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EKOLOŠKI POTENCIJAL AKUMULACIJA ZA VODOSNABDEVANJE U SRBIJI

ECOLOGICAL POTENTIAL OF THE RESERVOIRS FOR WATER SUPPLY IN SERBIA

IZVOD

Agencija za zaštitu životne sredine od 2012. godine vrši monitoring statusa površinskih voda Srbije prema zahtevima Okvirne direktive o vodi EU (2000/60/EC). Monitoring uključuje i akumulacije za vodosnabdevanje stanovništva. U ovoj studiji ukupno je obuhvaćeno 15 akumulacija. Za procenu ekološkog potencijala akumulacija praćeni su sledeći biološki elementi kvaliteta: fitoplankton, fitobentos i makroinvertebrate, opšti fizičko-hemijski elementi, specifične zagađujuće supstance i parametri trofičkog statusa. Eutrofikacija i njena posledica "cvetanje vode" su najozbiljniji problemi sa kojima se suočavamo poslednjih decenija. Situacija se dodatno komplikuje klimatskim promenama i globalnim zagrevanjem. Rezultati ispitivanja pokazuju da su procesi eutrofikacije akumulacija uznapredovali i da se to ozbiljno odrazilo na kvalitet vode: nemamo akumulacije koje imaju dobar i bolji ekološki potencijal. Dve akumulacije koje su blizu postizanja ovog potencijala su Radoinja i Prvonek. Zabrinjavajuće je što se veliki broj akumulacija za vodosnabdevanje nalazi u slabom ili lošem ekološkom potencijalu. U njima je jako narušena struktura i funkcionisanje životnih zajednica fitoplanktona i makroinvertebrata; veliki broj taksona ovih zajednica odsustvuje u odnosu na referentne uslove za jezera.

ABSTRACT

Since 2012 the Serbian Environmental Protection Agency (SEPA) has conducted monitoring of surface water status according to the Water Framework Directive requirements (2000/60/EC). The SEPA monitoring also included the reservoirs intended for water supply. In the present study 15 reservoirs were covered. For ecological potential assessment of reservoirs the following biological quality elements (BQEs) were monitored: phytoplankton, phytobenthos and macroinvertebates, general physico-chemical quality elements (PHQEs), specific polluting substances and parameters of trophic state. Eutrophication and its consequence of water blooming are the most important problems we met in last decades. Such conditions was additionally complicated by climate changes and global warming. The results of present research indicated that eutrophication process of the reservoirs is progressed reflecting on water quality: there are no reservoirs with good and better ecological potential. The worrying fact is that the most of reservoirs intended for water supply are chactaterized by poor or bad ecological potential. In these reservoirs the structure and function of phytoplankton and macroinvertebrate community were degraded; the majority taxa in mentioned communities are absent with regard to reference conditions for lakes.

UVOD

Eutrofikacija je poslednjih decenija, na globalnom nivou, jedan od najozbiljnijih problema koji utiče na kvalitet vode jezera i akumulacija. Povećanje nutrijenata dovodi do sve veće produktivnosti vodenih ekosistema, što može dovesti do prekomernog povećanja biomase algi ili makrofitske vegetacije. Iako fitoplankton ima ključnu ulogu u vodenim ekosistemima, kao osnovni producent organskih materija u vodi, njegovo prekomerno nagomilavanje može ozbiljno uticati na kvalitet vode, naročito u akumulacijama koje se koriste za vodosnabdevanje stanovništva. Neposredne

INTRODUCTION

In recent decades an eutrophication has been recognized as one of the most serious problems globally, affecting water quality of lakes and reservoirs. The increase of nutrients leads to increasing productivity of aquatic ecosystems, which can lead to an excessive increase of algal biomass or macrophytic vegetation. Although phytoplankton plays a key role in aquatic ecosystems as a basic producer of organic matter in water, its excessive accumulation can seriously affect water quality, especially in reservoirs used to supply water to the population. The immediate consequences of this excess growth are numerous,

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posledice ovog viška rasta su brojne, u rasponu od jednostavnog obilja suspendovanih čestica (sam fitoplankton, zooplankton, bakterije, gljivice i detritus), do povećanih koncentracija amonijaka, nitrita, vodonik-sulfida, metana, etana, huminskih kiselina, pa sve do lošeg ukusa i mirisa ribe i vode, zbog prisustva određenih algi i mogućeg razvoja toksičnih algi (Sulis et al., 2014). Ponekad je fenomen toliko očigledan da se golim okom može videti masa mikroskopskih algi koje izazivaju cvetanje, koje daje određeno obojenje vodnom telu. Izraz "cvetanje algi" označava situaciju u kojoj se 80-90 % mase mikroskopskih algi sastoji od jedne ili dve vrste (Sulis et al., 2014).

Još jedan važan aspekt eutrofikacije se ogleda u činjenici da su najčešći uzročnici "cvetanja" vrste koje pripadaju taksonomskoj grupi cijanobakterija. Cijanobakterije su potencijalno toksični organizmi, jer mogu da produkuju širok spektar toksina, koji pokazuju neurotoksično ili hepatoksično dejstvo, ili izazivaju iritaciju kože i očiju i gastrointestinalne smetnje.

