical range, from the lowest altitude of 180 m at canyon of River Tolminka to Mt. Triglav which is the highest peak in Slovenia at 2864 m. The major part of the area consists of carbonate rocks among which limestone prevails. Tectonic shifts, glacial transformation and intense karstification were important geomorphological processes here. Were the bedrock of the glacial-karstic basins impermeable, high-mountain lakes in this area would be even more numerous. Suitable bedrock only occurs in the Triglav Lakes Valley (Dolina Triglavskih Jezer) and in the area of Mt. Krn, with its Jurassic and Cretacious marls and sandstones, and on the Kriški Podi plateau and the Planina Jezero alp where consolidated moraine material predominates (Kunaver, 1998). There are 14 high-mountain lakes in the studied area, and the results of the research performed in the past decade show that some of them are subject to eutrophication. The analyses of the sediments prove that the human factor is an important transforming agent in this area (Brancelj *et al.*, 2000).

In the past, forges, alpine dairy farming and forestry were of the greatest economic importance in the area which, naturally, were responsible for

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nosti prinašajo s seboj, so kljub varovanju območja narodnega parka ogrozili tudi visokogorska jezera.

human environmental impacts. In the second half of the 20th century, the impacts increased because of developing tourism and recreation, especially the alpine huts, vacation houses, ski fields and transport infrastructure. In spite of protective measures undertaken in the TNP, certain interventions connected with these activities have also endangered some high-mountain lakes.

Planinske koče so točke, kamor vodijo poti skoraj vseh obiskovalcev gora. Posledica je velika obremenitev okolja, vključno z jezeri. Na sliki je koča na Planini pri Jezeru. (Foto: Anton Brancelj)
*Alpine huts are the meeting points for the most visitors to the mountains. They constitute an intensive pressure on the environment, including the lakes. On the photograph is the hut on Planina pri Jezeru. (Photo: Anton Brancelj)*

## METODE

V proučevanje smo vključili kombinacijo raziskovalnih analiz obstoječih podatkovnih baz (1996 – podatki PZS; 2000 a – podatki TNP; 2000 b – podatki IG), analiz zgodovinskih kart (2000 b – podatki IG) in virov (Melik, 1950; Novak, 1970; Valenčič, 1979), statističnih analiz in geografskih analiz, ki so vključevale geografske informacijske sisteme (GIS). Zgodovinski viri in karte so bili uporabljeni za razumevanje dogajanj in sprememb na obravnavanem območju, povezanih zlasti s planinskim pašništvom, fužinarstvom in gozdarstvom. Na osnovi omenjenih virov smo pripravili več slojev za geografski informacijski sistem obravnavanega območja: relief, hidro-

## METHODS

The investigation combined research analyses of the existing data bases (1996 - Data of PZS; 2000 a - Data of TNP; 2000 b - Data of IG), analyses of historical maps (2000 b - Data of IG) and sources (Melik, 1950; Novak, 1970; Valenčič, 1979), and GIS (including statistical and geographical analyses). Historical sources and maps were used to enable better understanding of processes and changes related, in particular, to the alpine pasturing, forges and forestry in the area discussed. From the abovementioned sources, several layers were made for the GIS within the study area: landforms, hydrographical network, lakes, locations of forges, locations of grafsko mrežo, jezera, lokacijo fužin, lokacijo planin (s številom GVŽ), lokacijo planinskih postojank (s podatki o nadmorski višini, starosti, oskrbi, obiskanosti) in cestno mrežo (s kategorijami in frekvenco). S tem smo si zagotovili tudi primerljivost posameznih dejavnosti. Prekrivanje posameznih slojev smo uporabili tudi za ugotavljanje območij največjih vplivov človekovih dejavnosti na tem območju. S kombinacijo metod smo identificirali značilne pokrajinske poteze, zgodovinske spremembe pokrajine ter spremembe v zemljiški rabi in ta spoznanja povezali z rezultati analiz sedimentov v visokogorskih jezerih (Brancelj, 1999 a; Brancelj in sod., 2000).

## ČLOVEKOVE DEJAVNOSTI DO SREDE 16. STOLETJA

Navzočnost človeka na tem območju sega v obdobje prazgodovine, saj so najdbe potrdile njegovo prisotnost že pred 7000 leti. Pri Dvojnem jezeru v Dolini Triglavskih jezer (1650 m n. v.) so našli srednjekamenodobno postajo z ostanki preprostega kamnitega orodja. Pelodne analize so pokazale, da je v času te poselitve pokrival dolino bujen mešani gozd z brestom, hrastom, bukvijo in lipo. Ni še docela pojasnjeno, kaj je vodilo tedanjega človeka tako visoko v gore. Razlage, ki jih dopolnjujejo še druge najdbe, kažejo bolj na sezonsko naselitev tega območja kot zgolj na obisk gora, npr. zaradi rudarjenja.

Fužinarstvo je tod obstajalo skoraj 2500 let. O antičnem železarstvu je precej materialnih dokazov. V prvotnem obsegu, za domačo rabo, se je pojavilo že 600 let pr. n. š. Razvilo se je na območju t. i. gozdnega železa, ki se je nabiralo v globelih po hribih (npr. Rudno polje). Pri primitivnih vetrnih pečeh so v dobi kmečkega železarstva izkoriščali naravni vlek, npr. termične vetrove na gorskih pobočjih. S tehničnim napredkom pa se je fužinarstvo od rudnih nahajališč v hribih selilo v doline k rekam in potokom. Na obravnavanem območju Triglavskega narodnega parka sta nastali dve fužini: Trenta in Stara Fužina.

Kmetijstvo, kot osnovna dejavnost prebivalcev v teh krajih, je bilo povezano s planinskim pašništvom, sezonsko živinorejo v hribovitem in gorskem območju od junija do septembra. Z razvojem planinskega gospodarjenja skozi stoletja je človek v največji možni meri izkoristil naravno okolje. Povezal je pičla ravna dolinska območja, skrčil gozdove za ureditev travnih in pašnih površin na gorskih pobočjih in planotah ter vključil v svojo rabo tudi

alps (with livestock number in head of cattle), locations of alpine huts (with altitude above sea level, age, supply, number of visitors) and road network (with category and transport frequency), to facilitate a comparison of the activities in question. By overlaying the individual layers the strongest impacts of the human activities in these areas were established. A combination of analyses were used to identify typical landscape features, historical changes of the landscape, changes in land-use, and to relate these findings to the results of sediment analyses (Brancelj, 1999 a; Brancelj *et al.*, 2000).

## HUMAN ACTIVITIES IN THE FIRST HALF OF THE 16TH CENTURY

Human presence in this area goes back to the prehistoric period, since archeological finds testify that man was present here as early as 7000 years ago. Near the lake Dvojno Jezero (1650 m ) in the Triglav lakes Valley, a site from the mid-Stone Age was found, with the remains of simple stone tools. Pollen analyses showed that at the time of this settlement the valley had been overgrown with abundant mixed forest of elm, oak, beech and linden. The reason that encouraged people to live so high in the mountains has not been clarified yet, but the available evidence, supported also by other finds, point to seasonal settling of this area; visits to the mountains for the excavation of ore, for example.

Forges were active in this area for almost 2500 years. There is quite abundant material evidence for the antiquity of ironworks. Their original purpose was for domestic use only, and as such they date back as early as 600 B.C. They developed in the area where the so-called forest-iron accumulated in the depressions in the mountains (e.g. Rudno polje). The primitive wind-driven forges of the peasant ironworks made use of the natural ‘draw’, such as thermal winds on the mountain slopes. With technological progress, forges began to be moved from ore sites in the mountains down to the valleys, to rivers and brooks. In the TNP, two forges existed: Trenta and Stara Fužina.

Agriculture, as the basic activity of the people in these areas, was linked to alpine pasturing and livestock rearing in the highland and high-mountain areas. The adaptation of economy to the Alpine world through centuries, enabled the optimal use of the natural conditions. Rare level valley were inter-connected, forests were cleared to make way planinske pašnike nad gozdno mejo. Dolinska in višinska območja je povezal v soodvisen in gospodarsko obstojen obrat. V dolinah so bile poljedelske površine za pridelovanje hrane in zimske krme za živino. V poletnih mesecih pa so živino odgnali v planine.

Najstarejše omembe planin se omenjajo v zgodovinskih listinah iz leta 973. V oznakah severne meje škofjeloškega gospostva se navaja planina Pečana (1472 m) pod Ratitovcem na jugovzhodnem robu obravnavanega območja. Nastanek planin je bil v prvi vrsti navezan na obsežnejše ravne ploskve, ki so nudile ustrezno pašo bodisi na na vododržni ali apniški osnovi. Zaželena je bila še bližina vodnega vira, ki pa ni bila pogoj, saj so tod izviri redki in neenakomerno razporejeni. Pastirji so si pomagali s snežišči v osojah in breznih, za živino pa so si uredili tudi mlake (kale, lokve), v katerih so zbirali

for meadows and pastures on the mountain slopes and plateaus, and the alps above the upper forest line were also used. The valleys and the highland areas were connected to form an interdependent and economically stable region. Fields for the production of food and fodder for livestock were in the valleys, while in summer months the livestock were taken to the alps.

The oldest records of alps occur in historical documents of 973. As the northern border of the Škofja Loka / Bischoflack dominion, the alp of Pečana (1472 m) under Mt. Ratitovec is mentioned; it lies in the south-east margin of the study area. Alps were primarily organised on the larger flat areas where good pasturing was possible, whether on non-permeable or limestone bedrock. Proximity of water sources was also desirable, but it was not a precondition, since water sources are rare here and unevenly distributed. Herdsmen made use of snow fields on shady slopes and in chasms, and they also create pools for livestock in which rainwater accumulated. During the spells of drought, they took their livestock to even more remote areas (e.g. from the Ovčarija alp to the Triglav lakes Valley, a two-hour walk away).

From the 15th century onwards, alps were more frequently mentioned in historical documents. Alps

Planšarstvo ima v visokogorju že dolgo tradicijo, ki je pustilo sledove tudi na jezerih. Na sliki je v letu 1999 opuščen ovčarski stan pri Krnskem jezeru. (Foto: Anton Brancelj)
*Alpine dairy farming has a long tradition and has left some effects on high-mountain lakes. On the photo is the shelter for sheep near Krnsko jezero abandoned in 1999. (Photo: Anton Brancelj)*

deževnico. Ob suši so gonili živino tudi na bolj oddaljene izvire (npr. s planine Ovčarija v dve uri hoda oddaljeno Dolino Triglavskih jezer). Od 15. stoletja so omembe planin v zgodovinskih listinah pogostejše. Najvišje planine so pripadale najstarejšim vasem v dolini. Nastale so ob zgornji gozdni meji. Posamezne vasi so običajno pasle v najbližjih in najlažje dostopnih planinah. Vendar so bile tudi izjeme, ko so posamezne planine menjavale svoje gospodarje (Melik, 1950).

Poletna pastirska naselja so kmetje postavljali ob zgornji gozdni meji, še v območju gozdnega drevja. Na obravnavanem območju imamo zelo malo krajevnih imen, ki bi pričala o krčenju gozda (Goreljek, Laz, Rut, Čretež, Četež). To je lahko posledica zgodnjega razmaha planšarstva, saj je bilo v srednjem veku sirarstvo tod že zelo razširjeno.

Krčenje drevja in grmovja na višje ležečih delih planin, npr. Ovčarije in Dednega polja, je potisnilo naravno mejo navzdol. Zgornja gozdna meja je pogojena s podnebjem (zlasti zračnimi temperaturami), reliefom in ekspozicijo, nanjo pa je vplival tudi človek (npr. nad Ovčarijo in Dednim poljem). Sedanja gozdna meja poteka nad Dolino Triglavskih jezer okoli 1700 m, najvišje pa 1880 m. Da gre za antropogeni vpliv, nam pokažejo višine dreves in povprečne dolžine terminalnih prirastkov (Lovrenčak, 1987). Če ne bi bilo človekovega vpliva, bi bila na severozahodnih pobočjih nad Dolino Triglavskih jezer meja gozda v višini okoli 1900 m. Na gozdni meji od dreves izrazito prevladuje macesen, le redko se pojavlja smreka.

Na nižjih planinah se je pasla goveja živina in konji, na višjih, skalnatih, pa drobnica, še zlasti ovce. Vzdrževanje planin je sililo kmete, da so kolektivno gospodarili in si delili pravice in bremena. Poleg skupnih pašnikov so imele nekatere vaške skupnosti pravico do paše v gozdovih. Zaradi tega so se med planšarji in fužinarji tudi razmeroma zgodaj pokazala trenja zaradi izkoriščanja gozdov.

Planino Jezera (v nadmorski višini okoli 1600 m), v bližini današnje planinske koče pri Sedmerih jezerih, južno od Dvojnega jezera, so na prehodu iz 15. v 16. stoletje vzeli bohinjskim kmetom in jo dodelili pastirjem z zahodnega roba obravnavanega območja, s Tolminskega in iz Čedada (Italija). Ti so prignali živino na pašo čez Komno, tako kot kasneje pastirji iz doline Soče. To je povzročilo prepire in spopade, ki se za bohinjske kmete niso dobro končali, saj so izgubili še drugo planino. V istem viru (okoli leta 1500) je navedeno, da je bila planina Jezera dolgo zapuščena in da so jo šele tolminski pastirji spet obnovili (Melik, 1950).

at the highest altitudes belonged to the oldest villages in the valley, and they were located at the upper forest line. Livestock from individual villages usually grazed on the nearest and most easily accessible alps. However, there were also exceptions, when the ownership of individual alps changed (Melik, 1950).

Summer settlements of herdsmen were set up at the upper forest line, still within the forest zone. Only a few topographic names testify to the clearing of woods in the area discussed (i.e. Goreljek, Laz, Rut, Čretež, Četež), which can be ascribed to the early development of alpine pasturing, since cheese-making was already a widespread practise in the Middle Ages.

The felling of trees and clearing of bushes on the alps at higher altitudes, such as Ovčarija and Dedno Polje, moved the effective forest line downwards. The present forest line runs above the Triglav lakes Valley at an altitude of about 1700 m and reaches its highest point at 1880 m. Anthropogenic influence is evident from the height of trees and average length of annual terminal increments (Lovrenčak, 1987). Were it not for the anthropogenic influence, the forest line on the north-west slopes above the Triglav lakes Valley lie at about 1900 m. At the forest line, larch dominates, and spruce occur only rarely.

Cattle and horses grazed on lower alps, while goats and especially sheep, were moved to higher, rocky alps. To maintain the alps it was necessary that the peasants practised a collective economy and shared their rights and burdens equitably. Besides sharing some pasturelands, certain village communities also had the right to pasture in the forests which incited conflicts over the exploitation of forests between the alpine dairy men and the ironworks owners.

The Planina Jezera alp (about 1650 m) in the vicinity of the present alpine hut in the Triglav lakes Valley, south of the lake Dvojno jezero, was taken from the possession of the peasants from Bohinj and allotted to the herdsmen from the western edge of the study area, i.e. the areas of Tolmin and Cividale (Italy). They brought their livestock across Komna to graze on the alps, like the herdsmen from the Soča valley did in later times. This gave rise to quarrels and fights, which did not end in favour of the peasants from Bohinj, because they eventually lost another alp. At around 1500 same source stated that the Planina Jezero alp had long been abandoned and it was only the herdsmen from the Tolmin area who restored it to life (Melik, 1950).

## ČLOVEKOVE DEJAVNOSTI DO KONCA 19. STOLETJA

V obdobju od 14. do 16. stoletja se je pridobivanje in predelovanje kovin razvilo v močno podjetniško dejavnost. V 16. stol. se je zaradi večjega povpraševanja povečala proizvodnja v tradicionalnih in novih fužinah. Na obrobju obravnavanega območja jih je nastalo šest: Mojstrana, Plavž (leta 1538), Sava, Radovna, Bohinjska Bistrica (leta 1540) in Pozabljeno (leta 1562) (Šmitek, 1989). Domačim fužinarjem so se tedaj pridružili še priseljenci iz Furlanije (Italija), ki so prinesli nove, uspešnejše metode dela in zmogljivejše naprave. V plavžih so uporabljali lesno oglje, ki so ga pridobivali v okoliških gozdovih. Leta 1581 je znašala letna proizvodnja železa v Stari Fužini 45 ton in v Bohinjski Bistrici, ki sicer leži že za mejami narodnega parka, 67 ton. Za 50 ton surovega železa so v 16. stol. porabili 5000 $m^3$ lesa, v začetku 19. stol. pa le še 2800 $m^3$ (Valenčič, 1979). Sredi 19. stoletja je fužinarstvo začelo pešati in konec 19. stoletja prenehalo. 1890 je bilo ustavljeno delo tudi v Bohinjski Bistrici in težišče železarstva se je preselilo na bližnje Jesenice, ki so bile še do nedavnega eno od aktivnih železarskih središč v Sloveniji.