Nacionalni program monitoringa kvaliteta voda akumulacija u Srbiji do 2011. godine nije pružao dovoljno podataka da se na adekvatan način sagleda stanje akumulacija. Tome je doprinela zastarela zakonska regulativa u ovoj oblasti. Akumulacije su ispitivane samo jedanput godišnje. Indeksi koji su korišćeni za biološku procenu kvaliteta voda bazirali su se na saprobiološkim karakteristikama planktonske zajednice i uglavnom su pokazivali dobro stanje akumulacija. Donošenjem nove zakonske regulative 2011. godine i usklađivanjem Programa monitoringa površinskih voda sa zahtevima Okvirne Direktive o vodi (ODV, 2000/60/EC), primenjena je potpuno drugačija metodologija ispitivanja akumulacija. Povećana je frekvencija ispitivanja na tri ispitivanja godišnje, povećan je broj ispitivanih lokaliteta i broj tačaka uzorkovanja po vertikalnom profilu akumulacije, primenjena je nova metodologija ispitivanja bioloških i fizičko-hemijskih elemenata kvaliteta i metoda procene statusa vodnih tela prema ODV. Od 2012. godine Programom nacionalnog monitoringa obuhvaćene su akumulacije koje se koriste za vodosnabdevanje stanovništva. Ispitivanje je sprovela Agencija za zaštitu životne sredine prema Uredbama o utvrđivanju godišnjeg programa monitoringa statusa voda za 2012., 2013., 2014., 2015., 2016., 2017., i 2018. godinu (Sl. glasnik RS br. 100/12; Sl. glasnik RS br. 43/13; Sl. glasnik RS br. 85/14; Sl. glasnik RS br. 46/15; Sl. glasnik RS br. 36/16; Sl. glasnik RS br. 35/18).

MATERIJAL I METODE

Biološki elementi kvaliteta (BQEs) koji su korišćeni za procenu ekološkog potencijala akumulacija su: fitoplankton, fitobentos i makroinvertebrate.

ranging from the simple high abundance of suspended particles (phytoplankton itself, zooplankton, bacteria, fungi and detritus) to increased concentrations of Ammonia, Nitrites, Hydrogen Sulfide, Methane, Ethane and humic acids, to bad flavor and smell in fish and water, due to the presence of certain algal taxa, and the possible development of toxic algae (Sulis et al., 2014). Sometimes this phenomenon is so obvious, that the naked eye can see the mass of microscopic algae, which produce blooms giving a particular colouring to the water body. The term "algal blooms" indicates 8090% of the mass of microscopic algae consists of one or two species (Sulis et al., 2014).

Another important aspect of eutrophication is reflected in the fact that the most common causes of "blooming" are species belonging to the taxonomic group of cyanobacteria. Cyanobacteria are potentially toxic organisms, because they can produce a wide range of toxins, which show neurotoxic or hepatotoxic effects or cause skin and eye irritation and gastrointestinal disorders as well.

The National monitoring programme of water quality of reservoir waters in Serbia by 2011 has not provided enough data to assess adequately state of the reservoirs. Obsolete legislation in this area has contributed to this. The reservoirs were examined only once a year. The indices used for the biological assessment of water quality were based on the saprobiological characteristics of the planktonic community and generally showed good condition of the reservoirs. With the adoption of new legislation in 2011 and by harmonizing the Surface Water Monitoring Programme with the EU Water Framework Directive (WFD, 2000/60/EC) requirements, a completely different methodology for investigation of reservoirs was applied. The frequency of investigation was increased to three times per year, the number of tested localities and the number of sampling points per vertical accumulation profile was increased, as well as new methodology for biological and physico-chemical quality elements and methods for assessing the status of water bodies according to WFD were applied.

Since 2012 the National monitoring programme included reservoirs used for water supply of the population. The survey was conducted by the Serbian Environmental Protection Agency according to the regulations on determining the annual water status monitoring program for 2012, 2013, 2014, 2015, 2016, 2017, and 2018 (Official Gazette of the RS No. 100/12; Official Gazette of the RS No. 43/13; Official Gazette of the RS No. 85/14; Official Gazette of the RS No. 46/15; Official Gazette of the RS No. 36/16; Official Gazette of the RS No. 35/18).

MATERIAL AND METHODS

The biological quality elements (BQEs) used to assess ecological potential of the reservoirs are: phytoplankton, phytobenthos and macroinvertebrates. Investigation of the reservoirs was

Ispitivanje akumulacija rađeno je tri puta godišnje: u proleće i leto u periodu termičke stratifikacije, i u jesen u periodu cirkulacije vode. U zavisnosti od morfometrijskih karakteristika akumulacije izvršen je odabir lokaliteta na kojima će se vršiti ispitivanja. Prvo je sprovedeno preliminarno ispitivanje osnovnih fizičko-hemijskih parametara (PHQEs) na više lokaliteta, zatim su odabrana 3-4 lokaliteta na kojima su sprovedena kompletna ispitivanja po dubini vodenog stuba. Lokaliteti u blizini brane označeni su sa A, u centralnom delu akumulacija sa B, zatim sa C ili D idući ka ulazu u akumulaciju. Temperatura vode merena je na svakih pola metra dubine. U periodu termičke stratifikacije prvo su određivane zone epilimniona, metalimniona (termokline) i hipolimniona. Dubinsko uzorkovanje vode za ispitivanje osnovnih fizičko-hemijskih pokazatelja, nutrijenata i hlorofila *a* obavljeno je korišćenjem hidrobiološke boce, ili pumpom i crevom.

Fitoplankton za kvalitativnu analizu uzorkovan je planktonskom mrežom promera okaca 25 μm, a za kvantitativnu analizu hidrobiološkom bocom ili pumpom i crevom sa različitih dubina. Algološki materijal fiksiran je formaldehidom ili Lugolovim rastvorom. Analiza fitoplanktona rađena je na invertnim mikroskopima: Nikon TE-2000U sa digitalnom kamerom DS-5M i softverskim programom NIS-Elements D, Zeiss Axiovert sa digitalnom kamerom i softverskim programom AxioVision 4.8 i Carl Zeiss Axio Observer D1 sa digitalnom kamerom AxioCam ICc 5 i softverskim programom ZEN 2. Kvantitativna analiza fitoplanktona rađena je po metodi Utermöhl (1958), prema standardu SRPS EN 15204: 2008.

Metodologija uzorkovanja fitobentosa (dijatoma) obavljena je prema standardu SRPS EN 13946: 2008. Prikupljeni materijal je fiksiran formaldehidom. Priprema preparata silikatnih algi obavljena je u skladu sa standardom SRPS EN 13946: 2008. Analiza fitobentosa obavljena je na mikroskopima koji su navedeni u analizi fitoplanktona. Identifikacija i prebrojavanje dijatoma i interpretacija dobijenih rezultata urađena je u skladu sa standardom SRPS EN 14407: 2008. Za izračunavanje dijatomnih indeksa korišćen je softverski program OMNIDIA.

Ispitivanje makroinvertebrata akumulacija izvršeno je jednom ili dva puta godišnje. Za uzimanje uzoraka korišćena je ručna mreža (dimenzija 25x25 cm, promera okaca 500 μm) prema AQEM protokolu (AQEM, 2002) i primenjena je "multi-habitat" procedura (Hering et al., 2004). Uzorkovano je prema standardu SRPS EN 27828: 2009. Svi uzorci fiksirani su na terenu korišćenjem 70%-og rastvora etanola. Identifikacija jedinki izvršena je u laboratoriji pomoću odgovarajuće literature, korišćenjem stereomikroskopa Carl Zeiss Stereo Discovery V.8 sa kamerom AxioCam ICc5 i ZEN 2 softverom i

performed three times a year: in spring and summer in the period of thermal stratification, and in autumn in the period of water circulation. Depending on the morphometric characteristics of the reservoir, the sites where the investigation will be performed were selected. Firstly, a preliminary examination of basic physico-chemical parameters (PHQEs) was conducted at several localities, then 3-4 localities were selected where complete examination were conducted along the depth of the water column. The sites near the dam are marked with A, in the central part of the reservoir with B, then with C or D going to the entrance to the reservoir. A water temperature was measured every half a meter of water depth. In the period of thermal stratification, the zones of epilimnion, metalimnion (thermocline) and hypolimnion were firstly determined. Deep sampling of water for testing basic physical and chemical indicators, nutrients and chlorophyll *a* was performed using a hydrobiological bottle, or a pump and hose.

Phytoplankton for qualitative analysis was sampled using a planktonic net with a diameter of 25 μm, and for quantitative analysis with a hydrobiological bottle, or pump and hose from different depths. The algal material was fixed with formaldehyde or Lugol solution. Phytoplankton analysis was performed on invert microscopes: Nikon TE-2000U with digital camera DS-5M and NIS-Elements D software, Zeiss Axiovert with digital camera and AxioVision 4.8 software and Carl Zeiss Axio Observer D1 with digital camera AxioCam ICc 5 and ZEN 2 software. Quantitative analysis of phytoplankton was performed by the Utermöhl method (1958), according to the standard SRPS EN 15204: 2008.

The sampling methodology of phytobenthos (diatoms) was performed according to the standard SRPS EN 13946:2008. The collected material was fixed with formaldehyde. A preparation of silicate algae slide was performed in accordance with the standard SRPS EN 13946: 2008. Analysis of phytobenthos was performed on microscopes listed in the analysis of phytoplankton. Identification and counting of diatoms and interpretation of the obtained results were done in accordance with the standard SRPS EN 14407: 2008. The OMNIDIA software was used for calculation of the diatom indices.

A survey of aquatic macroinvertebrates of the reservoirs was performed once or twice a year. A hand net (dimensions 25x25 cm, diameter 500 μm) according to the AQEM protocol (AQEM, 2002) was used for sampling and the "multi-habitat" procedure was applied (Hering et al., 2004). A sampling of macroinvertebrates was conducted according to the standard SRPS EN 27828: 2009. All samples were fixed in the field using 70% ethanol solution. Identification of specimens was performed in the laboratory by appropriate literature, using stereomikroskopa Leica MS 5. U zavisnosti od tipa vodnog tela na kome je akumulacija formirana, za ocenu ekološkog potencijala korišćeni su sledeći biološki parametri u okviru ASTERICS softvera (AQEM, 2002): saprobni indeks Zelinka & Marvan (Zelinka & Marvan, 1961), BMWP (Biological Monitoring Working Party) skor, Shannon-Weaver indeks diverziteta (Shannon, 1948), ukupan broj taksona, procentualno učešće Oligochaeta/Tubificidae u ukupnoj zajednici makroinvertebrata i broj taksona Ephemeroptera, Plecoptera i Trichoptera - EPT indeks (Armitage et al., 1983).

Trofički status akumulacija određen je preko Carlson indeksa trofičnosti (Carlson's Trophic State Index TSI) (Carlson, 1977). Procena ekološkog potencijala akumulacija na osnovu bioloških i fizičko-hemijskih elemenata kvaliteta urađena je prema Pravilniku o parametrima ekološkog i hemijskog statusa površinskih voda i parametrima hemijskog i kvantitativnog statusa podzemnih voda (Sl. glasnik RS, 74/2011, u daljem tekstu Pravilnik).