Oglarstvo, pridobivanje lesnega oglja v gozdu, je bilo tesno povezano s fužinarstvom, zelo pa je vplivalo tudi na razvoj gozdov. Najprej so za pridobivanje oglja izrabljali predvsem bukev, iz katere pridobivajo bolj kakovostno oglje kot iz iglavcev. Sečnja bukovine okoli kopišč je bila zelo intenzivna, pogosto na golo. Tako so posredno spodbujali širjenje iglavcev, zlasti smreke, ki je sprva hitreje osvajala poseke kot ostale drevesne vrste. Kasneje so jo načrtno sadili na izkrčena gozdna zemljišča, da so s tem povečevali donos lesa. Pri gospodarjenju z gozdom so se že v 14. in 15. stoletju pojavili številni nasprotni interesi med fužinarji oz. oglarji in kmeti. Prvi gozdni red iz leta 1406 določa lastniškopravna razmerja v smislu varstva gozdov pred pustošenjem (Veber, 1987). Kmetje so se pritoževali nad pustošenjem oglarjev, ki so posekali najlepša drevesa, a so le majhen del (vejevino) porabili za oglje. Fužinarji pa so se pritoževali nad izkoriščanjem gozdov s strani kmetov, ki so delali v gozdu rovte in pašnike. Ker so postale gozdne površine vrzelaste, so po njih kmetje začeli pasti tudi živino. Tako je bil leta 1603 izdan cesarjev odlok, ki je prepovedoval pašo v gozdu (ibid.). Z oglarstvom so bili občasno povezani tudi gozdni požari, ki so izbruhnili pri pripravi oglarske kope. Leta 1870, torej že v času upadanja fužinarske dejavnosti, je znašala po-

## HUMAN ACTIVITIES TO THE END OF 19TH CENTURY

Between the 14th and 16th centuries, the production and working of metals developed into an intense undertaking. Due to the increased demand in the 16th century, the production increased in both, the traditional and the new forges. Six new forges emerged on the margins of the study area: Mojstrana, Plavž (1538), Sava, Radovna, Bohinjska Bistrica (1540), and Pozabljeno (1562) (Šmitek, 1989). The local ironworks owners were now joined by immigrants from Friuli (Italy), who brought with them new, more efficient methods and devices of higher capacity. Charcoal was used in the furnaces, which was charred in the surrounding forests. In 1581, the annual production of iron in Stara Fužina amounted to 45 tons, and 67 tons in Bohinjska Bistrica which, however, lies outside the borders of the TNP. About 5000 $m^3$ of wood was necessary to make 50 tons of pig iron in the 16th century, and only 2800 $m^3$ at the beginning of the 19th century (Valenčič, 1979). In the mid-19th century, forges began to decline and they ceased to operate completely towards the end of the 19th century. In 1890, the production in Bohinjska Bistrica was also stopped, and the centre of ironworks moved to nearby Jesenice, which has remained one of the active iron-producing centres in Slovenia until today.

Charcoal burning in the forest was thus closely connected with forges, and it also greatly affected the forests. At the beginning, charcoal was made primarily from beech, which gives charcoal of a higher quality than coniferous trees. Beech trees were intensively felled around the charcoal burning sites, often to the extent of complete clearance. Thus, the spread of coniferous trees was indirectly stimulated, especially spruce which was faster in colonising the clearings than other tree species. Later on, spruce was made the main tree in the planned afforestation of the cleared sites in forests, with the purpose to increase the growth of wood. As early as the 14th and 15th centuries, numerous conflicting interests occurred in the forest economy between the ironworks owners and charcoal burners on the one hand, and peasants on the other. The first forest regulation of 1406 determined legal property relations in the sense of protecting forests against devastation (Veber, 1987). Peasants complained about the devastation caused by charcoal burners who had cut the finest trees, but only used a minor part of them (the branches) for charcoal, while ironworks owners complained about

Množica rib (koreslji) ob bregu Jezera na Planini pri Jezeru v času drsta. V to jezero so ribe naselili v 50. letih prejšnjega stoletja. (Foto: Anton Brancelj)
*A shoal of fish (crucian carp) in Jezero na Planini pri Jezeru at spawning time. Fish were introduced into the lake in 1950s. (Photo: Anton Brancelj)*

raba oglja v Stari Fužini 4358 m$^3$ in v Bohinjski Bistrici 15.158 m$^3$. Ker ima oglje 50 % prostornine lesa, je bilo samo za ti dve fužini potrebno letno posekati več kot 40.000 m$^3$ lesa. Pomembna posledica fužinarstva na tem območju je sprememba v sestavi drevesnih vrst: bukev se je umaknila in namesto nje se je razširila smreka.

peasants who made grasslands and pastures in the forests. Because clearings occurred in forests, peasants began to pasture livestock there as well. Therefore, in 1603 an imperial decree was passed, which banned pasturing in the forests (ibid.). Charcoal burning also occasionally caused wood fires, which broke out during the preparation of wood piles to be charred. In 1870, that is when forges had already begun to decline, charcoal consumption in Stara Fužina amounted to 4358 m$^3$, and 15,158 m$^3$ in Bohinjska Bistrica. Since a 50 % reduction in the volume of wood occurs during the burning of charcoal, more than 40,000 m$^3$ of wood had to be cut for these two forges only. Ironworks with the accompanying burning of charcoal, significantly influenced the tree composition of forests; beech declined and spruce spread to a large extent.

## ČLOVEKOVE DEJAVNOSTI V 20. STOLETJU

Območje Bohinja, v narodnem parku in deloma izven njega, obsega približno 300 km$^2$ in ima skoraj 8000 ha planinskih pašnikov, ki se po kvaliteti in legi močno razlikujejo. Največ jih je v visokogorskem kraškem svetu in le majhen del jih ima sklenjeno travno rušo. Tretjina, ali 2745 ha, je pra-

## HUMAN ACTIVITIES IN THE 20$^{TH}$ CENTURY

The Bohinj area, lying partly within the TNP and partly outside its borders, covers about 300 km$^2$ of land and has almost 8000 hectares of alpine pastures, which differ greatly with regard to their quality and location. Most of them lie in the high-mountain karst area, and only a few are covered with con-vih pašnikov. Leta 1966 jih je bilo še 90 % v uporabi, leta 1973 79 %, od tedaj dalje pa je ta delež vse bolj upadal. V prejšnjem stoletju je te pašne površine izkoriščalo 46 planin. Leta 1966 je obratovalo še 29 (63) in 1994 samo še 23 planin (Vojvoda, 1995, preglednica 1).

V povojnem obdobju se je na obravnavanem območju začelo zmanjševati število agrarnega prebivalstva, delež je od skoraj 33 % v letu 1961 upadel do leta 1991 na 7,4 %. Posledici tega sta bili tudi zmanjšanje števila planin in sprememba staleža (preglednica 1) in sestave živine na planinah. Poleti 1966 so na bohinjskih planinah pasli še 1220 GVŽ, leta 1994 pa 731 GVŽ (slika 1). V sestavi živine se je delež krav zmanjšal za 64 % in danes predstavlja le še tretjino črede, včasih pa je bilo krav nad polovico. Mladega goveda je skoraj polovica, medtem ko ga je bilo 1966. komaj četrtino. Močno pa se je povečal delež drobnice. Planšarska dejavnost je po 2. svetovni vojni torej močno upadla. V bohinjske planine je še v prvi polovici 20. stoletja odhajalo 90 % živine, ki so jo imeli kmetje v dolini, leta 1994 pa le še 42 %. Med vsemi štirinajstimi jezeri sta danes (1995) le še dve takšni, ob katerih pasejo. Ob jezeru na Planini pri Jezeru pasejo govedo in ob Dupeljskem jezeru drobnico.

Alpska pokrajina Triglavskega narodnega parka zaradi svoje raznolikosti, visoke reliefne energije, z nadmorsko višino spreminjajoče se flore in favne ter družbenih posebnosti že vsaj dve stoletji privablja razne obiskovalce. Prvi so bili gorniki, ki so zahajali v ta svet iz narodnobuditeljskih, kasneje kulturnih in naravovarstvenih razlogov, danes pa skoraj izključno iz turističnih in rekreativnih. Prve planinske poti so začeli nadelovati v drugi polovici 19. stoletja, ko so začeli graditi skromne koče, namenjene planincem, kar šest v obdobju 1871–1900.

| Leto<br>Year | 1830 | 1900 | 1910 | 1921 | 1960 | 1981 | 1991 |
|---|---|---|---|---|---|---|---|
| Število živine<br>Number of cattle | 2635 | 3609 | 3066 | 3387 | 2942 | 2175 | 1793 |
| Indeks<br>Index | 73.0 | 100 | 84.9 | 93.8 | 81.5 | 60.2 | 49.6 |
| Število planin<br>Number of ADF | 46 | | | | 29 | 26 | 23 |
| Povprečno število govedi na planini<br>Average number of cattle on ADF | 57.2 | | | | 101.4 | 83.6 | 77.9 |

Preglednica 1: Nekatere značilnosti planinskega pašništva v Bohinju (Slovenija) v obdobju 1830–1991 (vir: Vojvoda, 1995)

*Table 1: Selected characteristic of alpine dairy farming (ADF) in Bohinj area (Slovenia) between 1830 - 1991 (source: Vojvoda, 1995)*

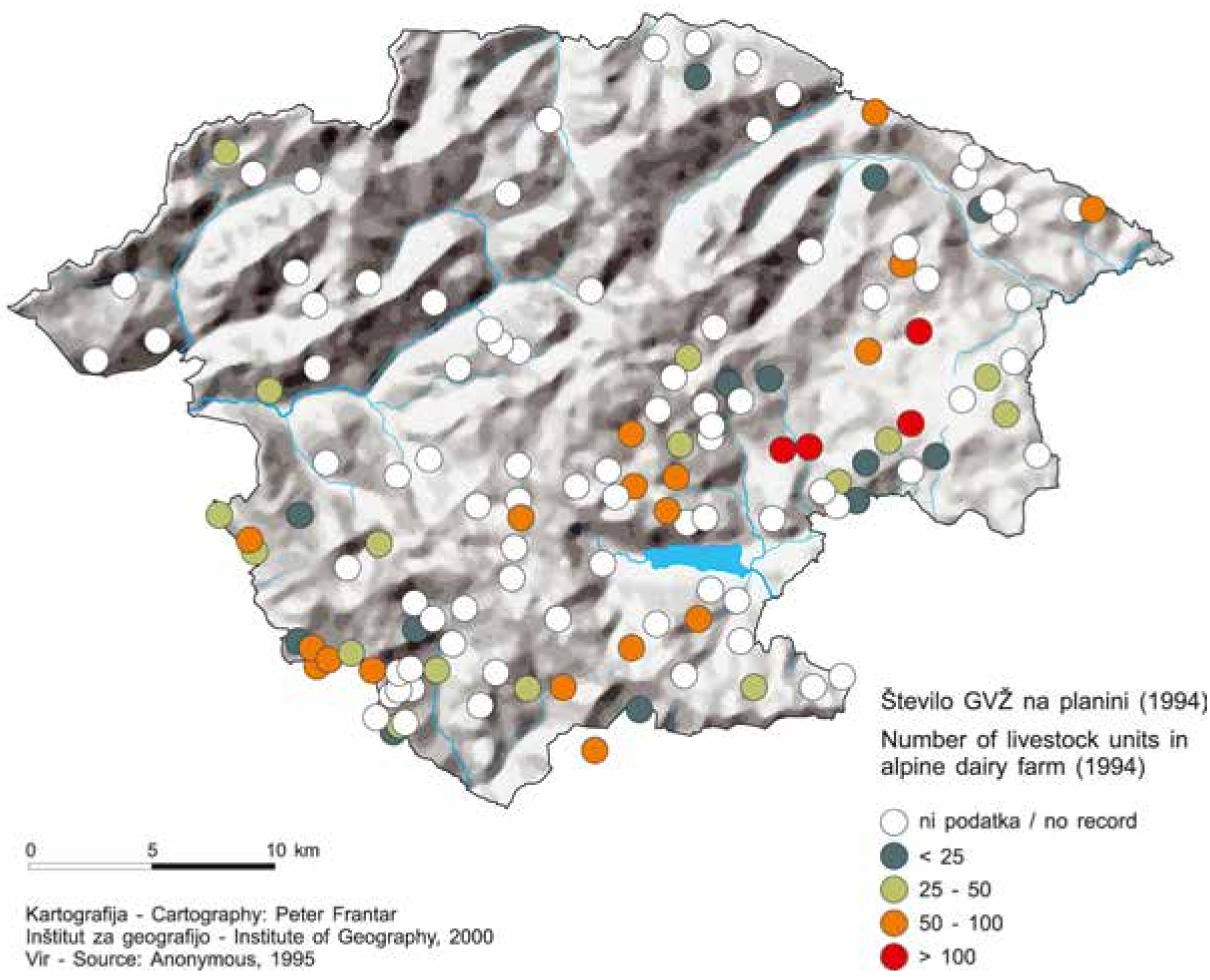
tinuous turf. One third, or 2745 hectares, can be ranked as proper pastures. In 1966, 90 % of them were still in use, and 79 % in 1973; since then, this proportion has radically declined. In the 19th century, these pasturing areas were used by 46 alps. In 1966 only 29 (63 %) were still in use, 26 in 1983, and only 23 in 1994 (Vojvoda, 1995) (Table 1).

The agrarian population in the study area began to decline in the post-War period, so that its percentage was reduced from 33 % in 1961 to 7.4 % in 1991. This decline also resulted in the decrease in the number of alps and the number and structure of livestock in the alps. In the summer of 1966, as many as 1220 head of cattle were still grazing on the alps of the Bohinj area, and only 731 head of cattle in 1994 (Figure 1). With regard to the herd structure, the number of cows declined by 64 %, and they represent only one third nowadays, while in the past, cows accounted for more than a half of a herd. Young cattle account for almost a half now, while this percentage hardly amounted to one quarter in 1966. On the other hand, the number of sheep and goats has considerably increased. Alpine dairy farming radically declined after 2nd World War. In the first half of the 20th century, as much as 90 % of livestock were still moved to the Bohinj area alps, whereas in 1994, this proportion was only 42 %. Of all the 14 lakes in the TNP, alpine pasturing is still practiced in the catchemnt of only two of them. Cattle graze on the alp of Planina pri Jezeru and goats and sheep by the lake of Dupeljsko jezero and Krnsko jezero.

Due to its diversity, the high relief, flora and the fauna which change with the altitude, and its social peculiarities, the alpine region of the TNP has continuously attracted various visitors for at least two centuries. The first were mountaineers who vis-

Od teh je bila le ena izven območja dostopov na najvišji slovenski vrh Triglav (2864 m). Do druge svetovne vojne so odprli še deset novih koč, ki pa so vse, razen Gomiščkovega zavetišča na Krnu, pod 2000 m. Nekatere med njimi se pojavljajo celo na koncu dolin, tik pod vznožjem hribov. To dokazuje, da je hoja v gore postajala vse bolj namenjena širšim množicam, katerih cilj ni bil več samo osvajanje težko dostopnih vrhov na večdnevnih turah, ampak tudi zgolj nezahtevni enodnevni družinski izleti v sredogorje. Največji razmah označevanja poti in gradnje planinskih koč pa je bil med letoma 1948 in 1955, ko so širom po območju današnjega parka od dolin do visokogorja odprli kar 12 novih postojank in takrat je pljusknil prvi množični val obiskovalcev (Dobnik, 1991) (slika 2). Od tedaj dalje niso več zgradili veliko novih koč, vendar so jih zlasti do začetka devetdesetih let večali in bogateje opremljali, tako da so se iz zatočišč spreminjale v restavra-

ited this area for reasons of awakening national awareness; later on, because of cultural and nature-protection reasons; while now, the purpose is exclusively tourism and recreation. The origins of the first mountain paths date back to the second half of the 19th century, when modest alpine huts were constructed to give shelter to mountaineers. As many as six were erected in the 1871-1900 period, of which only one was located outside the area of access to the highest Slovenian peak, Mt. Triglav (2864 m). Before the 2nd World War, ten new alpine huts were made, all of which, except for the Gomišček shelter on Mt. Krn, lie below 2000 m, or the far end of the valleys, at the foot of the mountains. This proves that mountaineering was gradually turning into a mass activity, the purpose of which was no longer the conquering of inaccessible peaks during trips of several days, but increasingly a non-demanding one-day family visit to moun-



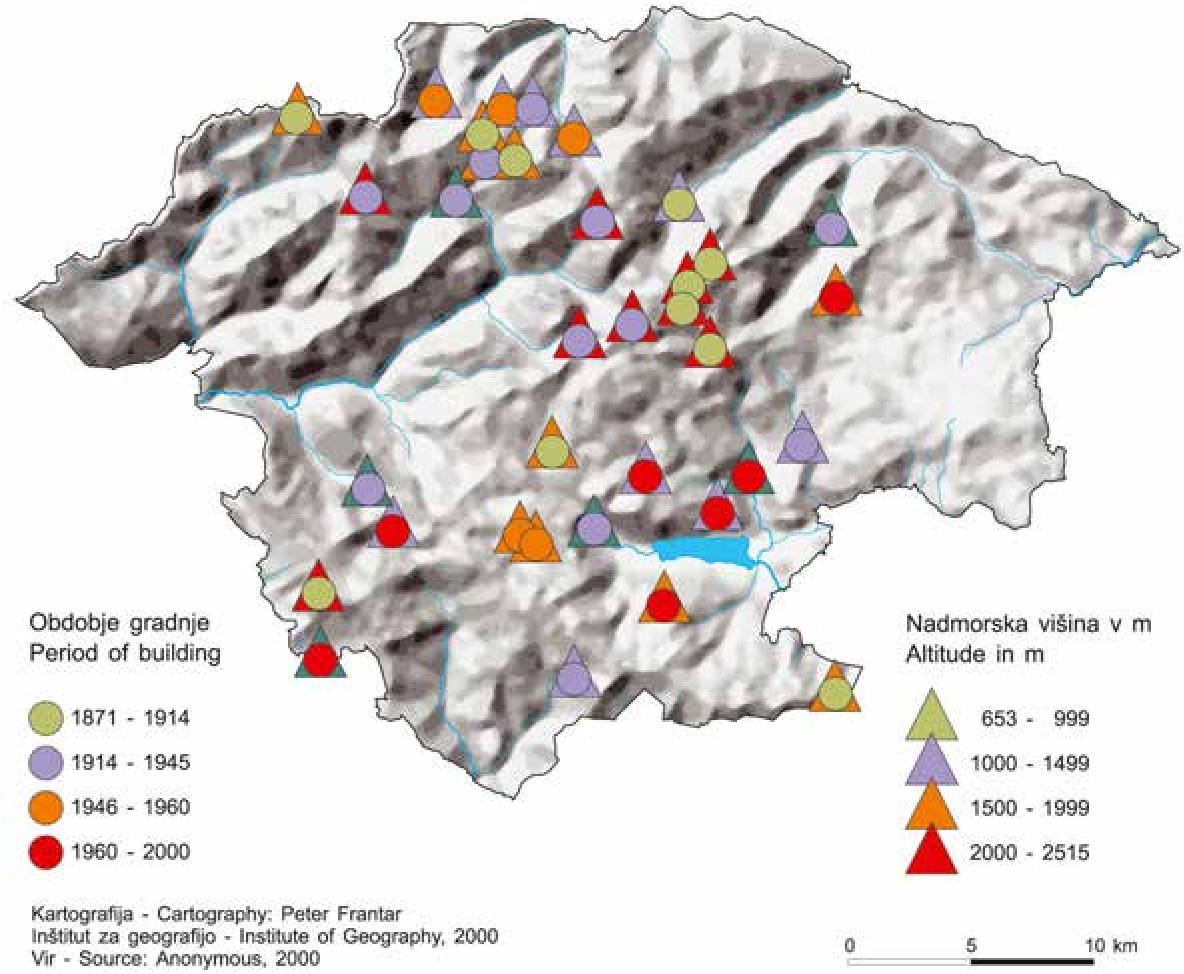

Slika 1: Stalež živine na planinah v Triglavskem narodnem parku (Slovenija) leta 1994

*Figure 1: Number of cattle on alpine diary farms in Triglav National Park (Slovenia) in 1994*

cije s pestro ponudbo in dobro opremljenimi prenočišči, toda brez skrbi za okolje. V tem času so začeli predvsem prebivalci iz urbaniziranih območij iskati možnosti za rekreacijo tudi v bolj oddaljenih območjih, ne le v neposredni okolici mest. To je bila posledica višjega osebnega standarda, več prostega časa in boljših, zlasti cestnih, povezav. V visokogorju se je na številnih množičnih prireditvah, ki so bile med planinci zelo priljubljene, zbiralo tudi po več sto ljudi hkrati.