REZULTATI I DISKUSIJA

Većina ispitivanih akumulacija pripada dimiktičkom tipu jezerskih sistema umereno-kontinentalne zone, koji karakterišu dva perioda cirkulacije vode, prolećni i jesenji, direktna termička stratifikacija u letnjem periodu i inverzna (obrnuta) stratifikacija u zimskom. Tokom blagih zima inverzna termička stratifikacija može izostati, pa je totalna cirkulacija i homotermija karakteristična i u zimskom periodu. Termički režim akumulacija ima najveći uticaj na sve ostale fizičko-hemijske i biološke elemente kvaliteta.

Na Grafiku 1 prikazane su temperature vode na najdubljoj tački, kod brane, u letnjem periodu, gde se uočava, manje ili više izraženo, termičko raslojavanje vode u akumulacijama uz izdvajanje tri sloja: epilimnion, metalimnion (termokline) i hipolimnion. Termičko raslojavanje vode utiče na njen hemizam. Stratifikaciju i mešanje kontrolišu dva najvažnija faktora u ekologiji fitoplanktona: dostupnost svetlosti i nutrijenata (Tilzer & Goldman, 1978).

Vertikalna raspodela i sadržaj rastvorenog kiseonika (DO) u vodi su osnovni pokazatelji ekološkog statusa/potencijala jezera i akumulacija. Termička stratifikacija dovodi do stratifikacije rastvorenog kiseonika u vodi. U letnjem periodu kiseonična stratifikacija je naročito izražena: sadržaj kiseonika u vodi progresivno opada sa dubinom. U većini akumulacija u površinskom sloju vode primećena je pojava supersaturacije. Na nekim akumulacijama kao što su Garaši, Bresnica, Uvac (Sjenica) i Vrutci supersaturacija je izražena u metalimnionu. Najveći procenat zasićenja vode kiseonikom konstatovan je na dubini koja je 1 do 2 m iznad dubine maksimalnog hlorofila a, ili na istoj dubini. Sadržaj rastvorenog kiseonika u vodi u većini

Carl Zeiss Stereo Discovery V.8 stereomicroscope with AxioCam ICc5 camera and ZEN2 software, and Leica MS5 stereomicroscope. Depending on type of water body on which the reservoir was formed, the following biological parameters were used to assess the ecological potential within the ASTERICS software (AQEM, 2002): Zelinka & Marvan Saprobic Index (Zelinka & Marvan, 1961), BMWP (Biological Monitoring Working Party score), Shannon-Weaver Diversity Index (Shannon, 1948), total number of taxa, percentage participation of Oligochaeta/Tubificidae in the total macroinvertebrate community, and number of taxa of Ephemeroptera, Plecoptera and Trichoptera - EPT Taxa (Armitage et al., 1983).

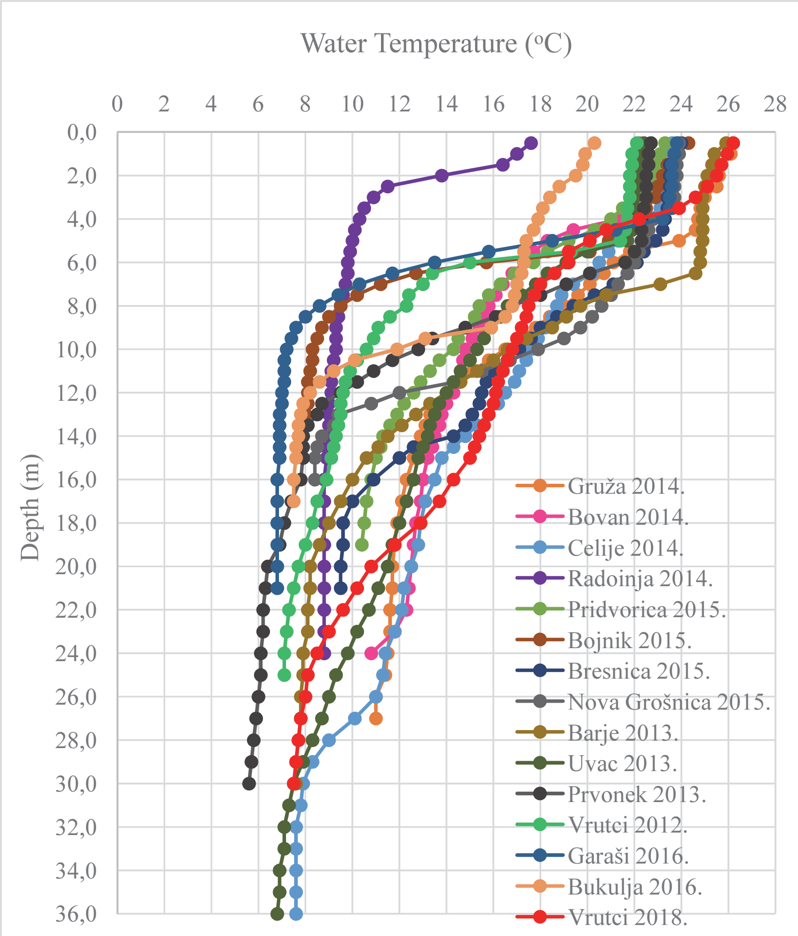
Trophic state of the reservoirs was determined using the Carlson's Trophic State Index (TSI) (Carlson, 1977). An assessment of ecological potential of the reservoirs based on biological and physico-chemical quality elements was performed according to the Regulation on parameters of ecological and chemical status of surface waters and parameters of chemical and quantitative status of groundwater (Official Gazette of the RS, 74/2011, hereinafter the Regulation).