V šestdesetih letih so zgradili edino večje visokogorsko smučarsko središče Vogel s 36 km prog ob devetih žičniških napravah, s kapaciteto 4650 smučarjev na uro in letnim obiskom nad 150.000 smučarjev. Manjše, nižje in okoljsko manj občutljivo smučišče je Zatrnik, ki so ga zgradili desetletje kasneje z 19 km prog ob petih žičnicah in s kapaciteto 4500 smučarjev na uro. V istem obdobju pa so zgradili tudi tri krajše vlečnice na dveh lokacijah na

tains with easier access. The greatest boom of marking the paths and constructing alpine shelters took place between 1948 and 1955, when as many as 12 new huts, located in valleys as well as in high mountains, were open for public use in the area of the present TNP. This marked the first wave of mass visits (Dobnik, 1991) (Figure 2). Since then, not many new huts have been erected, but until the beginning of the 1990s, the existing ones were extended and better furnished, so that they were changed from shelters into restaurants with well furnished overnight facilities. Unfortunately, all of this was done without any concern for the environment. This was the time, when especially the inhabitants of urbanised areas began to look for possibilities of recreation in more remote areas, which was the result of a higher personal standard of living, more leisure time, and better transport connections, especially by road. At numerous mass events in the




Slika 2: Planinske koče v Triglavskem narodnem parku (Slovenija) in obdobje izgradnje
*Figure 2: Mountain cottages in Triglav National Park (Slovenia) and the period of their building*

Pokljuki z manjšimi kapacitetami. Torej so bili vsi smučarski objekti zgrajeni pred razglasitvijo Triglavskega narodnega parka.

Z razvojem gospodarstva se je vedno bolj razvijala tudi gozdarska dejavnost in tako so gradili gozdne ceste vse bolj v osrednji del narodnega parka, kjer je konfiguracija terena to sploh omogočala, še zlasti z južne in zahodne strani. Od skupno 365 km jih je namreč v tem delu več kot 300 km. Tako je bil precej olajšan dostop do marsikaterega izhodišča planinskih poti, ali celo na nekatere planine, zlasti tam, kjer so postavljene planinske koče ali pa še pasejo živino. Kljub vsemu pa večina gozdnih cest vseeno ni odprta za javni promet.

V 25 naseljih v parku živi nekaj več kot 2000 prebivalcev, vendar se njihovo število vse bolj zmanjšuje, v zahodnem delu parka v zadnjih petdesetih letih za več kot polovico. Obdobje po drugi svetovni vojni je prineslo spremembe v razporeditvi prebivalcev. V hribovskih naseljih se je njihovo število zmanjšalo, v dolinskih, kjer je več možnosti za zaposlitev, pa naraščalo. V nižinskem svetu prevladujejo strnjena gručasta naselja, medtem ko so v višjem svetu mlajša razložena naselja, nastala iz nekdanjih planin in rovtov.

Razvoj se vse bolj seli v turistična središča ob zunanjem robu parka: Bovec, Kranjska Gora, Bled in del Bohinja. Z zmanjšanjem pomena primarnih dejavnosti so v prevladujočih mešanih delavsko-kmečkih gospodinjstvih zlasti od sedemdesetih let dalje vse bolj opuščali manj kakovostna ali bolj oddaljena kmetijska zemljišča. Pogosto so senožeti, planine ali gozdne robove razparcelirali in jih s pomožnimi kmetijskimi objekti ali brez njih prodali za gradnjo počitniških hišic. Negativni učinki gradnje oziroma spreminjanja namembnosti stavb so zlasti fiziognomski, funkcijski, socialni, ekonomski in okoljski. Do leta 1981, ko je bil sprejet zakon o TNP in je bila prepovedana nadaljnja gradnja počitniških hiš, so zgradili veliko večino objektov, delno na osnovi zazidalnih načrtov in delno kot črne gradnje. Največ jih je v Bohinju (Ukanc 99, Ribčev Laz 65) in na Pokljuki (Goreljek 144) ter v bližini reke Soče (Trenta 79, Soča 45) (Popis prebivalstva ..., 1991). V vzhodnem delu današnjega Triglavskega narodnega parka so postavljali prve počitniške objekte premožnejši intelektualci iz urbanih okolij že v tridesetih letih 20. stoletja.

Dobra cestna dostopnost do izhodišč planinskih poti in celo v sredogorje, gosta mreža označenih in vzdrževanih poti ter veliko število prebogato opremljenih koč in počitniških hiš je vodilo na nekaterih najbolj obleganih območjih v preveli-

high-mountains, which were very popular with mountaineers, several hundreds of people gathered at a time.

In the 1960s, the only big ski centre, Vogel, was made in the high-mountains; with its 36 km of ski slopes, with nine ski lifts and a capacity of 4650 skiers per hour it had an annual visit of over 150,000 skiers. A smaller ski field, lying lower and environmentally less sensitive, was made ten years later at Zatrnik. This has 19 km of ski slopes, five ski lifts, and a capacity of 4500 skiers per hour. In the same period, three shorter ski lifts of minor capacity were also erected at two locations of Pokljuka. Thus, all these ski fields and facilities were made before the Triglav area was declared a national park.

Along with the growing economy, forestry has also developed, and forest roads were constructed, leading deeper and deeper into the heart of the national park, wherever the configuration of land allowed it, particularly from the southern and western directions. Of the total of 365 km, more than 300 km occur in this area. Thus access was considerably improved to the start of numerous mountain paths, and even to some alps, especially to those with alpine huts or where cattle still graze. Nevertheless, most forest roads are not open to public.

In the 25 settlements in the TNP more than 2000 inhabitants live; however, their number is continuously decreasing, especially in the western part of the park, where it has declined by more than a half in the last fifty years. The post-War period brought changes in the distribution of the population. The number of inhabitants in mountainous settlements decreased, while it increased in the valleys where employment possibilities were much better. In the lowlands, continuous settlements prevail, while at higher altitudes, more recent, dispersed settlements have emerged on the former alps and clearings.

Development is moving increasingly to the tourist centres at the edge of the TNP, such as at Bovec, Kranjska Gora, Bled and a part of Bohinj. As primary activities in the prevailing mixed, peasant-worker households were losing importance, farming lands of poorer quality and those located at a greater distance were increasingly abandoned, especially from the 1970s onwards. Quite often, grassy slopes, alps or the fringes of forests were partitioned and sold, whether with, or without, farming outbuildings, to people from outside the region as the sites for their vacation houses. The construction of new houses or changing the use of the old buildings exerted negative impacts especially on the ko obremenjevanje gorskega okolja, ki je zaradi specifičnih okoljskih in družbenih značilnosti zelo občutljivo.

Klasične športno-rekreacijske dejavnosti (izletništvo, nabiralništvo, planinstvo, alpinizem, smučanje, turno smučanje in kajakaštvo) in nove, alternativne dejavnosti (športno plezanje, gorsko kolesarjenje, vožnja s terenskimi motornimi vozili, pasjo vprego, rafting, kanjoning ter letenje z jadralnimi padali in zmaji) so vse bolj prisotne v prostoru TNP (Šolar in Lukan, 1996). Problem je, ker je vse več takšnih, ki so zasnovane na tržnem principu in so zaradi tega vedno bolj množične, kar vodi v okoljske probleme, ker je vedno pogosteje presežena nosilna sposobnost okolja.

Izvajanje teh dejavnosti je precej odvisno od dostopnosti. Zaradi številnih lahkih vstopov v park se število obiskovalcev iz leta v leto povečuje, tako da po ocenah letni obisk že presega dva milijona obiskovalcev. Višek sezone je avgusta in prvi teden septembra, izven tega obdobja pa je obisk številčnejši v drugi polovici tedna. Najbolj je obremenjena cestna povezava med zahodnim in vzhodnim delom TNP čez najvišji cestni gorski prelaz v Sloveniji (Vršič, 1611 m), ki je čez zimo zaprt (slika 3). Na dan se na njem ustavi povprečno po 500 ljudi (Šolar, 1994). Zelo obremenjeni pa sta tudi cesti ob Bohinjskem jezeru in na Pokljuko. Ob teh cestah je več kot polovica vseh naselij in so tudi dostopi do najatraktivnejših delov parka, namenjenih rekreaciji.

Zlasti planinstvo kot najbolj množična turistično-rekreativna dejavnost s svojo množičnostjo prekomerno obremenjuje občutljivo gorsko okolje. Gostota planinskih poti v parku je preko 1000 m na 1 $km^2$ in je nobeno območje v Sloveniji ne presega. Koncentracija poti je najgostejša prav v triglavski skupini s 1108 m na 1 $km^2$, ki je zaradi svoje velike površine tudi zelo raznolika in ima zelo visoko pokrajinsko primernost za planinarjenje. Pestrost se kaže tudi v tem, da je od 89 planinskih poti kar 15 zahtevnih in osem zelo zahtevnih (Jereb, 1996), pa tudi oskrba s 15 kočami od 35, kolikor jih skupaj v TNP, je precej nadpovprečna. Tudi rezultati ankete med planinci dejansko kažejo na to, saj se več kot štirim petinam vprašanih zdi ponudba v kočah primerna (Šolar, 1994).

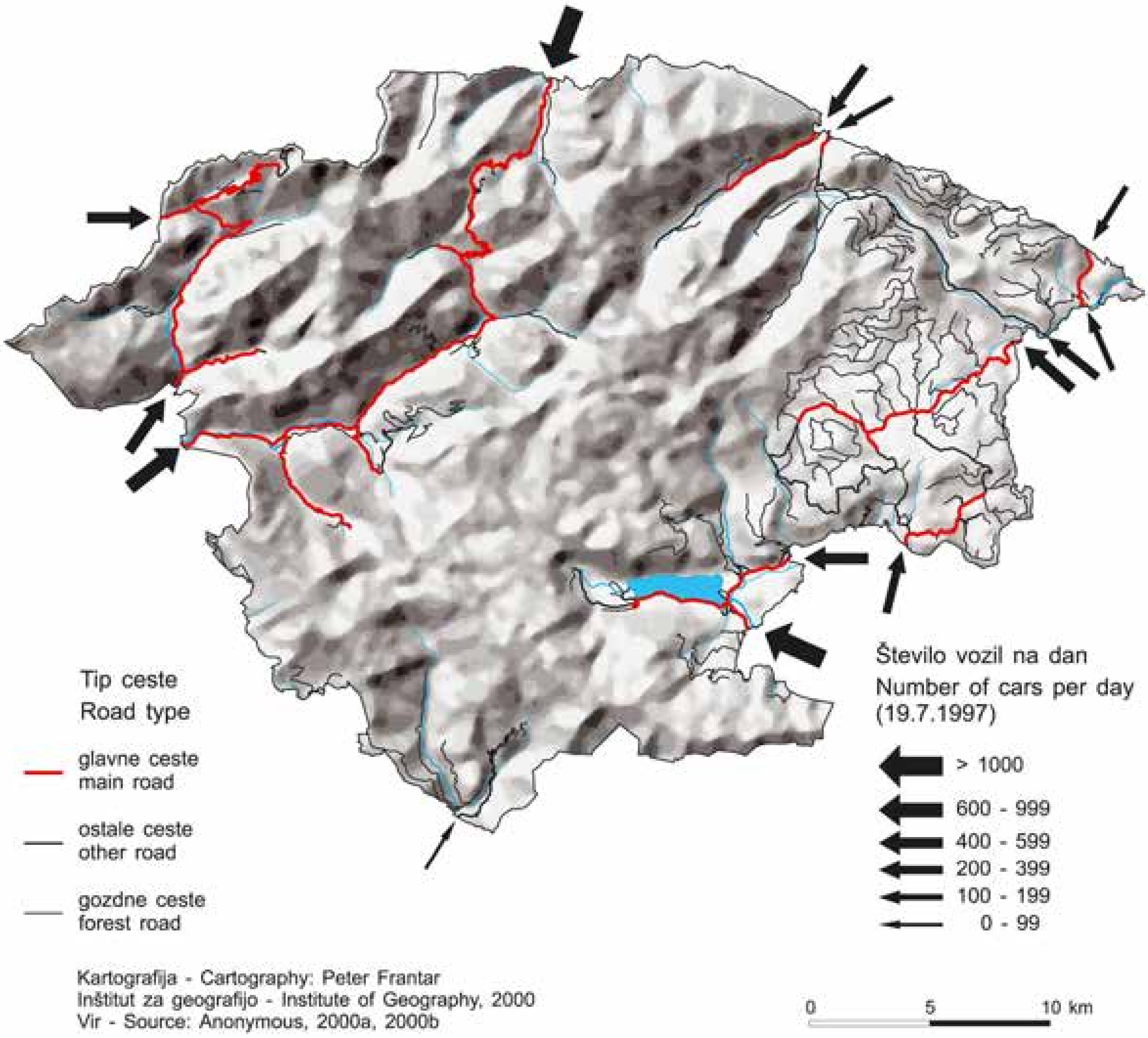
Planinarjenje je mehka oblika rekreacije v odprtem prostoru, kljub vsemu pa prihaja do prekomernega obremenjevanja okolja zaradi prevelike množičnosti pojava. Tako npr. pomeni vsak korak določen pritisk na podlago, 600 korakov na isto travno rušo v enem letu pa povzroči njen propad (Ma-

physiognomy, function, social structure, economy and environment of the area. By 1981, when the law creating the TNP was passed, which also banned the building of vacation houses, a great number of them had already been constructed, partially in accordance with the building regulations, and partially as illegal constructions. They are most numerous in Bohinj (99 in Ukanc, 65 in Ribčev Laz), on Pokljuka (144 in Goreljek), and along the Soča river (79 in Trenta, 45 in Soča village) (1992, Varstvo …). In the eastern part of the present TNP, the first vacation houses were erected as early as the 1930s by well-to-do intellectuals coming from urban environments.

Easy access by road to the start of mountain paths or even to mountains of medium height, a dense network of marked and well maintained paths, and a large number of over-furnished alpine huts and vacation houses prompted, in the most frequented areas, pollution of the mountain environment which, because of specific environmental and social features, is very sensitive.

Classical recreational activities (excursions, fruit and herb picking, mountaineering, mountain climbing, alpine skiing, skiing trips and canoeing) as well as new, alternative activities (sports rock-climbing, mountain-biking, jeep-driving, dog-sledging, rafting, canyoning, hang-gliding and parachute-sailing) take place in the TNP ever more frequently (Šolar & Lukan, 1996). The trouble is that more and more of these activities are based on marketing principles, therefore they are gradually acquiring the character of mass activities, which eventually leads to environmental problems because tolerable thresholds of the environment are frequently exceeded.

These activities greatly depend on the accessibility of the sites and because there are numerous easy access routes to the TNP, the number of visitors has increased from year to year, so that, according to estimations, the annual frequency already exceeds two million visitors. The peak of the season falls in August and the first week of September, and during the rest of the year, visitors usually come in greater numbers in the second half of a week. Most frequented is the road connection between the western and the eastern part of the TNP, i.e. across the highest mountain pass in Slovenia, Vršič (altitude 1611 m), which is closed in winter (Figure 3). On average, about 500 people stop daily on this pass (Šolar, 1994). The road along Bohinj lake and the one leading to Pokljuka are also heavily used. More than a half of all the settlements in the TNP, as well as the access to the most attractive parts of the Park intended for recreation, lie along these two roads.




Slika 3: Gostota cestnega omrežja v Triglavskem narodnem parku (Slovenija) in število vozil na dan za 19. 07. 1997
*Figure 3: Density of road network in Triglav National Park (Slovenia) and number of vechicles per day on July 19 1997*

her, 1995). Najbolj so občutljiva vlažna in visokogorska rastišča. Posledica uničenja rastlin je večji odtok vode, kar vodi v pospešeno erozijo. Na najbolj obremenjenih območjih se zadržuje tudi vse manj živali, še zlasti gamsov (*Rupicapra rupicapra*) in kozorogov (*Capra ibex*).