RESULTS AND DISCUSSION

Most of investigated reservoirs belong to dimictic type of lake system of the temperate continental climates, which are characterized by two periods of water circulation, spring and autumn, direct thermal stratification in summer and inverse (reverse) stratification in winter. During mild winters, inverse thermal stratification may be absent, thus total circulation and homothermy are characteristic in the winter as well. The thermal regime of reservoirs has the highest impact on all other physico-chemical and biological quality elements.

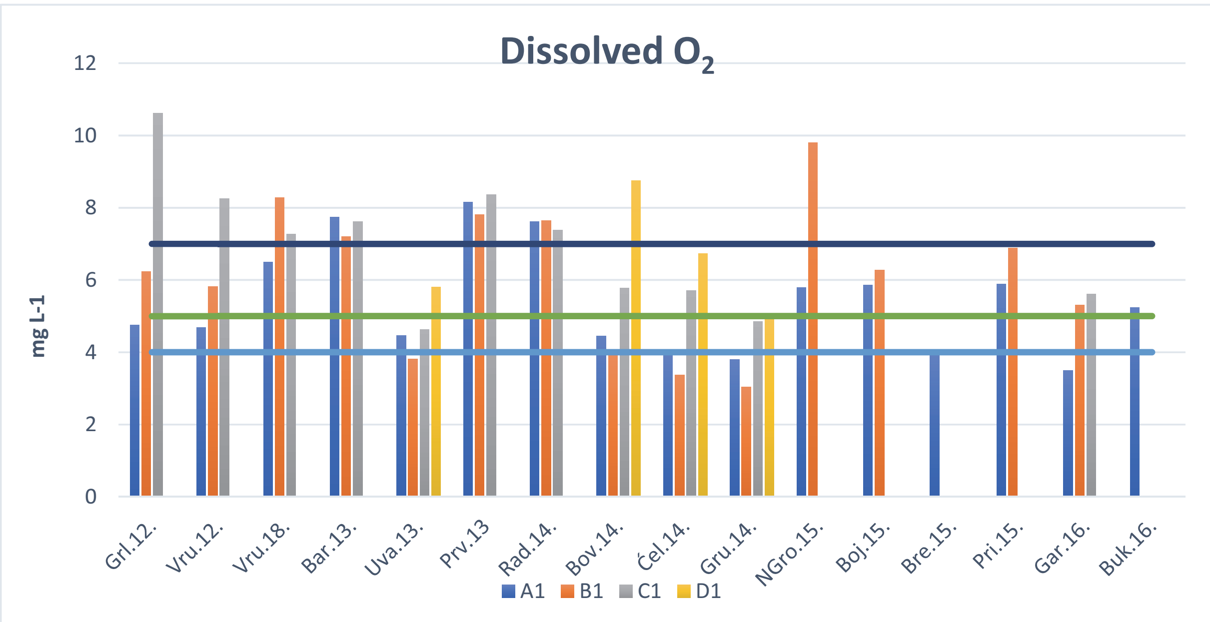
The Graph 1 showed the water temperatures in the deepest point, near the dam, in the summer period, where more or less pronounced thermal stratification of water in the reservoirs was observed, with three layers being separated: epilimnion, metalimnion (thermocline) and hypolimnion. Thermal stratification of water affects its chemistry. Stratification and mixing are controlled by two most important factors in phytoplankton ecology: availability of light and nutrients (Tilzer & Goldman, 1978).

The vertical distribution and content of dissolved oxygen (DO) in the water are the basic indicators of the ecological status/potential of lake and reservoir. Thermal stratification leads to stratification of dissolved oxygen in water. In the summer, oxygen stratification is particularly pronounced: the oxygen content in the water progressively decreases with depth. In most reservoirs in the surface layer of water the occurrence of supersaturation was observed. On some reservoirs, such as Garaši, Bresnica, Uvac



Grafik 1. Raspored temperature vode u akumulacijama, na lokalitetu kod brane (A1), u letnjem periodu

Graph 1. Distribution of water temperature in the reservoirs, at the locality near the dam (A1) in summer period



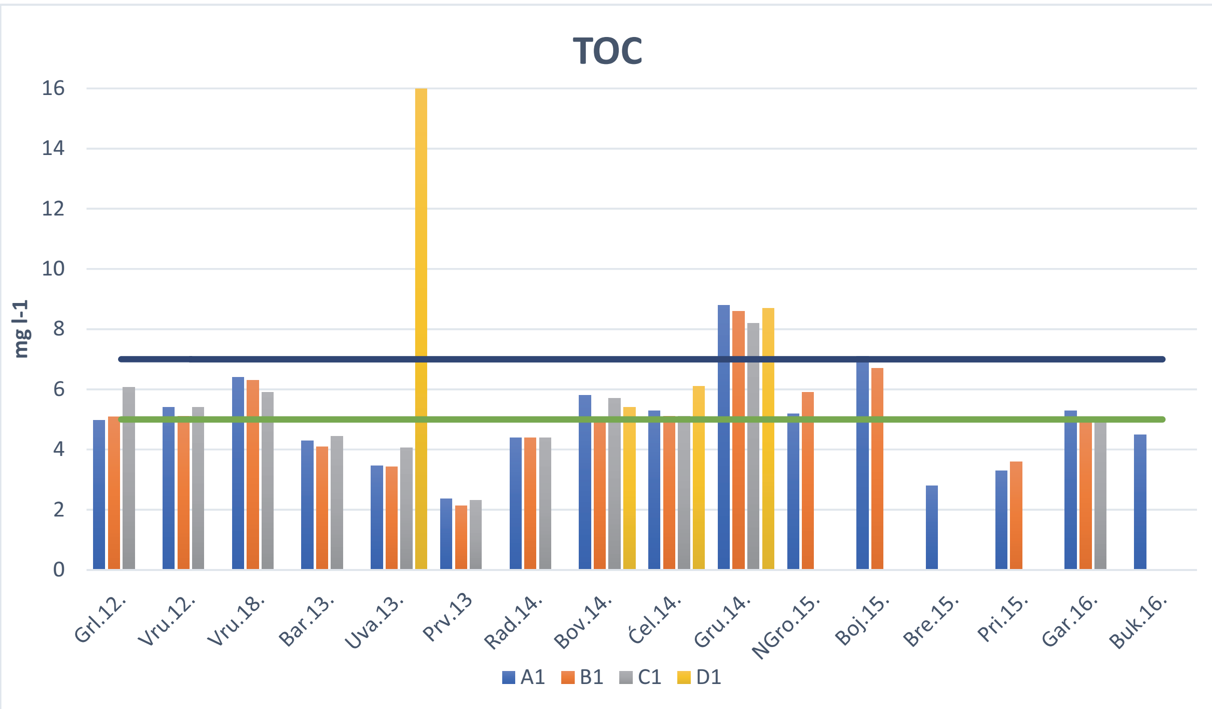
Grafik 2. Vrednosti koncentracija rastvorenog kiseonika u vodi (C10) na različitim lokalitetima u akumulacijama