Bolj kot samo gibanje planincev pa je problematično zadrževanje v kočah in zlasti posledice, ki jih prinaša tovrstni množični obisk. Največji problemi so v njihovi oskrbi, energetski oskrbi, v ravnanju z odpadnimi vodami in trdnimi odpadki (preglednica 2). Od vseh pokrajinotvornih elementov v TNP je najbolj ogrožena voda, in to zaradi odpadnih voda in trdnih odpadkov. Prav posebej pa bi bilo treba paziti na vode, saj predstavljajo izviri v TNP petino

Mountaineering in particular, as the most popular tourist-recreational activity, over-burdens the sensitive mountainous environment with its excessive number of participants. The density of mountain paths in the TNP amounts to over 1000 m km$^{-2}$ and is unsurpassed by any other area in Slovenia. The highest concentration of paths, (1108 m km$^{-2}$), is in the proximity of Mt. Triglav, which is a diverse due to its large size and very suitable for mountaineering. Of the total 89 mountain paths, 15 are 'demanding' and eight 'very demanding'. (Jereb, 1996). The 15 alpine huts in this area (out of a total of 35 in the entire TNP) is also well above average. The results of a poll carried out among the mountaineers actually show that more than 80 %

Preglednica 2: Prevladujoč način oskrbovanja planinskih koč v Triglavskem narodnem parku (Slovenija) leta 1996 (vir: 1997, Varstvo ...)

*Table 2: The most common way of supply of mountain huts in Triglav National Park (Slovenia) in 1996 (source: 1997, Varstvo...)*

| | Oskrba z živili Supply with goods | Energetska oskrba Supply with energy | Obravnava odpadnih vod Sewage waters treatment |
|---|---|---|---|
| Avto Car | 16 | | |
| Žičnica Cable car | 6 | | |
| Konj Horse | 4 | | |
| Helikopter Helicopter | 9 | | |
| Električno omrežje Public electricity | | 13 | |
| Sončna energija Solar energy | | 18 | |
| Agregat Electrical generator set | | 4 | |
| Enoprekatna greznica One-compartment cesspools | | | 7 |
| Triprekatna greznica Three-compartment cesspools | | | 23 |
| Ponikovalnica Sink | | | 5 |

vodnega potenciala Slovenije (1992 b, Varstvo ... ), zato je skrb za njihovo čim manjše onesnaževanje nujna. V neposredni bližini štirih visokogorskih jezer (Krnsko jezero, Sedmera jezera, Kriška jezera in Jezero na Planini pri Jezeru) so postavljene planinske koče, ki imajo urejeno zbiranje odplak v triprekatnih greznicah, in tako vsaj deloma zavirajo še bolj pospešeno evtrofizacijo jezer.

Smučarski center Zatrnik je zaradi lastninskih težav skoraj propadel. Občasno deluje le ena vlečnica in tako ne predstavlja omembe vrednega obremenjevanja okolja. Medtem ko na Voglu, visokogorskem smučišču, vsako leto prihaja do številnih strojnih posegov v reliefno zelo razgiban ranljiv teren. Posledica tega je sprememba občutljive zgradbe in strukture tal ter vegetacije. Obstajajo pa tudi obsežni načrti za nadaljnji razvoj tega središča s širitvijo smučarskih terenov in dodatnim zasneževanjem. Smučišče na Voglu, ki je v neposrednem zaledju nižje ležečega Bohinjskega jezera, povzroča pomembno dodatno onesnaževanje vode zaradi sredstev za vzdrževanje žičnic in teptalnih

of those questioned are satisfied with the facilities in these alpine huts (Šolar, 1994).

Mountaineering is a 'low impact' type of outdoor recreation; nevertheless, the environment gets overloaded, due to the excessive numbers of participants.Each step imposes a certain pressure on the ground, and 600 steps on the same turf can destroy it (Maher, 1995). Humid and high-mountain vegetation areas are the most sensitive, and the destruction of vegetation results in stronger drainage of water, which leads to progressive soil erosion. There is also less and less wildlife in the most frequented areas, especially numbers of chamois (*Rupicapra rupicapra*) and ibex (*Capra ibex*) have decreased.

More than the physical impact of the mountaineers, their residence in the alpine huts is problematic, and especially the consequences which result from mass visits. The greatest problems lie in goods supply, energy supply and in handling sewage and wastes (Table 2). Of all the landscape-forming elements the quality of water is the most endangered, owing to sewage waters and solid wastes. Particular and urgent action is required to minimise water pollution as the springs in the TNP account for 20 % of potential water supply in Slovenia (1992, Varstvo ...). In the immediate vicinity of four high-mountain lakes (Krnsko jezero, Dvojno jezero, Kriška jezera and Jezero na Planini pri Jezeru) alpine huts are located in which the collection of waste waters is organised in three-compartment cesspools, thus, partly at least slowing down the progressive eutrophication of the lakes.

The ski centre of Zatrnik has almost ceased to operate because of quarrels over property rights and one ski lift only operates temporarily, which does not represent an excessive environmental load. On the other hand, at Vogel, a high-mountain ski centre, numerous interventions by machines are undertaken every year on the vulnerable mountain slopes, the consequence of which is manifested by changes in the constitution and structure of the ground and vegetation. Moreover, ambitious plans have already been made for the future development strojev ter sredstev za utrjevanje snega. Seveda pa povzročajo velike koncentracije obiskovalcev visokogorskega smučarskega središča podobne probleme kot planinci v kočah in njihovi okolici.

Novih počitniških hiš v Triglavskem narodnem parku ne gradijo več, vendar tudi stare predstavljajo stalne obremenjevalce okolja, saj do težje dostopnih objektov stalno nelegalno gradijo ceste ali pa širijo obstoječe. Problemi energetske oskrbe, odvajanja in čiščenja odplak ter odvoza smeti so podobni kot pri planinskih kočah, vendar je situacija še bistveno slabša, saj nadzora stanja in morebitnega sankcioniranja nihče ne izvaja. Opravljena ni bila tudi nobena raziskava med lastniki sekundarnih bivališč. Med avtohtonimi gospodinjstvi je bila v prvi polovici devetdesetih let opravljena anketa (Barbič, 1994), katere rezultati kažejo, da ima štiri petine gospodinjstev urejeno kanalizacijo, pri čemer se kot urejena pojmuje že enoprekatna greznica s prelivom. Po rezultatih iste ankete je precej bolj zaskrbljujoče stanje urejenosti odtokov iz hlevov, ki jih ni niti polovica speljanih v gnojnično jamo. Samo polovica stalno naseljenih hiš ima urejen odvoz odpadkov, pri počitniških hišah pa je ta delež še manjši. Tako nastajajo v bližini naselij oziroma razpršenih objektov divja odlagališča odpadkov. Vedno bolj prihaja do konflikta med avtohtonim in alohtonim prebivalstvom, saj domačini spoznavajo, da so s prodajo zemljišč za počitniške hiše dopustili razvrednotenje fiziognomije alpske pokrajine. Z gradnjo sta se namreč bistveno spremenila videz in funkcija stalnih (vasi) in občasnih (planšarije) naselij, poleg tega se je gradnja razširila v prej nikdar naseljena območja. Problematično je, ker je precej nanovo nastalih objektov tudi v zaledju jezer, še zlasti Jezera na Planini pri Jezeru, in v tem težko dostopnem območju je komunalna infrastruktura še toliko bolj pomanjkljiva.

Vse druge že omenjene športno-rekreacijske dejavnosti se zaenkrat še vedno pojavljajo v tako majhnem obsegu, da zelo malo obremenjujejo okolje, tako da zaradi njih ni ogrožena nosilna sposobnost. Res pa se skoraj vse aktivnosti v tem prostoru koncentrirajo v določenih dneh in takrat nedvomno prihaja do preobremenitev okolja, saj je nosilna sposobnost, vsaj z lokalnega vidika, presežena.

Poleg vode je najbolj ogrožen pokrajinotvorni element zrak. Triglavski narodni park je namreč velik potencial čistega zraka, ki pa je pogosto že prizadet zaradi stalnih in občasnih lokalnih virov onesnaževanja. Predvsem poškodovani gozdovi na Pokljuki in v Fužinarskih planinah kažejo, da gre tudi za globalno onesnaževanje kot posledico tako

of this centre which envisage the extension of ski fields and supplementary use of snow blowers. The ski field on Vogel, which lies in the immediate hinterland of the lower-lying Bohinj lake, causes heavy water pollution because of the substances used in maintaining the ski lifts and caterpillars and snow consolidating agents. It is evident that the great concentration of visitors in this high-mountain ski centre causes similar problems as do mountaineers in the alpine huts and their surroundings.

New vacation houses are no longer built in the TNP, but, the old ones represent a permanent impact on the environment, since illegal roads to poorly accessible houses are constantly being built, or widened if they already exist. The problems of energy supply, drainage and treatment of sewage and waste removal are similar to those in the alpine huts, but, the situation is essentially worse because there is nobody to control the situation and impose possible sanctions. Research into the ownership of secondary dwellings has not been udertaken. A survey of existing households was made in the first half of the 1990s (Barbič, 1994), the results of which show that 80 % of the households have 'organised' sewage systems. However, the definition of 'organised' sewage systems included single-compartment overflow cesspools! According to the results of the same survey, the situation concerning organised drainage from stables is much more worrying, since less than half of the farmers have connected their outbuildings to manure pools. Only a half of the permanently inhabited houses have access to organised waste collection and this percentage is even smaller for vacation houses. Thus, illegal dumps occur in the surroundings of the settlements. A conflict between 'native' and incoming populations grows ever deeper because the locals have become aware that by selling their lands for vacation houses, they have allowed a devaluation of the physiognomy of the alpine landscape. The new buildings have essentially altered the image and function of permanent (villages) and temporary (alpine dairies) settlements; in addition, buildings have also spread into the formerly non-inhabited areas. Particular problems occur because numerous new buildings were also built in the catchment of lakes; for example at lake Jezero na Planini pri Jezeru in an area of difficult access, where the public utilities and infrastructure are now even more deficient.

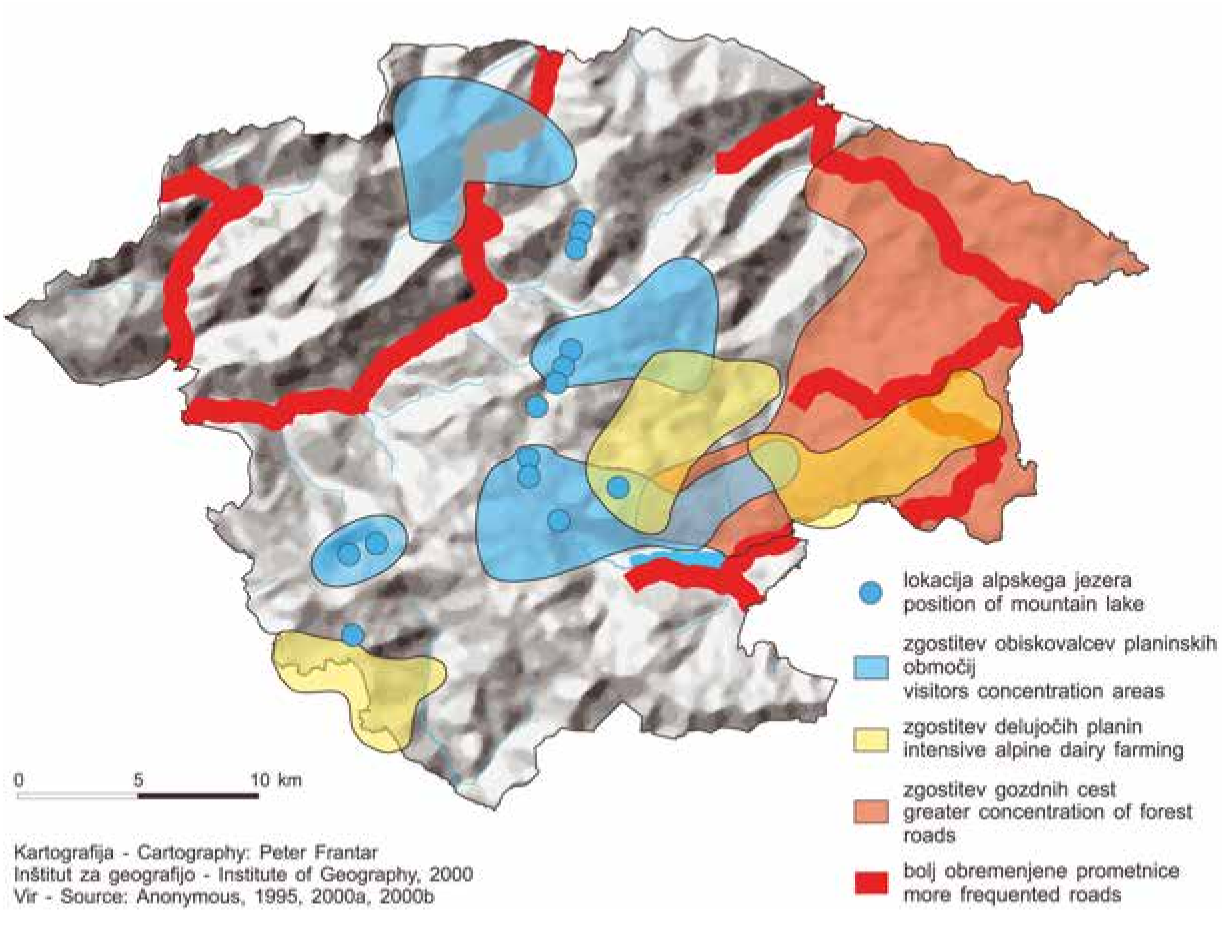
At present the scope of the other above-mentioned sports-recreational activities is still so limited that the load they impose on the environment is not of great concern. However, as almost all the imenovanega daljinskega transporta (Batič in sod., 1999).

Rekreacija v narodnem parku mora biti povsem podrejena varstvu narave in se mora razvijati v smislu doživljanja in izobraževanja v naravi. Usmerjanje obiskovalcev parka na določena območja, ki so žrtvovana za ohranitev večine edinega narodnega parka v Sloveniji, je vsekakor pravilna strategija razvoja, ki že kaže prve pozitivne rezultate. Žal točnega števila obiskovalcev po posameznih območjih ni mogoče podati, lahko pa ocenimo, da so najbolj obremenjena območja Triglava, Bohinjskega jezera, Triglavskih jezer, Krnskega jezera, Trente in Vršiča (slika 4).

activities performed in this area concentrate in certain days, the environment is then undoubtedly overburdened and when viewed from the local perspective, the tolerable threshold is exceeded.

Besides water, air is the second most endangered component of the landscape. The TNP's potential for unpolluted air is often affected by permanent and temporary local pollution sources. The damaged forests on the Pokljuka plateau and in the Fužinarske planine mountains obviously result from global pollution, resulting from long-distance transport pollution (Batič *et al.*, 1999).

Recreation in the national park should be entirely subordinated to environmental protection and should develop to promote education and the experience of the natural environmnet. Directing the tourists to certain areas of the TNP which are 'sacrificed' in order to maintain the major part of the only national park in Slovenia, has proved to




Slika 4: Območja najbolj intenzivne rabe prostora v Triglavskem narodnem parku (Slovenija)
*Figure 4: Areas of intensive landscape use in Triglav National Park (Slovenia)*

Erozija je na nekaterih odsekih gorskih poti, ki so močno obiskane, lahko velik problem. Slika je bila posneta na poti nad Petim triglavskim jezerom. (Foto: Anton Brancelj)
*On parts of high-mountain trails that are highly frequented, erosion can be a serious problem. The photo was taken just above the Fifth Triglav Lake. (Photo: Anton Brancelj)*

be a feasible developmental strategy and has already produced some positive results. Unfortunately, the exact number of visitors to individual areas cannot be obtained, but it can be estimated that the most frequented areas of the TNP are the ones of Mt. Triglav, some lakes (Bohinjsko jezero, the Triglav lakes, Krnsko jezero), Trenta and the Vršič pass (Figure 4).

## ZAKLJUČKI

V Triglavskem narodnem parku smo evidentirali tri glavne dejavnosti, ki so imele odločilno vlogo pri vplivih na okolje. To so bile planinsko pašništvo, oglarjenje s fužinarstvom in turizem ter rekreacija. Intenzivnost človekovih vplivov se je spreminjala in skozi stoletja stopnjevala. Do sredine 16. stoletja so bili učinki povezani predvsem s poseljevanjem planin in rudarjenjem. Sledil je razcvet fužinarstva v podjetniško dejavnost z intenzivnim oglarjenjem in sekanjem zlasti bukovega drevja. Do konca 19. stoletja je prišlo do zatona fužinarstva in gospodarjenje na tem območju se je vrnilo v meje avtarkičnega, samooskrbnega gospodarstva. V 20. stoletju se že pojavijo zametki vplivov industrializa-

## CONCLUSIONS

Three main activities were identified in the TNP, which influence the environment most strongly: alpine dairy farming, forges in association with charcoal burning, and tourism and recreation. Human impacts changed and intensified through the centuries. Until the mid-16$^{th}$ century, the impacts were mainly related to the process of settling the alps and ore excavation. This was followed by the development and expansion of forges, accompanied by intense felling of trees, beech in particular, for charcoal burning. By the end of the 19$^{th}$ century, forges had declined, and life in this area returned to autarkic economy. The origins of industrialisation and its consequent environmental cije, ki se na tem območju razmahne sredi stoletja. Visokogorska območja postanejo zanimiva tudi za alohtone prebivalce, pride do razmaha turizma in rekreacije. Človekove dejavnosti seveda vplivajo tudi na kakovost vode visokogorskih jezer. Vplivi so lahko posredni in neposredni in jih lahko razvrstimo v tri skupine: vnašanje škodljivih in strupenih snovi (npr. pri vzdrževanju in obnavljanju planinskih postojank), vnašanje hranilnih snovi (iz turističnih objektov in zaradi planinskega pašništva) in poseganje v vrstno sestavo jezerskih združb (vnašanje rib) (Brancelj, 1999 b). Dosedanje izkušnje kažejo, da lahko določene negativne posledice človekovih dejavnosti v visokogorskem svetu omilimo, saj jih čisto preprečiti ne moremo. Pri tem pa je pomembno zlasti poznavanje njihovih raznovrstnih vplivov in ozaveščanje prebivalcev ter obiskovalcev o pomenu in občutljivosti teh visokogorskih ekosistemov.

impacts, date from the early 20th century; it was in full swing by mid-century. The high-mountain areas became interesting for people living outside the regions, and tourism and recreation began to flourish. However, human activities affect the quality of water in high-mountain lakes. The impacts are direct or indirect and can be divided into three groups: inputs of harmful and poisonous substances (e.g. resulting from the maintenance and restoration of alpine huts), inputs of nutrients (from tourist facilities, and because of alpine pasturing), and direct interventions that affect the species composition of lakes (e.g. inputs of fish) (Brancelj, 1999 b). Experience has shown that certain negative results of human activities in the high-mountain world can be mitigated, although they can not be completely prevented. In doing so, it is of special importance to know well the diverse impacts of the activities and to inform the inhabitants and visitors of the significance and sensitivity of these high-mountain ecosystems.

Poglavje 14 Chapter

# Zaključki Conclusions

Anton BRANCELJ*

Presenetljivo je, da visokogorska jezera v vzhodnem delu Julijskih Alp, ki po nekaterih lastnostih odstopajo od drugih visokogorskih jezer v Alpah, dolgo časa niso pritegnila pozornosti raziskovalcev. Vse do sredine 90. let 20. stoletja v teh jezerih skoraj ni bilo opravljenih poglobljenih in sistematičnih raziskav. Resnici na ljubo moramo priznati, da tudi marsikje drugje po Alpah stanje ni bilo nič boljše. Naše vedenje o jezerih v Julijskih Alpah, njihovi zgodovini in stanju, predvsem pa o vzrokih za sedanje stanje, se je v zadnjem desetletju močno povečalo. In to prav na račun dolgotrajnih in sistematičnih multidisciplinarnih raziskav.

Štirinajst sicer razmeroma majhnih jezer v vzhodnem delu Julijskih Alp ima zaradi nekaterih naravnih danosti dokaj izjemen položaj med ostalimi visokogorskimi jezeri v Alpah. Nahajajo se na močno zakraselih triasnih in jurskih apnenčastih skladih, kar že samo po sebi omejuje obstoj večjih vodnih teles na površini. Tik ob nekaterih jezerih ležijo vhodi v znane, pa tudi še neraziskane jamske sisteme. Močna zakraselost onemogoča površinsko pretakanje vode iz enega jezera v drugega, razen ob izjemnih dogodkih. Povezave, vsaj med nekaterimi jezeri, obstajajo pod površino, vendar so po dosedanjih raziskavah šibke. Že v preteklosti je nekaj raziskav potrdilo podzemne povezave med posameznimi jezeri in izviri v dolini. Tako sta Jezero na Planini pri Jezeru ter ponor na Planini Laz povezana z izviroma Savice in Govica oz. s potokom Suha in Savica, medtem ko je Zgornje oz. Srednje Kriško jezero povezano z izvirom Krajcarice.

Sledilni poskusi v Dolini sedmerih jezer so po-

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It is surprising that the high-mountain lakes in the eastern part of the Julian Alps, which differ in several of their characteristics from similar lakes in the Alps, did not attract the attention of researchers earlier. Up to the mid-1990s there were no intensive and systematic work undertaken in these lakes. To be fair, the same can be said for the whole area of the Alps. Our knowledge of the lakes in the easternpart of the Julian Alps, their condition as well as their history, has however improved considerably over the last decade, as a result of steady, systematic and multidisciplinary research.

Fourteen relatively small lakes in the Julian Alps have, because of their specific location, have quite a unique position among the high-mountain lakes on the Alps. They are positioned on intensively karstified Triassic and Jurassic limestone strata, which is limiting factor *per se* for existence of bigger permanent surface waterbodies. In some cases, the entrances to explored or still unknown cave systems are just next to the lakes. Intensively karstified areas do not support surface flow of water from one lake to another except in some exceptional circumstances. According to our present knowledge, subsurface connections exist between some lakes, but they are irregular and sporadic. In the past, tracer experiments confirmed underground connections between some high-mountain lakes and springs in the valleys. Water from Jezero na Planini pri Jezeru, for example, appears in the springs of Savica and Govic, and water from the sinkhole on Planina Laz appears in the torrent Suha and in the spring of Savica. Zgornje and/or Srednje Kriško jezero

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kazali dvoje. Po eni strani smo ugotovili, da se Jezero v Ledvicah obnaša kot tolmun v hudourniku, kjer se po močnem deževju v zelo kratkem času izmenja vsa voda. To je verjetno glavni vzrok, zakaj je jezero v tako dobrem stanju. Po drugi strani se je izkazalo, da so povezave z jezeri in izviri nižje po dolini precej počasne in šibke. Iz jezer prevladujejo odtoki v podzemne rove, ki ležijo pod jezeri in šele, ko se ob deževju ti kanali povsem zapolnijo, se začne del vode intenzivneje izlivati v bližnja dolvodna jezera (sistem Jezero v Ledvicah–Močilec–Dvojno jezero). Sicer pa se ob normalnih razmerah večji del vode podzemno odteka proti Savici. Črno jezero je tako izvzeto iz vodnih povezav z ostalimi jezeri v Dolini sedmerih jezer.

Zaradi specifične hidrologije je tako vsako jezero pravzaprav samostojna funkcionalna oz. ekološka enota. Tako obstajajo med jezeri velike razlike, čeprav včasih ležijo blizu skupaj. Odličen primer za to je Dvojno jezero. Ob visoki vodi sta obe jezerski kotanji med seboj povezani in se po fizikalnih in kemijskih lastnostih vode ne razlikujeta. Brž ko pozno spomladi vodna gladina upade in med kotanjama ni več povezave, se vsako začasno jezero obnaša po svoje. Velike razlike so v temperaturi, le nekoliko manjše pa tudi v ostalih fizikalnih in kemijskih lastnostih vode. Tudi v sestavi favne in flore so med njima razlike, in to tako kvalitativne kot kvantitativne.

Zakrasela okolica in sama lega jezer na apnencu daje posebne značilnosti kemijskim in fizikalnim lastnostim njihove vode. Zaradi apnenčaste podlage in pretakanja padavinske vode po podzemnih kanalih preden dospe v jezero, je v vodi veliko raztopljenega apnenca oz. kalcijevih ionov ($Ca^{2+}$). Prevodnost vode je zato velika, pH vrednosti so visoke, prav tako tudi alkaliteta oz. zmožnost nevtraliziranja vodikovih ionov ($H^+$). Vpliv kislega dežja na ta jezera je minimalen, obraten kot pri številnih jezerih na drugačni geološki podlagi, npr. kislih bazaltnih kamninah. So pa zato ta jezera bolj podvržena povečevanju količine hranilnih snovi za rastline v vodi (evtrofikacija).

Evtrofikacija je normalen pojav v razvoju vsakega jezera in je pravzaprav znak staranja. V vsako jezero po naravni poti prihajajo hranilne snovi za rastline, ki so podlaga za delovanje celotnega jezerskega ekosistema. Del teh snovi se preko iztoka hitro odstrani iz jezera, del jih z odmrlimi organizmi potone na dno in se nalagajo v sedimentu, del pa se v procesu mineralizacije organske snovi vrača nazaj v vodni stolpec, kjer jih rastline ponovno porabijo za nastanek nove biomase. V geološko mla-

both has a connections with the spring of Krajcarica.

The tracer experiments in the Triglav Lakes valley have revealed two major facts. Jezero v Ledvicah actually functions as a pool in a torrent where, after a heavy rain, the water is replaced in a very short time. This is probably the main reason for the excellent condition of the lake. On the other hand, connections between the lakes and the springs in the valley are poorly developed and slow. Water from the lakes flows into subterranean galleries below them. Only when the water completely fills the galleries does part of it divert into lakes in the lower part of the valley (the system Jezero v Ledvicah – Močivec – Dvojno jezero). When the water level is normal, most water flows in the direction of the Savica spring. Črno jezero appears to constitute a completely indipendant part of the hydrological system of the Triglav Lakes valley.

Because of the specific hydrological system in the area, each lake behaves as a functional and ecological unit. Even between adjacent lakes large differences can be detected. The best example is the system Dvojno jezero. During high water, both lakes behave as a unit and no difference in water quality can be detected. When, in late spring the water level decreases, the two basins behave independantly. The most obvious feature is difference in temperature. Similar differences can be observed in other physical and chemical parameters and in the qualitative and quantitative composition of flora and fauna.

The location of the lakes on limestone geology have a significant influence on the physical and chemical properties of the lake water. Percolation of water through limestone bedrock in sub-surface channels before entring the lakes results in high concentrations of calcium carbonate in the lake water, including calcium ions ($Ca^{2+}$). High conductivity and pH values as well as high alkalinity, giving high buffering capacity against hydrogen ions ($H^+$) result from such conditions. Effects of acid rain on the lakes are thus minimised in comparison with lakes on many other types of geology, for example on acid basalt rocks. However, lakes on limestone are much more sensitive to increases in plant nutrients, known as eutrophication.

Eutrophication is a normal process in the evolution of most of the lakes and it is actually a sign of aging of a lake. Nutrients are transported into all lakes and they are a primary component for the functioning of lake ecosystems. Some nutrients leave the lakes quickly by outflow. Some are incorporated in dead organisms deposited on the botdih jezerih, ki so običajno oligotrofna, je v vodnem stolpcu in tudi v sedimentu razmeroma malo hranilnih snovi. S staranjem jezera se vse več hranilnih snovi kopiči v sedimentu, od koder se del vrača nazaj v vodo. Takrat jezero prehaja v evtrofno stanje. Posledica je, da se jezerska kotanja začne polniti s sedimenti, ki jih pritoki prinesejo od drugje, del materiala pa izvira iz samega jezera. To so ostanki rastlin in živali, ki se skozi celotno obdobje trajanja jezera kopičijo na dnu. Zaradi določenih razmer, predvsem zaradi pomanjkanja kisika na dnu, je mineralizacija motena ali nepopolna, zato se vse več organske snovi kopiči v sedimentu. Po drugi strani pa se tudi tisti del hranilnih snovi, ki bi v normalnih razmerah ostal v sedimentu, vrača nazaj v vodni stolpec, kjer ponovno vstopi v izgradnjo organske snovi. To so razmere, ki jih lahko označimo kot hipertrofne in vodijo v propad jezera oz. v naslednjo stopnjo razvoja, to je nastanek barja.

Jezera v Julijskih Alpah je v zadnjih nekaj sto letih doletelo kar nekaj dogodkov, povezanih s po-

Odsev vrhov Velikega Špičja na gladini Jezera v Ledvicah (Foto: Anton Brancelj)
*Reflection of peaks of Veliko Špičje in the surface of Jezero v Ledvicah (Photo: Anton Brancelj)*

tom and stored in the sediment. Others are released from dead organisms in a process of mineralisation and re-appear again in the water column, where plants use them for production of new biomass. In geologically young lakes, which are normally oligotrophic, there is a relatively low concentration of nutrients in the water column and in the sediment. In the course of time more and more nutrients are deposited in the sediment and part of them is recycled back into the water column. At this stage, lakes become more and more eutrophic.

Lakes naturally fill with sediment, part of which is largely transported from the watershed, but part of it originates from within the lake itself. Such material is composed of the remains of plants and animals and accumulates on the bottom throughout whole period of a lake's existence. In some specific conditions, especially during oxygen depletion, a process of mineralisation is disturbed and is incomplete, and organic material starts to accumulate on the bottom. At the same time, some nutrients, which in the normal situation remain immobilised in the sediment, return back to the water column and are used again for synthesis of new biomass. This is characteristic of hypereutrophic lakes and is usually an indicator of imminent transiton from standing water body to marsh or bog.

večevanjem hranilnih snovi v vodi. Nekatere so povzročili naravni pojavi, na nekatere pa je vplival človek. Vsekakor pa je zgodovina jezer precej bolj pestra, kot bi to pričakovali glede na njihovo oddaljenost in tudi velikost. Za razliko od večine ostalih visokogorskih jezer v Alpah in širše v Evropi ležijo jezera v Julijskih Alpah na seizmično močno aktivnem območju. Šibkejši in močnejši potresi so pustili sledove tudi v jezerskih sedimentih. Po eni strani so vplivali na hitrost prirastka sedimenta, po drugi strani pa na količino oziroma na povečan vnos hranilnih snovi v jezera. Del hranil je prihajal z organskim drobirjem, ki je skupaj s plazom spolzel v jezero in se je tam še naprej mineraliziral. Po drugi strani pa so potresi in plazovi povzročali tudi premešanje in vrtinčenje sedimenta. Pri tem se je del hranilnih snovi iz sedimenta pospešeno vračal nazaj v vodni stolpec, s čimer se je začasno povečala evtrofikacija jezera. Povečanje količine hranil je najprej vplivalo na bolj bujno rast alg v jezerih. Tem spremembam so sledile tudi živali, čeprav je bila včasih njihova reakcija nekoliko počasnejša, kot bi jo pričakovali glede na povečano količino hrane. Potresi so imeli, vsaj po dosedanjih rezultatih, večji vpliv v jezerih nad gozdno mejo. Drevesa s svojimi koreninami namreč preprečujejo drsenje grušča s pobočij nad jezeri v sama jezera. S tem pa se zmanjšuje tudi vnos hranilnih snovi.

Daleč največji vpliv na jezera, ki je povezan s hranilnimi snovmi in posledično tudi z organizmi v jezerih, pa ima človek. Začelo se je z izsekavanjem gozda v neposredni okolici jezer pred nekaj stoletji. Posledica tega je bila začasna erozija. Tako je prišlo v jezera več hranilnih snovi, bodisi že v mineralizirani obliki ali pa v organskem drobirju, ki se je tu še naprej razgrajeval, pri tem pa porabljal kisik. Požigalništvo in požari, ki so spremljali izsekavanje, so bili drugi vir hranilnih snovi. Tretji vir so bile živali na paši, ki so se zadrževale ob jezeru, njihove iztrebke, skupaj s pepelom od požarov, pa je voda izpirala v jezera. V zadnjih desetletjih je naseljevanje rib povzročilo v nekaterih jezerih nepopravljive posledice. Ribe so se hranile s planktonskimi organizmi, s čimer so posegle tudi v proces kroženja hranilnih snovi v jezeru. Po drugi strani pa so nekatere druge vrste, ki si iščejo hrano z brskanjem po dnu, prispevale k dodatnemu pospešenemu vračanju hranil nazaj v vodni stolpec. Glede na količino hranilnih snovi v jezerih in tudi po biomasi, predvsem fito- in zooplanktona, spadata vsaj Krnsko jezero in Jezero na Planini pri Jezeru med zelo postarana jezera. Nekatera druga, zlasti tista, ki ležijo blizu planinskih koč ali blizu močno obljudenih

In recent centuries the lakes in the Julian Alps have been impacted by several external influences, which increased the concentration of the nutrients in the water column. Some of them were natural events and some induced by Man. As a result the history of the lakes is much more diverse than may be expected from their remoteness and small size. Unlike most high-mountain lakes in other parts of the Alps, the lakes in the eastern part of the Julian Alps lie on a seismically active area. Earthquakes have left some traces in the sediment. They increased the accumulation rate of sediments as well as the concentration of the nutrients in the water column. Part of the nutrients were transported into the lakes by organic debris, together with littoral slumping and the process of mineralisation continued in the lakes. Earthquakes and slumps also induced mixing and redistribution of the sediment. Some nutrients were released back to the water column where they contributed to temporary eutrophication of the lakes. In the first stage, the increased level of nutrients increased the growth of algae, later followed by animals. The reactions of the latter were somewhat slower as would be expected due to the increased food level. As far as we can reconstruct, the effects of earthquakes were more intensive in the lakes above the tree line. Tree roots stabilise terrestrial sediments and prevent its transport into the lakes. At the same time, input of nutrients is reduced.

By far the most important influence on nutrient transport into the lakes, and consequently on the organisms within them, has been Man. The process commenced a few centuries ago with forest cutting, which resulted in temporary erosion. The concentration of nutrients in the lakes increased. Nutrients were transported into the lakes either in mineral form or as organic debris, which was mineralised in the lakes by a process, which needs oxygen. Fire–raising and fires accompanying forest cutting, were the next source of nutrients. The third source was domestic animals grazing around the lakes, and their excrement, together with ash from the fires, was washed into the lakes. In the last few decades introduction of the fish into some lakes has triggered irreparable damage. Some fish feed on planktonic organisms and thus affect nutrient cycling. Othres feed on organisms in the littoral zone and, during their search for food, disturb the sediment and nutrients are released. In terms of nutrient concentration in the water column, as well as biomass (particularly those of phyto and zooplankton), the lakes Krnsko jezero and Jezero na Planini planinskih poti, pa so na dobri poti, da jima sledijo. Tukaj velja poudariti, da traja sezona obiskov v gorah le tri do štiri mesece. Človekovi vplivi se tako skoncentrirajo na razmeroma kratko poletno obdobje. Po drugi strani pa jezera zaradi neugodnih temperaturnih razmer nimajo na razpolago dovolj časa, da bi nevtralizirala vsaj del negativnih posledic človekove dejavnosti, ki so ali pa še vedno potekajo, v njihovi neposredni bližini (odplake, umivanje in pranje, celo kopanje). Nizke temperature vode in celo več kot pol leta trajajoč ledeni pokrov močno upočasnijo mineralizacijo organskih snovi na dnu jezer. Po drugi strani je oskrba globljih plasti jezer s kisikom zaradi ledu onemogočena.