Graph 2. The values of Dissolved Oxygen concentration in water (10-percentile) at different localities in the reservoirs akumulacija opada već u metalimnionu na veoma niske vrednosti, kao što je to slučaj u akumulacijama: Ćelije, Bovan, Pridvorica, Garaši i Bojnik (Brestovac). Jedine dve akumulacije u kojima nije konstatovan deficit kiseonika u hipolimnionu u letnjem periodu su Radoinja i Prvonek.

Prema Pravilniku, za procenu ekološkog potencijala za sadržaj rastvorenog kiseonika u vodenom stubu, na godišnjem nivou, vrednost parametra određuje se kao C10 (10-percentil). Na Grafiku 2 može se videti da je vrednost C10 sadržaja rastvorenog kiseonika u vodi odgovarala dobrom i boljem ekološkom potencijalu samo u akumulacijama Prvonek, Radoinja i Barje. U najdubljim delovima akumulacija, kod brane (lokalitet A) i u centralnim delovima akumulacija (lokalitet B), sadržaj rastvorenog kiseonika u vodi (vrednost C10) odgovara lošem ekološkom potencijalu u akumulacijama: Ćelije, Gruža, Bresnica, Garaši i Uvac (Sjenica) u centralnom delu akumulacije. Slabom ekološkom potencijalu sadržaj rastvorenog kiseonika u vodi odgovara u akumulacijama: Grlište, Vrutci 2012. godine, Uvac kod brane i u kanjonu i Bovan, a umerenom u akumulacijama: Bojnik (Brestovac), Pridvorica, Bukulja i Vrutci 2018. godine. U plitkim delovima svih akumulacija (lokaliteti C i D) sadržaj rastvorenog kiseonika u vodi odgovara dobrom i boljem ekološkom potencijalu, međutim, zbog male dubine u tim delovima ne uspostavlja se termička stratifikacija pa samim tim kiseonik slobodno difunduje do dna akumulacija i on nije relevantan pokazatelj ekološkog stanja. Sadržaj ukupnog

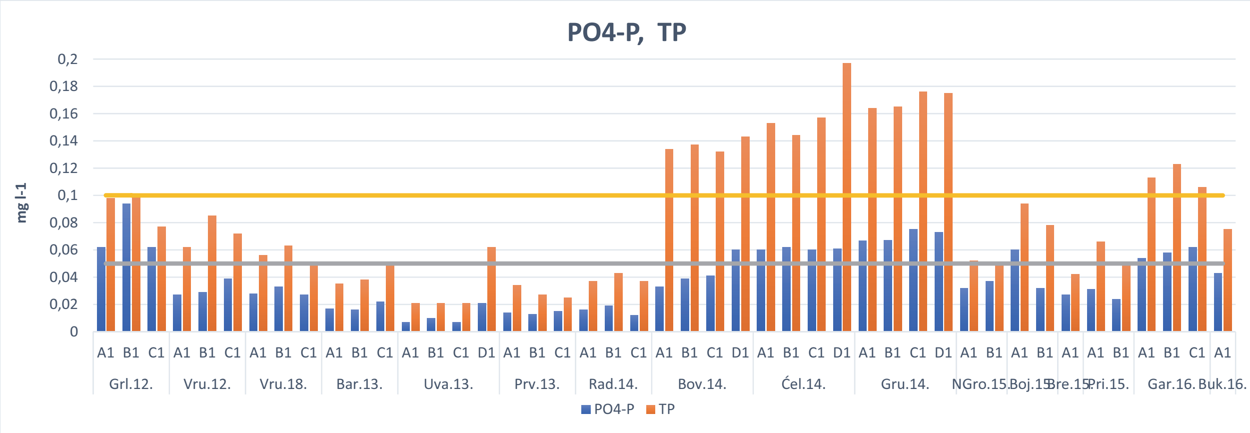
(Sjenica) and Vrutci supersaturation was expressed in metalimnion. The highest percentage of water saturation with oxygen was found at a depth that is 1 to 2 m above the depth of the maximum chlorophyll *a*, or at the same depth. The content of dissolved oxygen in water in most reservoirs decreases already in the metalimnion to very low values, as is the case in the reservoirs: Ćelije, Bovan, Pridvorica, Garaši and Bojnik (Brestovac). The only two reservoirs without oxygen deficiency in the hypolimnion in the summer period are Radoinja and Prvonek.