Vsaj v treh jezerih, ki so zaradi turizma močno ogrožena (Dvojno jezero – obe kotanji in Črno jezero), je zaradi spleta okoliščin stanje nekoliko boljše, kot bi sicer bilo. Vsa tri jezera so globoka med 5 in 8 metri in svetloba sega do dna. Sproščanje hranilnih snovi iz sedimenta, ki je posledica (občasnega) pomanjkanja kisika na dnu, vzpodbudi bujno rast nitastih zelenih alg, ki se razpredejo tik nad

Kristalno čista voda v Rjavem jezeru daje vtis lebdenja. (Foto: Anton Brancelj)

*Crystal-clear water makes the illusion of hovering. (Photo: Anton Brancelj)*

pri Jezeru are highly impacted. Some others, particularly those close to mountain huts and frequently used trails, are in danger of following them. It is important to stress that the tourist season in the high-mountain areas lasts only three or four months. Human impact is therefore concentrated within a short summer period. Low temperatures in the lakes slow down the processes, which can neutralise at least part of the negative effects of human activities, which took, or still take, place near the lakes (sewage disposal, washing, even swimming). Low temperature and long–lasting ice cover decrease the rate of mineralisation of organic material on the lake bottom. Ice cover also prevents transport of oxygen to the near–bottom layers.

In three lakes, highly endangered because of the impact of tourism (Dvojno jezero – both basins and Črno jezero) the situation is somewhat better because of a coincidence of factors. The lakes are 5 to 8 m deep and sunlight penetrates to the bottom. Nutrients released from the sediment as a result of (temporary) oxygen depletion, increase the growth of filamentous green algae just above the sediment surface. The algae function like a nutrient trap and prevent nutrient transport into the water column. Although the release of nutrients from the sediment is probably intensive, chemical analyses of water in

dnom. Te prestrežejo večino hranil in s tem preprečijo prenos hranil navzgor v vodni stolpec. Kemijske analize vode v stolpcu tako pokažejo nizke vrednosti hranilnih snovi, čeprav le-te verjetno pospešeno izhajajo iz sedimenta. Proti jeseni, ko začno alge na dnu odmirati, se v večjih ali manjših kosmih odtrgajo od dna in priplavajo na površje in šele takrat se ljudje zavedo, da je z jezeri nekaj narobe. Dokler bo voda v jezerih dovolj bistra, da bo svetloba segala do dna, bo stanje ostalo takšno, kot je. Ko pa se bodo svetlobne razmere na dnu toliko poslabšale, da nitaste alge ne bodo več mogle uspevati na dnu in se bo s tem njihova vloga filtra izgubila, se bodo namnožile planktonske alge in do tedaj bistra voda se bo zaradi obilice alg obarvala motno zeleno.

Poleg neposrednega onesnaževanja prihajajo v jezera številne snovi tudi iz zraka, bodisi z dežjem ali z vetrom. Izvor teh snovi je lahko razmeroma blizu, lahko pa tudi zelo oddaljen. Nekatere so tudi škodljive ali celo nevarne. Med nevarnimi snovmi so radioaktvni delci, nastali med jedrskimi poskusi v 60. letih, in pa delci, nastali ob nesreči v Černobilu in jih je v sedimentu jezer kar veliko. Prav to dokazuje, da se lahko tovrstni vplivi širijo res zelo daleč in da na Zemlji ni več neonesnaženega predela. Kroglasti ogljikovi delci (SCP) v sedimentu, katerih izvor je izgorevanje fosilnih goriv, kažejo, da so se prvi vplivi industrijskega onesnaževanja v visokogorskih jezerih Julijskih Alp začeli nekako ob koncu 19. stoletja in da je v 50. in 60. letih doseglo svoj višek. Z naftno krizo v 70. letih se je onesnaževanje nekoliko zmanjšalo, vendar je kmalu sledilo, sicer kratkotrajno, novo povečanje. Ko pa se je v Evropi v 80. letih začel kot energent vse bolj uveljavljati plin, se je ta vir onesnaževanja močno zmanjšal. Kroglasti ogljikovi delci sami po sebi sicer niso nevarni ali strupeni. Izkazalo pa se je, da je njihovo število v sedimentu v pozitivni korelaciji z nekaterimi drugimi, bolj nevarnimi in strupenimi snovmi – policikličnimi aromatskimi ogljikovodiki (PAH). Tako SCP-ji kot PAH-i imajo isti izvor – izgorevanje fosilnih goriv. Meritve koncentracij PAH-ov vzdolž vertikalnega profila sedimenta so pokazale podobno zgodovino kot pri SCP-jih, namreč močno povečanje po drugi svetovni vojni in upadanje v 80. letih. Z vidika geografske razporeditve PAH-ov pa so meritve njihovih koncentracij v posameznih jezerih pokazale, da je glavni vir onesnaževanj v predelih, ki ležijo zahodno oz. severozahodno od Julijskih Alp. Njihove koncentracije v jezerih namreč upadajo prav v smeri od zahoda proti vzhodu, od koder pride tudi največ vremenskih motenj z

the water column show low nutrient concentrations. In the autumn, when algae on the bottom die, they emerge on the surface of the lakes and thereby indicating to the causal observer the severe situation in the lakes. Until transparency is adequate to permit light to reach the bottom of the lakes, this situation will continue. As soon as light intensity drops and filamentous algae can no longer thrive on the bottom, the concentration of phytoplankton in the water column will increase and lake water will take on a murky green colour.

An additional material is transported into the lakes from air–borne sources, being transported by wind and rain. Sources of such material can be close to the lakes or far away. Some materials are harmful and dangerous. Among dangerous materials are radioactive particles released into the atmosphere during tests of nuclear weapons in the 1960s and during the Chernobyl accident in 1986. Their concentration in the lake sediment is still relatively high. This indicates that human activities have effects on the global scale and there are no pristine areas left on Earth. Spheroidal carbonaceous particles (SCP) in the sediment, which have their origin in the combustion of fossil fuels, indicates that industrial pollution extended to the lakes in the Julian Alps from the end of the 19th century and reached a maximum in the 1950s and 1960s. The oil crisis of 1970s reduced the pollution, followed by a short but intensive increase. In 1980s, Europe started to use gas as a source of energy and long range transport of SCP and associated material decreased significantly. SCP are not harmful by themselves but they are indicators for other, harmful and potentially toxic, compounds, such as polycyclic aromatic hydrocarbons (PAH). Both SCP and PAH have the same source – combustion of fossil fuels. Concentrations of PAH in sediment cores are similar to those of SCP, with a steep increases after 1945 and a decreases in the 1980s. The concentrations of PAHs in the lakes indicates that the main source of pollution is from the west and north-west of the Julian Alps. Their concentrations in the lakes decreases from west to east in line with the direction that most precipitation enters the region. High-mountain lakes in the eastren Julian Alps are among those lakes receiving relatively high loads of SCPs and PAHs, not only in the Alps, but on the European scale.

Using radioactive particles as markers in sediment cores, we can determine the accumulation rate of the sediment. In the lakes in the eastern part of the Julian Alps, it is between 1 and 3 mm per year. Rate of accumulation depends on the trophic dežjem. Tako po koncentraciji SCP-jev kot tudi PAH-ov spadajo visokogorska jezera v vzhodnem delu Julijskih Alp med bolj obremenjena v Evropi in ne samo v Alpah.

S pomočjo razporeditve radioaktivnih delcev v globinskem profilu sedimenta se da ugotoviti hitrost njegovega prirastka. Hitrost nastajanja sedimenta znaša v jezerih Julijskih Alp med 1 in 3 mm na leto. Debelina prirastka je predvsem odvisna od trofičnega stanja jezera. V oligotrofnem Jezeru v Ledvicah je povprečni prirastek okoli 1 mm na leto, medtem ko je v močno evtrofnem Jezeru na Planini pri Jezeru kar okoli 3 mm. V Jezeru v Ledvicah, kjer je razmeroma malo vodnih organizmov, le-ti vsako leto le malo prispevajo k priraščanju sedimenta. Prav tako je majhen tudi transport delcev iz okolice jezera (organski drobir, delci kamenja, prst). V nasprotju s tem je prirast v Jezeru na Planini pri Jezeru zaradi obilice alg, dokaj hiter. Alge potem, ko odmrejo, potonejo na dno, vendar se zaradi pomanjkanja kisika le počasi mineralizirajo. Enako velja tudi za planktonske rakce in drug organski drobir, ki prispe v jezero.

Flora in favna visokogorskih jezer v vzhodnem delu Julijskih Alp je razmeroma bogata, vendar še

status of a lake. In the oligotrophic Jezero v Ledvicah the annual increment is about 1 mm and in the highly eutrophic Jezero na Planini pri Jezeru it is about 3 mm. In Jezero v Ledvicah there are relatively few organisms, so their annual contribution to the sediment is small. The transport of particles from the lake catchment (organic debris, stone particles, and soil) is also relatively low. In Jezero na Planini pri Jezeru the annual accumulation rate is high because of high concentrations of algae in the water column. After their death the algae sink to the bottom, where there is permanent oxygen depletion which slows down the process of mineralisation. The same is true for zooplankton and organic debris, transported into the lake from the shore.

The flora and fauna in high-mountain lakes of the Julian Alps are relatively rich but our knowledge of them is not complete. More is known about the flora, which is mainly composed of algae. The situation is quite different for the fauna. In the littoral zone, there are several groups of animals, which are poorly studied. Relatively good knowledge exists on some groups of insects, which include water–dwelling larvae and groups of Copepoda and

vedno ne dovolj dobro poznana. Vrzeli v poznavanju so nekoliko manjše pri flori, ki jo predstavljajo skoraj izključno alge, medtem ko je pri favni drugače. Kar nekaj skupin je, ki so še vedno slabo raziskane, predvem tiste v obalnem pasu. Med živalmi so daleč najbolje raziskane nekatere skupine žuželk, katerih ličinke živijo v vodi, ter vodne bolhe (Cladocera) in ceponožci (Copepoda). Med njimi je nekaj posebnosti. Tako npr. v Mlaki v Dolu pod Stadorjem živijo primitivni rakci vrste *Chirocephalus diaphanus*, ki so sicer razširjeni tudi drugod po Evropi, so pa zaradi onesnaževanja ali izsuševanja marsikje že izginili. Druga posebnost je ceponožec *Diaptomus hadzici*, ki je endemit Balkanskega polotoka in je Jezero na Planini pri Jezeru njegovo najbolj severno nahajališče. Druga vrsta, *Pseudomoraria triglavensis*, je bila opisana po primerkih iz Močivca in je zaenkrat pozana samo s te lokacije. Vodna bolha vrste *Chydorus sphaericus* je verjetno ena najbolj splošno razširjenih vrst tudi v svetovnem merilu. Osebki iz visokogorskih jezer Julijskih Alp in tudi nekaterih drugih jezer v Alpah pa so posebnost v tem, da se jeseni v populaciji pojavijo grbasti osebki. Pojav zaenkrat pripisujemo nenadnim ohladitvam vode v obrežnem pasu v jesenskem času, ko se zaradi nizkih temperatur pri levitvah pojavijo motnje, ki vodijo v grbaste oblike.

Klimatske razmere so nasplošno eden od pomembnih dejavnikov, ki določajo ne samo razmere na kopnem, ampak tudi v visokogorskih jezerih. Voda na površini jezer se le redko segreje preko 15 °C, že 2–3 metre pod gladino pa je temperatura celo leto okoli 4 °C. Dolgoletne meritve temperature zraka na Kredarici, pa tudi drugje v Alpah, so pokazale, da se temperatura zraka, in s tem tudi vode v jezerih, v zadnjih desetletjih povišuje. To vpliva tudi na organizme, ki ostanejo po smrti v jezerih kot del sedimenta. Z analizo ostankov v sedimentih smo tako ugotovili, da so se pojavile toploljubne vrste, medtem ko so vrste, ki prenašajo le nizke temperature, izginile ali pa se je število njihovih osebkov zmanjšalo. Podobno smo lahko opazili tudi v vzorcih planktona, ki smo ga nabirali v zadnjih desetih letih.

Vpliv človeka na jezera je bil že v preteklih stoletjih znaten (krčenje gozda, pašništvo), nato pa se je v zadnjem stoletju še intenziviral (onesnaževanje na večje razdalje, vnašanje rib). Sedaj je glavna grožnja jezerom množični turizem, ki je pravzaprav večplastni pojav. Zaradi gradnje novih komunikacij in izboljševanja že obstoječih ter spremembe namembnosti pastirskih stanov postajajo gorski in visokogorski predeli vse bolj dostopni večjemu šte-

Cladocera (water fleas). Other groups are poorly known, also there are some unusual examples. For example, in Mlaka v Dolu pod Stadorjem, there are representatives of a primitive group of crabs (Anostraca), *Chirocephalus diaphanus*. They were common in some places in Europe, but became extinct because of pollution. Anothe curiosity is a copepod *Diaptomus hadzici* which is endemic of the Balkan Peninsula, and Jezero na Planini pri Jezeru is the most northern location of the species. Another species, *Pseudomoraria triglavensis*, was described from the spring Močivec which is its only known location. The cladoceran species *Chydorus sphaericus* is one of the most widespread species on the Earth. Specimens from the high-mountain lakes from the Julian Alps, and from some other lakes in the Alps, are unique, because in autumn humpback specimens appear within their populations. This phenomenon is probably related to the sudden drops of temperature in the littoral zone, which interfere with the normal processes of moulting, resulting in hump–backed specimens.

Climate conditions are among the most important elements determining not only conditions on the land but also in the high-mountain lakes. Surface water temperatures rarely exceed 15 °C, and only 2–3 metres below the surface there is a constant temperature of 4 °C throughout the year. Long–term measurements of air temperature on Kredarica and in some other parts of the Alps show that air temperature, and consequently water temperature, have increased in the last few decades. Increase of temperature has influenced the organisms living in the lakes which leave their remains in the sediment. Analysing the remains we found that thermophilic species invaded the lakes and species tolerant only to low temperatures disappeared or their populations shrank. We have found the same trend in zooplankton samples collected over the last decade.

Human impact on the lakes during the last few centuries has been significant (forest cutting, pasturing) and has intensified in the last century (long distance pollution, fish introduction). Nowadays the main threat is mass tourism, which is a multi–layered problem. Building new communications and improving those already existing, changing the use of alpine farmhouses, making mountain and high-mountain regions accessible to more people, attracted there by good huts, all have their effect. Increased access is encouraged by good communications (roads, transport by helicopters, cable railway), energy supply (especially replacing electrical genvilu ljudi, ki jih tja privablja tudi vse boljša oskrba planinskih koč. To je spet povezano z dobrimi komunikacijami (poti, helikopterski prevozi, žičnice), z oskrbo z energijo (v preteklosti generatorji, sedaj sončne celice) in dvigovanjem nastanitvenega standarda (topla voda, sanitarije, prehrana). Veliko ljudi pomeni veliko obremenjevanje okolja (sanitarni in komunalni odpadki in tudi erozija na planinskih poteh), ki je le v nekaj primerih zadovoljivo rešeno. Pri tem so najbolj obremenjena jezera pod gozdno mejo, kjer je skoncentrirana večina turistične dejavnosti in je zadrževalni čas ljudi večji. Višje ko ležijo jezera, manj so izpostavljena, še zlasti če ležijo izven ustaljenih planinskih poti. Izjemi sta Zeleno in Rjavo jezero. V Zelenem jezeru vodni makrofiti še uspejo nevtralizirati negativne vplive obiskovalcev (umivanje in tudi opravljanje potrebe). K boljšemu stanju jezer nad gozdno mejo prispeva tudi geološka zgradba, saj prevladuje pretakanje vod v navpični smeri, s tem pa se vplivno območje potencialnega onesnaževanja z bregov močno zmanjša.

Štirinajst majhnih visokogorskih jezer v vzhodnem delu Julijskih Alp je v zadnjem desetletju razkrilo nekaj skrivnosti. Pri tem se je izkazalo, da so s strokovnega vidika zelo zanimiva, zaradi okoliščin zelo raznovrstna, v geološkem smislu zelo dinamična in predvsem, zaradi človeka zelo ogrožena.

erators with solar energy) and accommodation standards (hot water, sanitation, food). Increased visitor numbers means high pressure on the environment (wastewater from sanitation, garbage, erosion on trails) and these problems have been mitigated in only a few cases. The most vulnerable are the lakes below the tree line, where most tourist activities are concentrated and the residence time of visitors is relatively long. Lakes at higher altitudes are less threatened, particularly if they are far away from the main trails. The exceptions are Zeleno jezero and Rjavo jezero. Macrophytes in Zeleno jezero are probably the most important mitigating factor that neutralises the negative influence of visitors by absorbing the nutrients and organic material discharged by human wastes. Part of the relatively good conditions of the lakes above the tree line can be attributed to geology. The main water flow is in a vertical direction, which significantly reduces the effective area of potential pollution from the shore.

In the last decade studies of 14 high-mountain lakes in the eastern part of the Julian Alps have revealed their scientific interest, their environmental diversity and their geologic dynamism. Most importantly it is clear that these lakes are extremely endangered because of human activities.