According to the Regulation, the assessment of ecological potential for the content of dissolved oxygen in the water column, on annual level, the value of the parameter is calculated as C10 (10th percentile). The Graph 2 shows that the C10 value of the dissolved oxygen content in the water corresponds to a good and better ecological potential only in the Prvonek, Radoinja and Barje reservoirs. In the deepest parts of the reservoirs, near the dam (locality A), and in the central parts of the reservoirs (locality B), the content of dissolved oxygen in the water (C10 value) corresponds to poor ecological potential in the following reservoirs: Ćelije, Gruža, Bresnica, Garaši and Uvac (Sjenica) in the central part of the reservoir. The content of dissolved oxygen in the water corresponds to the poor ecological potential in the following reservoirs: Grlište, Vrutci in 2012, Uvac near the dam and in the canyon and Bovan, and to the moderate ecological potential in the reservoirs: Bojnik (Brestovac), Pridvorica, Bukulja and Vrutci in 2018. In shallow parts of all reservoirs



Grafik 3. Prosečne godišnje vrednosti ukupnog organskog ugljenika (TOC) na različitim lokalitetima u akumulacijama

Graph 3. Mean annual values of Total Organic Carbon (TOC) at different localities in the reservoirs



Grafik 4. Prosečne godišnje vrednosti ortofosfata (PO4-P) i ukupnog fosfora na različitim lokalitetima u akumulacijama

Graph 4. Mean annual values of Orthophosphates (PO4-P) and Total Phosphorus (TP) at different localities in the reservoirs

organskog ugljenika u vodi (TOC) je, takođe, važan pokazatelj ekološkog stanja. Prosečne vrednosti TOC na godišnjem nivou (Grafik 3) odgovaraju dobrom i boljem ekološkom potencijalu u akumulacijama Radoinja, Prvonek, Barje, Uvac kod brane, u centralnom delu i u kanjonu, Bresnica, Pridvorica i Bukulja, umerenom u akumulacijama: Grlište, Vrutci 2012. i 2018. godine, Bovan, Ćelije, Nova Grošnica i Garaši, slabom u akumulaciji Gruža i na ulazu u akumulaciju Uvac.

Prosečne godišnje vrednosti ortofosfata i ukupnog fosfora, prema Pravilniku, su povišene u akumulacijama: Grlište, Bovan, Ćelije, Gruža i Garaši i odgovaraju umerenom ekološkom potencijalu. Granična vrednost ukupnog fosfora za umeren potencijal (III klasa) iznosi 0,100 mg L^{-1} (Grafik 4).

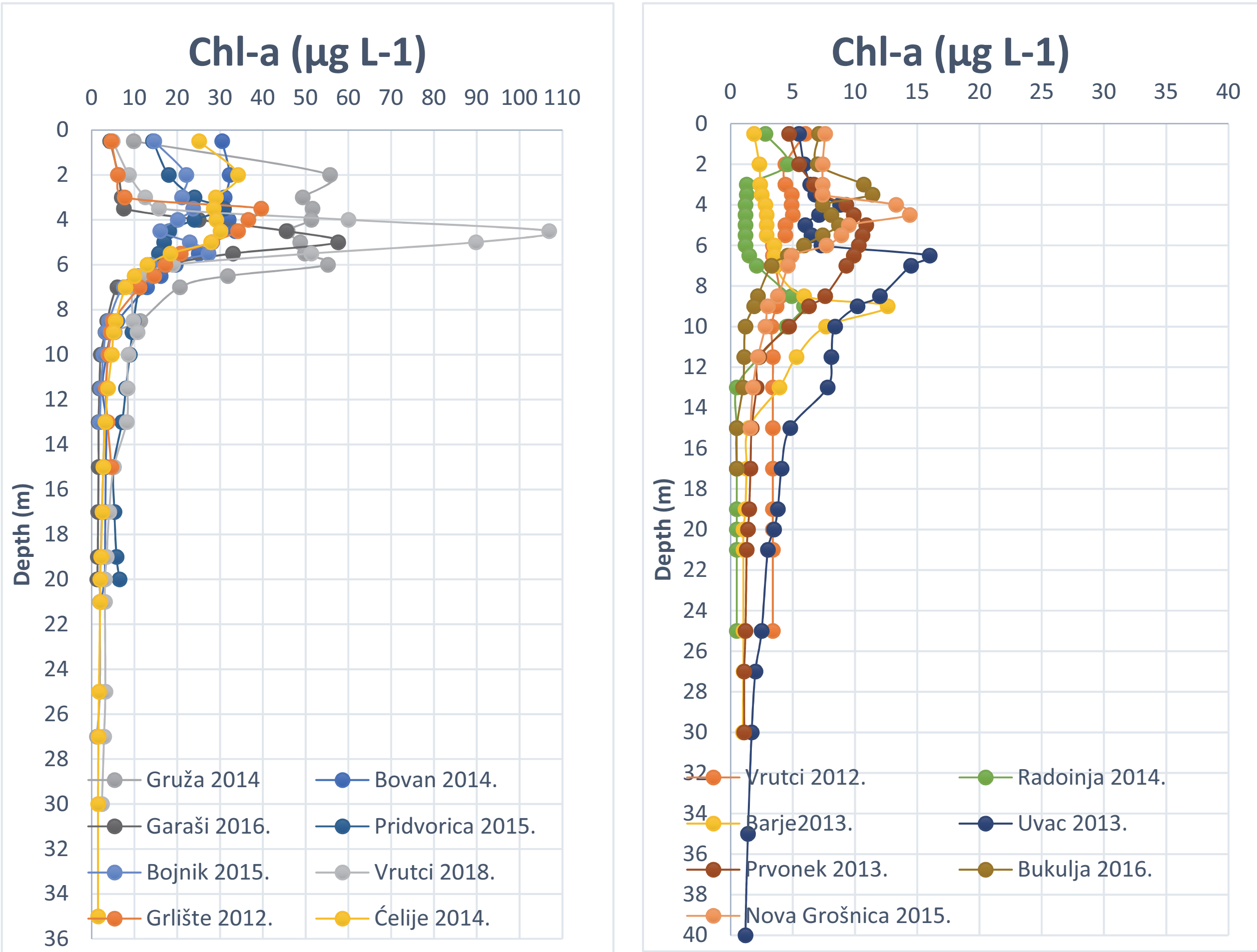
Prema OECD klasifikaciji trofičkog statusa jezera i akumulacija (OECD, 1982), koju kao osnov za klasifikaciju uzimaju mnoge zemlje EU, vrednosti ukupnog fosfora > 0,035 mgL^{-1} smatraju se povišenim i odgovaraju eutrofnim uslovima (IV klasa), dok vrednosti > 0,100 mgL^{-1} odgovaraju hipereutrofnim uslovima (V klasa). Prema ovim kriterijumima, u svim našim akumulacijama vladaju eutrofni i hipereutrofni uslovi, osim akumulacije Prvonek koja je mezotrofnog tipa. Akumulacije Radoinja i Barje su prema prosečnim vrednostima ukupnog fosfora na donjoj granici eutrofije.