Nadzornik (Foto: Anton Brancelj) / *Supervisor (Photo: Anton Brancelj)*

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# Seznam alg iz jezer vzhodnega dela Julijskih Apl

# List of algae from the lakes of the eastern part of the Julijan Alps

| | Jezero pod Vršacem | Rjavo jezero | Zeleno jezero | Jezero v Ledvicah | Dvojno peto jezero | Dvojno šesto jezero | Črno jezero | Jezero na Planini pri Jezeru | Krnsko jezero | Dupeljsko jezero | Jezero v Lužnici | Zgornje Kriško jezero | Srednje Kriško jezero | Spodnje Kriško jezero |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CYANOPHYTA | | | | | | | | | | | | | | |
| *Anabaena sp.* Bory | | | X | | | | | | | | | | | |
| *Aphanocapsa biformis* (Rabenhorst) A. Braun | | X | | | | | | X | | | | | | |
| *Aphanocapsa sp.* Nägeli | | X | X | X | X | X | X | X | X | | | X | | X |
| *Aphanothece grevillei* (Hassal) Rabenhorst | | | | X | | | | | | | | | | |
| *Aphanothece microscopica* Nägeli | | | X | | | | | | | | | | | |
| *Aphanothece sp.* Nägeli | | X | | | | | | | | | | X | X | X |
| *Calothrix parietina* Thuret | | | X | X | X | X | X | X | X | X | | X | X | X |
| *Calothrix sp.* Agardh | X | | | | | X | | | X | | | | | |
| *Chamaesiphon confervicolus* A. Braun | | | | | X | | | | | | X | X | X | |
| *Chamaesiphon fuscus* (Rostafinski) Hansgirg | X | X | | | | X | | | | | | | | |
| *Chamaesiphon polonicus* (Rostafinski) Hansgirg | | | | | | | | | | | | | X | |
| *Chroococcus giganteus* W. West | | | | | X | X | X | X | X | | | | | |
| *Chroococcus helveticus* Nägeli | | | | X | | | | | | | | | | |
| *Chroococcus limneticus* Lemmermann | | | | | | | X | | | | | | | |
| *Chroococcus minor* (Kützing) Nägeli | | | | | | | | | | X | | | | |
| *Chroococcus minutus* (Kützing) Nägeli | | X | | X | X | X | | X | X | | | | X | X |
| *Chroococcus tenax* (Kirchner) Hieronymus | | | | | | | | | | | X | | X | X |
| *Chroococcus turgidus* (Kützing) Nägeli | | X | X | | X | | | X | X | X | | | X | X |
| *Chroococcus westii* (W.West) Boye-Petersen | | X | | X | | | | | | | | | X | |
| *Coelosphaerium kutzingianum* Nägeli | | | | | X | X | X | X | | | | | | |
| *Coelosphaerium naegelianum* Unger | | | | | | | | | X | | | | | |
| *Dactylococcopsis rhaphidioides* Hansgirg | | | | | | | | | X | | | | | |
| *Dermocarpa aqua-dulcis* (Reinsch) Geitler | | | X | | | | | | | | | | | |
| *Dichotrix sp.* Zanardini | | | | | X | | | | | | | | | |
| *Gloeocapsa aeruginosa* Kützing | | X | X | X | | | | | | | | X | | |
| *Gloeocapsa alpina* Nägeli em. Brand | | | X | X | X | X | | X | X | | | X | X | |
| *Gloeocapsa kützingiana* Nägeli | X | X | X | X | X | X | | X | X | | | | | X |
| *Gloeocapsa magma* (Brébisson) Hollerbach | X | X | X | X | X | X | X | X | X | | | | | X |
| *Gloeocapsa minor* (Kützing) Hollerbach | | | | | | | X | | | | | | | |
| *Gloeocapsa montana* Kützing | | | | X | | | | | | | | | | |
| *Gloeocapsa rupestris* Kützing | | | | | | | | | | X | | | | |
| *Gloeocapsa sp.* (Kützing) Hollerbach | X | | | | | | | | | | | | | |
| *Gloeothece rupestris* (Lyngbye) Bornet | | | X | X | | | | | | X | | | | X |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Gomphosphaeria aponina* Kützing | X | | X | | X | X | X | | | | | | | |
| *Gomphosphaeria fusca* Skuja | X | | X | | | | | | | | | | | |
| *Gomphosphaeria lacustris* Chodat | | | X | X | X | | | | | | | | | |
| *Holopedia dednensis* Pevalek | | | | | | | | | | X | | | | |
| *Homoeothrix juliana* (Meneghini) Kirchner | | | | X | | | | | | | | | | |
| *Homoeothrix sp.* (Thuret) Kirchner | | | X | X | X | X | | X | X | | | | | |
| *Hydrocoleus subcrustaceus* Hansgirg | | X | X | X | | X | X | X | | | | | | |
| *Leptochaete rivularis* Hansgirg | X | X | X | X | X | X | X | X | X | | | X | X | X |
| *Lyngbya epiphytica* Hieronymus | | | X | | | | | X | | | | | | |
| *Lyngbya kützingii* Schmidle | | | | | | X | | X | | | X | X | X | |
| *Lyngbya limnetica* Lemmermann | | X | X | X | X | X | X | | X | | | | X | |
| *Lyngbya major* Meneghini | | | X | | | X | X | X | X | | | | | X |
| *Lyngbya martensiana* Meneghini | | X | | | | | | | | | | | | |
| *Lyngbya sp.* Agardh | X | | | | | | | | | | | | | |
| *Merismopedia elegans* A. Braun | | | X | | X | X | | | X | X | | | | |
| *Merismopedia glauca* Nägeli | | | X | | | | X | X | X | X | X | X | | |
| *Merismopedia punctata* Meyen | X | X | X | | X | X | | | | | | | | |
| *Merismopedia tenuissima* Lemmermann | | | X | | | | | | | | | | | |
| *Microcoleus sp.* Desmazieres | | | | | | | X | X | | | | | | |
| *Microcoleus vaginatus* (Vaucher) Gomont | X | | | | | | | | | | | | | |
| *Microcystis aeruginosa* Kützing | | | | | | | | | | | | | | X |
| *Microcystis pulvera* (Wood) Forti | | | | | X | X | X | X | | | | X | | |
| *Microcystis sp.* Kützing | | | X | X | X | X | X | X | | X | | | | |
| *Nostoc commune* Vaucher | X | X | | | | | | | | X | | | | |
| *Nostoc kihlmannii* Lemmermann | | X | | | | | | | | | | | | |
| *Nostoc microscopicum* Carmichael | | | X | | | | | | | | | | | |
| *Nostoc muscorum* Agardh | | | | | | | | X | | | | | | X |
| *Nostoc sp.* Vaucher | | | | | X | X | | | | | | | | |
| *Oscillatoria agardhii* Gomont | | | | | | | | X - | | | | | | |
| *Oscillatoria amoena* (Kützing) Gomont | | | | | | X | | | | | | | | |
| *Oscillatoria chlorina* Kützing | | | X | | | | | | | | | | | |
| *Oscillatoria formosa* Bory | | | | | X | | | X | X | X | | | | |
| *Oscillatoria irrigua* (Kützing) Gomont | X | X | X | | | | | | | | | | | |
| *Oscillatoria limnetica* Lemmermann | | | X | | X | X | | | | | | | | |
| *Oscillatoria limosa* Agardh | | | X | X | | X | | X | X | X | | | | X |
| *Oscillatoria princeps* Vaucher | | | | | X | X | | X | | | | | | |
| *Oscillatoria sp.* Vaucher | X | | | | | | | | X | | | | | |
| *Oscillatoria subtilissima* Kützing | X | X | X | | X | X | | X | X | | | X | | X |
| *Phormidium autumnale* (Agardh) Gomont | | | | | | | | X | | | | X | | |
| *Phormidium corium* (Agardh) Gomont | X | X | X | X | X | X | X | | X | X | X | X | X | X |
| *Phormidium favosum* (Bory) Gomont | X | X | X | X | X | X | X | X | | X | | X | X | |
| *Phormidium retzii* (Agardh) Gomont | | | | | | | | X | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Phormidium sp.* Kützing | | X | | | | | X | X | | | | | X | |
| *Phormidium subfuscum* (Agardh) Kützing | | | | | | | | | X | | | | | |
| *Plectonema radiosum* (Schidermayer) Gomont | | X | | X | X | X | X | | | | | | X | |
| *Plectonema sp.* Thuret | | | | | X | | | | | | | | | |
| *Pleurocapsa fluviatilis* Lagerheim | X | X | X | | | | | | | | | | | |
| *Pleurocapsa minor* Hansgirg em. Geitler | X | X | X | X | X | X | X | X | | | | X | X | X |
| *Pleurocapsa montana* Racib. | | X | X | | X | X | | | X | | | | | |
| *Pseudanabaena catenata* Lauterborn | | | | | | | | | | | | X | X | |
| *Pseudanabaena constricta* (Szafer) Lauterborn | | | | | X | X | | X | X | X | | | | |
| *Pseudanabaena galeata* Böcher | | | X | X | | | | X | X | | | X | | |
| *Pseudanabaena limnetica* (Lemmermann) Komárek | | | | | X | X | | | | X | | | | |
| *Pseudanabaena sp.* Lauterborn | | | | | | | | X | | | | | | |
| *Scytonema myochrous* (Dillwyn) Agardh | X | | | | | X | X | | | | | X | | |
| *Scytonema sp.* Agardh | | | | X | | X | | X | | | | | | |
| *Stigonema ocellatum* (Dillwyn) Thuret | | X | | | | | | | | | | | | |
| *Symploca sp.* Kützing | | | | | | | | | X | | | | | |
| *Synechococcus sp.* Nägeli | | | | | | | | | | X | | | | |
| *Tolypothrix distorta* Kützing | | | | | | | X | | | | | | | |
| *Tolypothrix sp.* Kützing | | | | | | | | X | | | | | X | |
| CHRYSOPHYCEAE | | | | | | | | | | | | | | |
| *Chrysococcus sp.* Klebs | | | | | | | | | X | | | | | |
| *Dinobryon acuminatum* Ruttner | | | | | | | | | X | | | | | |
| *Dinobryon divergens* Imhof | | | X | X | X | X | X | | X | X | | | | |
| *Mallomonas sp.* Perty | | | | | | | X | | | | | | | |
| BACILLARIOPHYCEAE | | | | | | | | | | | | | | |
| *Achnanthes conspicua* A. Mayer | X | X | X | | | X | | X | X | X | X | X | X | |
| *Achnanthes flexella* (Kützing) Brunth. Kützing | X | X | | X | X | | X | X | X | X | | X | | X |
| *Achnanthes fragilaroides* Petersen | X | | | | | | | | | | | | | |
| *Achnanthes helvetica* (Hustedt) Lange-Bertalot | | X | X | X | X | | | X | X | X | X | | | X |
| *Achnanthes laevis* Oesterup | X | | | | | | | | | | | | | |
| *Achnanthes lanceolata* (Brébisson) Grunow | X | | X | X | X | X | | X | X | X | | X | X | X |
| *Achnanthes minutissima* Kützing | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Achnanthes sp.* Bory | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Amphora libyca* Ehrenberg | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Amphora ovalis* Kützing | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Amphora pediculus* (Kützing) Grunow | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| *Amphora sp.* Ehrenberg | | | | | | | | X | | | | | | |
| *Amphora veneta* Kützing | | X | | | | | | | | | | | | |
| *Anomoeoneis styriaca* (Grunow) Hustedt | | | | | | | | | | | | X | X | |
| *Anomoeoneis vitrea* (Grunow) Ross | | | X | X | | X | | X | X | | | | | X |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Asterionella formosa* Hassall | X | | X | | X | | | X | | | | | | |
| *Aulacoseira sp.* Thwaites | X | X | X | X | X | X | X | | X | X | X | X | X | X |
| *Caloneis alpestris* (Grunow) Cleve | X | | | X | X | X | X | | | | | X | | X |
| *Caloneis silicula* (Ehrenberg) Cleve | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Campylodiscus hybericus* Ehrenberg | | | | | | | | | | | | X | | |
| *Cocconeis pediculus* Ehrenberg | | | | | | | | | | | X | X | | |
| *Cocconeis placentula* Ehrenberg | X | | | X | X | | | X | | X | X | | | |
| *Cyclotella comensis* Grunow | | | | | | | | | | | | | X | |
| *Cyclotella krammerii* Håkansson | | | | | | | | X | X | | | | | |
| *Cyclotella meneghiniana* Kützing | | | | | | | X | | | | | | | |
| *Cyclotella ocellata* Pantocsek | | | | | | | | | | | X | | X | |
| *Cyclotella radiosa* (Grunow) Lemmermann | X | X | X | X | X | X | X | X | X | | X | X | | X |
| *Cyclotella sp.* (Kützing) Brébisson | X | | | | | X | | X | | | | | | |
| *Cymatopleura elliptica* (Brébisson) W. Smith | | | | | | X | | | | | | | | |
| *Cymatopleura solea* (Brébisson) W. Smith | | | | | X | | | | | | | | | |
| *Cymbella affinis* Kützing | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Cymbella amphycephala* Nägeli | | | | | | | | X | | X | | | | |
| *Cymbella caespitosa* (Kützing) Brun | | | X | X | X | X | X | X | X | X | X | | X | X |
| *Cymbella cistula* (Ehrenberg) Kirchner | | | | X | X | X | X | X | X | X | X | | | |
| *Cymbella cuspidata* Kützing | | | | | X | | X | X | | X | X | | | X |
| *Cymbella delicatula* Kützing | | X | X | X | | X | | | | | X | | X | X |
| *Cymbella ehrenbergii* Kützing | | X | X | | X | X | X | X | X | X | X | | X | X |
| *Cymbella gracilis* (Ehrenberg) Kützing | | | | X | X | | | | | | X | | | |
| *Cymbella helvetica* Kützing | | | X | | | | | X | | | X | | | |
| *Cymbella leptoceros* (Ehrenberg) Kützing | | | | | | | | X | | | | | | |
| *Cymbella microcephala* Grunow | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Cymbella minuta* Hilse | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Cymbella reichardtii* Krammer | | | | | | | | X | X | X | X | X | X | |
| *Cymbella reindhartii* Grunow | | | | | | | X | | | | | | | |
| *Cymbella silesiaca* Bleisch | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Cymbella sinuata* Gregory | X | | | | X | | | X | | X | X | X | | X |
| *Cymbella sp.* Agardh | | X | X | X | | | X | | X | | | | | X |
| *Cymbella subaequalis* Grunow | | X | X | X | X | X | | X | X | | X | | | X |
| *Cymbella tumida* (Brébisson) Van Heurck | | | | | | | | | X | | | | | |
| *Denticula sp.* Kützing | X | | | | | | | | | | | | | |
| *Denticula tenuis* Kützing | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Diatoma mesodon* (Ehrenberg) Kützing | X | | | | | | | | | | | | | |
| *Diatoma vulgaris* Bory | | | | | | X | | X | | | X | X | X | X |
| *Didymosphenia geminata* (Lyngbye) M. Schmidt | | | | | X | | | | | | | | | |
| *Diploneis elliptica* (Kützing) Cleve | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Diploneis minuta* Petersen | | | | | | X | | X | | | | | | |
| *Diploneis oblongella* (Nägeli) Cleve-Euler | | | | | | | | | | | | | | X |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Diploneis oculata* (Brébisson) Cleve | X | | X | | | | X | | | | | | | |
| *Diploneis ovalis* (Hilse) Cleve | | | | | | X | X | | X | | X | | X | X |
| *Diploneis sp.* Ehrenberg | | | | | | | X | | X | | | | | |
| *Epithemia adnata* (Kützing) Brébisson | | | | | | | | | X | | | | | |
| *Epithemia sorex* Kützing | | | X | | | | | X | X | | | | | |
| *Epithemia sp.* Kützing | | | | | X | X | | | | | | | | |
| *Eunotia exigua* (Brébisson) Rabenhorst | X | | | | | | | | | | | | | |
| *Eunotia praerupta* Ehrenberg | | | | | X | X | X | X | X | | | | | |
| *Eunotia sp.* Ehrenberg | | | X | | | | X | | | | | | | |
| *Eunotia tenella* (Grunow) Hustedt | | X | | | | | | | | | | | | |
| *Fragilaria capucina* Desmazieres | | | X | | | | | | | X | | | | |
| *Fragilaria construens binodis* (Ehrenberg) Hustedt | X | | X | X | | X | X | | | | X | X | | X |
| *Fragilaria construens construens* (Ehrenberg) Grunow | | | | | X | X | X | X | | X | X | | | |
| *Fragilaria construens venter* (Ehrenberg) Grunow | | | X | | | | X | X | X | X | X | X | | |
| *Fragilaria crotonensis* Kitton | X | X | X | | X | | | X | | | | | | |
| *Fragilaria nanana* Lange-Bertalot | | | | | | | | | X | | | | | |
| *Fragilaria parasitica* (W. Smith) Grunow | | | | X | X | X | | | | | | | | X |
| *Fragilaria pinnata* Ehrenberg | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Fragilaria ulna acus* (Kützing) Lange-Bertalot | X | | X | | | X | | X | X | X | | X | | |
| *Fragilaria ulna ulna* (Nitzsch) Lange-Bertalot | | | | | | X | | X | X | X | | | | |
| *Gomphonema acuminatum* Ehrenberg | | | X | | | X | X | X | | X | | | | X |
| *Gomphonema angustum* Agardh | X | X | X | X | X | X | X | X | | | X | X | X | X |
| *Gomphonema clavatum* Ehrenberg | | X | | X | X | X | | X | X | X | X | | | |
| *Gomphonema gracile* Ehrenberg | | | | X | X | X | | | | X | | | | |
| *Gomphonema minutum* Agardh | X | X | | X | X | X | X | | | X | X | | | X |
| *Gomphonema sp.* Agardh | | | | | X | X | X | | | | X | | | |
| *Gomphonema truncatum* Ehrenberg | | | X | | | X | X | X | X | X | | | | X |
| *Gyrosigma acuminatum* (Kützing) Rabenhorst | | | | X | | | | | | | | | | |
| *Hantzschia amphioxys* (Ehrenberg) Grunow | X | X | X | | | X | X | X | X | | X | | | |
| *Melosira varians* Agardh | | X | | | | | | | | | X | | | |
| *Meridion circulare* (Greville) Agardh | X | | | | | | | | | | | | | X |
| *Navicula amphibola* Cleve | | | | | | | | | X | | | | | |
| *Navicula atomus* (Kützing) Grunow | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Navicula capitatoradiata* Germain | | | | | | | X | | | | | | | |
| *Navicula clementis* Grunow | | | | X | X | X | | X | | | | | | |
| *Navicula contenta* Grunow | X | X | | X | X | X | X | X | X | X | X | X | X | X |
| *Navicula cryptotenella* Lange-Bertalot | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Navicula dicephala* (Ehrenberg) W. Smith | | | | | | | X | | | X | | | | |
| *Navicula disjuncta* Hustedt | | | | X | | | | | | | X | X | X | X |
| *Navicula fragilaroides* Krasske | | X | X | X | X | X | X | | X | | X | | | |
| *Navicula gallica* (W. Smith) Lagerstedt | | X | | | | X | | | | | X | | | |
| *Navicula laevissima* Kützing | X | X | | | | X | X | X | X | X | X | | | X |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Navicula lapidosa* Krasske | | X | | | | | | | | | | | | |
| *Navicula menisculus* Schumann | | | X | | X | X | | X | X | X | | | X | X |
| *Navicula mutica* Kützing | X | X | | X | | X | X | | | | X | X | | X |
| *Navicula placentula* (Ehrenberg) Grunow | | | | X | | | | | | | | | | |
| *Navicula pupula* Kützing | X | | X | | X | X | X | X | X | X | X | X | X | X |
| *Navicula radiosa* Kützing | X | | X | X | X | X | X | X | X | X | X | X | X | X |
| *Navicula reichardtiana* Lange-Bertalot | | | | | X | | | | | | | | | |
| *Navicula schoenfeldii* Hustedt | | | | X | | | | | | | | | | |
| *Navicula seminulum* Grunow | | X | | | | | | | | | | | | |
| *Navicula sp.* Bory | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| *Navicula tripunctata* (O. F. Müller) Bory | | | X | | | | | | | | | | | |
| *Navicula trivialis* Lange-Bertalot | | | | | X | X | | X | | | | X | X | X |
| *Neidium affine* (Ehrenberg) Pfitzer | | | | | | | | | X | X | | | | |
| *Neidium binodeforme* Krammer | | | X | | | | | | | | | | | |
| *Neidium binodis* (Ehrenberg.) Hustedt | | | | | | | | | | X | | | | |
| *Neidium dubium* (Ehrenberg) Cleve | | X | X | | X | X | X | X | X | X | X | X | X | |
| *Neidium iridis* (Ehrenberg) Cleve | | | X | X | X | X | X | X | X | X | | | X | X |
| *Nitzschia acicularis* (Kützing) W. Smith | | | | | | | | X | | X | | | | |
| *Nitzschia angustata* Grunow | | | X | X | | | X | X | X | X | | | | |
| *Nitzschia angustatula* Lange-Bertalot | | | | | | X | | | | | | | | |
| *Nitzschia capitellata* Hustedt | | | | | | | | | X | | | | | |
| *Nitzschia fonticola* Grunow | X | X | X | | | | | X | X | X | X | X | X | X |
| *Nitzschia frustulum* (Kützing) Grunow | | | X | | | | | X | X | | X | | | X |
| *Nitzschia linearis* (Agardh) W. Smith | | | | X | X | X | X | X | | X | | | | X |
| *Nitzschia palea* (Kützing) W. Smith | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Nitzschia paleacea* Grunow | | | | X | | | | X | | | | | | |
| *Nitzschia panduriformis* Gregory | | | | | X | | | | | | | | | |
| *Nitzschia sp.* Hassall | X | | X | X | | X | | | X | X | | X | X | |
| *Nitzschia vitrea* Norman | | | | | X | | | | | | | | | |
| *Pinnularia borealis* Ehrenberg | | | | | X | | | X | | X | X | | | |
| *Pinnularia interrupta* W. Smith | | | | | X | | X | | X | | X | | | |
| *Pinnularia maior* (Kützing) Rabenhorst | | | | | X | | | | | X | | | | |
| *Pinnularia microstauron* (Ehrenberg) Cleve | X | | X | X | X | X | | X | | X | X | X | | X |
| *Pinnularia sp.* Ehrenberg | | | | | | X | X | | | | | | | |
| *Pinnularia viridis* (Nitzsch) Ehrenberg | | X | X | X | X | X | X | | X | X | X | | X | |
| *Stauroneis anceps* Ehrenberg | | X | X | | | X | | X | X | X | X | X | X | |
| *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg | | | | | | | X | | | | | | | |
| *Stauroneis smithii* Grunow | X | | X | X | | | | X | | X | | X | | X |
| *Stephanodiscus dubius* (Fricke) Hustedt | | | | | | | X | | X | | X | | | X |
| *Stephanodiscus parvus* Stoermer & Håkansson | X | | | | | | | X | | X | | | | |
| *Stephanodiscus sp.* Ehrenberg | | | | | | | X | X | | | | | X | |
| *Surirella angusta* Kützing | X | | | | | | | X | | | | | | X |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Surirella bifrons* Ehrenberg | X | | X | | | X | X | | X | X | X | | | X |
| *Surirella biseriata* Brébisson | | | | | | | | | X | | X | | | |
| *Surirella constricta* W. Smith | | | | | X | | | | | | | | | |
| *Surirella linearis* W. Smith | X | | X | | | | | | | | | | | |
| *Surirella minuta* Brébisson | | | | | X | | | | | | | | | |
| *Surirella sp.* Turpin | | | X | | | | | | | | | | | |
| *Surirella spiralis* Kützing | | | | | X | | | | | | | | | |
| *Tabellaria flocculosa* (Roth) Kützing | | | | | | | | | | X | | | | |
| PYRROPHYTA | | | | | | | | | | | | | | |
| *Cryptomonas sp.* Ehrenberg | | | | | | | | X | | | | | | |
| *Glenodinium montanum* Klebs | | | | | | | X | | | | | | | |
| *Glenodinium oculatum* Stein | | | | | | X | X | | | | | | | |
| *Gymnodinium palustre* Schilling | | | | | X | X | | | | | | | | |
| *Gymnodinium paradoxum* Schilling | X | X | X | | | X | | | | | | | | |
| *Peridinium cinctum* (Müller) Ehrenberg | | | | | | X | | | | X | | | | |
| *Peridinium sp.* Ehrenberg | | | | | X | | | X | X | X | | | | |
| EUGLENOPHYTA | | | | | | | | | | | | | | |
| *Euglena caudata* Hübner | | | | | | | | | | X | | | | |
| *Euglena sp.* Ehrenberg | | | | X | | | | | | | | | | |
| *Euglena spirogyra* Ehrenberg | | | | | | | | X | | | | | | |
| *Phacus caudatus* Hübner | | | | | | | | X | | | | | X | |
| *Phacus longicauda* (Ehrenberg) Dujardin | | | | | | | | X | | | | | | |
| *Phacus pleuronectes* (O. F. Müller) Dujardin | | | | | | | | X | | | | | | |
| *Phacus sp.* Dujardin | | | | | | | | X | | X | | | | |
| *Trachelomonas hispida* Stein. em. Defl. | | | | | | X | | X | | | | | | |
| *Trachelomonas volvocina* Ehrenberg | | | | | X | X | | | | | | | | |
| CHLOROPHYCEAE | | | | | | | | | | | | | | |
| *Ankistrodesmus convolutus* Corda | | | X | | | | | | | | | | | |
| *Ankistrodesmus falcatus* (Corda) Ralfs | | | X | | | | X | | X | | | | | X |
| *Ankistrodesmus sp.* Corda | | | | | | | | | | X | | | X | |
| *Bulbochaete sp.* Agardh | | X | X | | | | | | | X | | | | |
| *Characium sp.* A. Braun | | | | X | X | | | | | | | | | |
| *Chlamydomonas bacillus* Pascher et. Jahoda | X | X | X | X | | | | | | | | | | |
| *Chlamydomonas nivalis* Wille | | | | | | | | | | X | | | | |
| *Chlamydomonas perpusilla* Gerloff | X | | | | | | | | | | | | | |
| *Chlamydomonas sp.* Ehrenberg | | | | | X | X | X | X | | X | | X | | |
| *Chlorella sp.* Beyerink | X | X | | | | | | | | | | | X | |
| *Chlorella vulgaris* Beyerink | | | X | | X | X | | X | | | | | X | |
| *Chlorococcum infusiorum* (Schrank) Meneghini | | | | | X | X | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Chloromonas chlorogoniopsis* (Ettl) Gerloff et Ettl | | | X | | | | | | | | | | | |
| *Cladophora glomerata* (Line) Kützing | | | | | | | | | | X | | | | |
| *Cladophora sp.* Kützing | | | | | | | | | | X | | | | |
| *Coelastrum microporum* Nägeli | | | | | | X | | | | | | | | |
| *Coelastrum pseudomicroporum* Koršikov | X | X | | | | | | | | | | | | |
| *Elakatothrix gelatinosa* Wille | | | | X | | | X | | | | | | | X |
| *Geminella interrupta* Turpin | | | X | | | | | | X | X | | | X | |
| *Geminella mutabilis* (Nägeli) Wille | | | X | | | | | | | X | | | X | |
| *Gloeocystis botryoides* Kützing | | | | | | | | | | | | | X | |
| *Haematococcus sp.* Agardh | | | | | | | | | | | | | X | |
| *Hyalotheca dissiliens* (Smith) Brébisson | | | | | | | | | | | | | X | |
| *Keratococcus bicaudatus* Pascher | | X | | | | | | | | | | | | |
| *Koliella corcontica* Hindak | | | X | | | | | | | | | | | |
| *Microspora pachyderma* (Wille) Lagerheim | | | | | | | | | | | | | X | |
| *Microspora tumidula* Hazen | | | | | | | | | | | | | X | |
| *Monoraphidium griffithii* (Berkeley) Komárková-Legnerová | | | | | | | | | | X | X | | | |
| *Oedogonium echinospermum* A. Braun | | | X | | | | | | | | | | | |
| *Oedogonium sp.* Link | X | X | X | X | | | | X | | X | | X | X | |
| *Oocystis pelagica* Lemmermann | | | X | | | X | | | | | | | X | |
| *Oocystis rupestris* Kirchner | | | | | | | | | X | | | | X | |
| *Pandorina morum* (Müller) Bory | | | | | | | | X | | | | | | |
| *Pediastrum boryanum* (Turpin) Meneghini | | | X | | X | | | X | | X | | X | X | |
| *Pediastrum duplex* Meyen | | | | | | | | | | X | | | X | |
| *Pediastrum sp.* Meyen | | | | | | | | X | | | | | | |
| *Planctosphaeria gelatinosa* G. M. Smith | X | | X | X | X | X | X | X | X | X | | | X | X |
| *Pleurococcus vulgaris* Beyerink | | | | X | | | | | | | | | X | |
| *Richteriella botryoides* (Schmidle) Lemmermann | | | | | | | | | X | | | | | |
| *Scenedesmus abundans* (Kirchner) Chodat | | | | | | | | X | X | | | | | |
| *Scenedesmus acuminatus* (Lagerheim) Chodat | | | | | | | | X | | X | | | | |
| *Scenedesmus acutus* Meyen | | | | | | | | | | X | | | | |
| *Scenedesmus bijugatus* Hansgirg | | | X | | | | | | X | X | | | | |
| *Scenedesmus brasiliensis* Bohlin | | | X | | | | X | | | X | | | | |
| *Scenedesmus denticulatus* Lagerheim | | | | | | | | | | X | | | | |
| *Scenedesmus discimorphus* Chodat | | | X | | | | | | | | | | | |
| *Scenedesmus ecornis* (Ralfs) Chodat | | | | | | X | | X | X | X | | | | |
| *Scenedesmus quadricauda* (Turpin) Brébisson | | | X | | | | | X | | X | | | | |
| *Scenedesmus sp.* Meyen | | X | | | | | | | | | | | | |
| *Selenastrum gracile* Reinsch | | | | | | | X | | | | | | | |
| *Selenastrum sp.* Reinsch | | | | | | | | X | | | | | | |
| *Stichococcus lacustris* Chodat | | | | X | | | | | | | | | | |
| *Tetraedron sp.* Kützing | | | | | | | | | X | | | | | |
| *Tetraedron trigonum* (Nägeli) Hansgirg | | | | | | | | | X | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Tetraspora sp.* Link | | | | | | | | | X | | | | | |
| *Ulothrix subtilissima* Rabenhorst | | | | | | | X | | | | | | | |
| *Ulothrix tenuissima* Kützing | | X | | | | | | | | X | | | | |
| *Ulothrix zonata* Kützing | | | | | | | | | X | | | | | X |
| *Willea irregularis* (Wille) Schmidle | | | | | | | | | X | | | | X | X |
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| *Closterium acerosum* (Schrank) Ehrenberg | | | | | | | | | X | | | | | |
| *Closterium ehrenbergii* Meneghini | | | | | | | | | | X | | | | |
| *Closterium leibleinii* Kützing | | | | | | | | | X | X | | | | |
| *Closterium moniliferum* (Bory) Ehrenberg | | | | | X | X | | | | | | | | |
| *Closterium parvulum* Nägeli | | | | | | | | X | | | | | | |
| *Closterium sp.* Nitzsch | | | | | | | | X | X | | | | | |
| *Closterium venus* Kützing | | | | | | | | X | X | | | | | |
| *Cosmarium abbreviatum* Racib. | | | | | | | | | | | | | X | |
| *Cosmarium alpinum* Racib. | | | | | | | X | | | X | | | | |
| *Cosmarium botrytis* Menenghini | | | X | | X | | X | X | | | X | X | | |
| *Cosmarium constrictum* Delp. | | | X | | | | | | X | X | | | | |
| *Cosmarium curtum* (Brébisson) Ralfs | | | | X | X | X | X | | | | | X | | X |
| *Cosmarium didymochondrum* Nordstedt | | | X | | X | | | | | | | | | X |
| *Cosmarium elipsoideum* Elfw. | | | | | | | | X | | | | | X | |
| *Cosmarium formosulum* Hoff. | X | | | | | | | X | | | | | | |
| *Cosmarium globosum* Bulnh. | | X | | | X | X | X | | | | | | X | |
| *Cosmarium granatum* Brébisson | | | | | X | | | | | | | | | |
| *Cosmarium hammeri* Reinsch | | X | | | | | | | X | | | | X | |
| *Cosmarium heimerlii* West. | | | | | | | | | X | X | | | | |
| *Cosmarium impressulum* Elfw. | | | | | | X | | | X | | X | | | |
| *Cosmarium laeve* Rabenh. | | | X | X | | X | X | | | | | | | |
| *Cosmarium obliquum* Nordstedt | | | | | | | | | | X | | | | |
| *Cosmarium obsoletum* (Hantzsch) Reinsch | | | | | | | | | X | | | | | |
| *Cosmarium ochthodes* Nordstedt | | X | | | X | X | | X | | X | | | | |
| *Cosmarium ornatum* Ralfs | | | | | | | | | X | | | | | |
| *Cosmarium regnelii* Wille | | | | | | | | | | X | | | | |
| *Cosmarium reniforme* (Ralfs) Arch. | | | X | | | | | | | | X | | | |
| *Cosmarium sp.* Corda | | | X | | | | X | X | X | X | X | X | | X |
| *Cosmarium subpachidermum* Schmidle | | | | | X | X | | | | | | | | |
| *Cosmarium subprotumidum* Nordstedt | | | | | | | | | | | | | X | |
| *Cosmarium subtumidum* Nordstedt | | | | | | | | X | X | | | | | |
| *Cosmarium tetraophtalmum* (Kützing) Brébisson | | | | | | | | | X | | | | | |
| *Cosmarium thwaitesii* Ralfs | | | | | X | X | | | | X | | | | |
| *Cosmarium tumidum* Lundell | | | X | | | | | X | X | X | | | | X |
| *Cosmarium tumens* Nordstedt | | | | | | | | X | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cosmarium undulatum* Corda | X | | | | | | | | | X | | | | |
| *Euastrum oblongum* (Grev.) Ralfs | | | | | | | | | X | | | | | |
| *Euastrum crassicole* Lundell | | | | | | | | | | | | | X | |
| *Gonatozygon brebissonii* De Bary | | | | | | | | | | | | | | X |
| *Gonatozygon monotaenium* De Bary | | | | | | | | | | | | | X | |
| *Mougeotia sp.* Agardh | | | | | | X | | | | X | | | X | |
| *Pleurotaenium trabecula* (Ehrenberg) Nägeli | | | X | | X | X | | | | X | | | | |
| *Spirogyra sp.* Link | X | | X | | X | X | X | X | X | X | X | X | X | X |
| *Staurastrum cristatum* (Nägeli) Arch. | | | | | | | | X | | X | | | | |
| *Staurastrum cuspidatum* Brébisson | | | | | | | | X | | X | | | | |
| *Staurastrum dejectum* Brébisson | | | | | | | | | X | X | | | | |
| *Staurastrum dilatatum* Ehrenberg | | | | X | | | | | X | | | | | |
| *Staurastrum gracile* Ralfs | X | | X | X | X | | | X | X | X | | | | X |
| *Staurastrum granulosum* (Ehrenberg) Ralfs | | | | | | | | X | X | X | | | | |
| *Staurastrum inflexum* Brébisson | | | | | | | | X | X | X | | | | |
| *Staurastrum muticum* Brébisson | | | | | | | | X | X | X | | | | |
| *Staurastrum planctonicum* Teiling | | | X | | | | | | | | | | | |
| *Staurastrum polymorphum* Brébisson | | | X | X | | | | X | X | X | | | | X |
| *Staurastrum punctulatum* Brébisson | | | | | | | X | | | | | | | |
| *Staurastrum sp.* Meyen | | | X | | | | | X | X | X | | | | |
| *Zygnema pectinatum* (Vaucher) Agardh | X | | | | | | | | | | | | | |
| *Zygnema sp.* Agardh | | | | | X | X | X | X | X | | | | | |
| RHODOPHYTA | | | | | | | | | | | | | | |
| *Asterocystis sp.* Gobi | | | | | | | | | | X | | | | |

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