Fitoplankton najbrže reaguje na fizičko-hemijske promene strukture jezerskih ekosistema. Promene koje se dešavaju u jezerskim ekosistemima najpre utiču na fitoplanktonsku zajednicu. Ove promene dovode do transformacije sastava fitoplanktona i dominacije zajednica algi (Sönmez et al., 2017).

(localities C and D), the content of dissolved oxygen in water corresponds to good and better ecological potential, however, due to the small depth in these parts the thermal stratification was not established, and therefore oxygen diffuses freely to the bottom of reservoirs and it is not a relevant indicator of ecological conditions. The content of total organic carbon in water (TOC) is also an important indicator of ecological status. Mean annual TOC values (Graph 3) correspond to good and better ecological potential in the reservoirs: Radoinja, Prvonek, Barje, Uvac near the dam, in the central part and in the canyon, Bresnica, Pridvorica and Bukulja, moderate in the following reservoirs: Grlište, Vrutci 2012 and 2018, Bovan, Ćelije, Nova Grošnica and Garaši, poor in the Gruža reservoir and at the entrance to the Uvac reservoir.

The mean annual values of orthophosphate and total phosphorus, according to the Regulation, are increased in the following reservoirs: Grlište, Bovan, Ćelije, Gruža and Garaši, and correspond to the moderate ecological potential. The limit value of total phosphorus for moderate potential (Class III) is 0.100 mg L^{-1} (Graph 4).

According to the OECD classification of trophic status of lakes and reservoirs (OECD, 1982), which is taken as a basis for classification by many EU countries, values of total phosphorus > 0.035 mgL^{-1} are considered as increased, and correspond to eutrophic conditions (Class IV), whilst values >0.100 mgL^{-1} correspond to hypereutrophic conditions (Class V). According to these criteria, eutrophic and hypereutrophic conditions prevailed in all our reservoirs, except the Prvonek reservoir which is mesotrophic type. The Radoinja and Barje reservoris are in the lower limit of eutrophy according to the average values of total phosphorus.



Grafik 5. Koncentracije hlorofila a na najdubljoj tački, kod brane (A1), u akumulacijama u letnjem periodu

Graph 5. The concentration of chlorophyll a in the deepest sampling point, at the locality near dam (A1) in the reservoirs in summer period

Zagrevanjem površinskih slojeva vode u prolećnom periodu dolazi do intenzivnije produkcije fitoplanktona i povećanja sadržaja rastvorenog kiseonika u vodi. Karakteristične su površinske populacije fitoplanktona sa dominacijom silikatnih algi. Od trofičkog statusa akumulacija zavisi prostorna i vremenska distribucija životnih zajednica. U oligotrofnim jezerima raspoloživa količina primarnih nutrijenata, koji kontrolišu produktivnost, naglo se smanjuje u površinskim slojevima, što potiskuje populacije fitoplanktona ka pribežištu u zoni ispod termokline. U površinskim slojevima ostaje jedino mala količina obnovljivih primarnih nutrijenata koja omogućava opstanak letnje siromašne zajednice pri površini (Laušević, 1995). Takva je situacija u akumulaciji Radoinja, koja je oligotrofno-mezotrofnog tipa, gde se fitoplankton odlikuje jednoličnim sastavom i niskom produktivnošću. Konstatuje se jedan maksimum razvića, u letnjem periodu, sa slabo izraženim pikom u zoni ispod termokline, a najveća koncentracija hlorofila *a* ustanovljena je na 9 m dubine (Grafik 5).

Phytoplankton reacts the fastest to physico-chemical changes in the structure of lake ecosystems. The changes that occur in lake ecosystems firstly affect the phytoplankton community. These changes lead to a transformation of phytoplankton composition and dominance of algal communities (Sönmez et al., 2017).

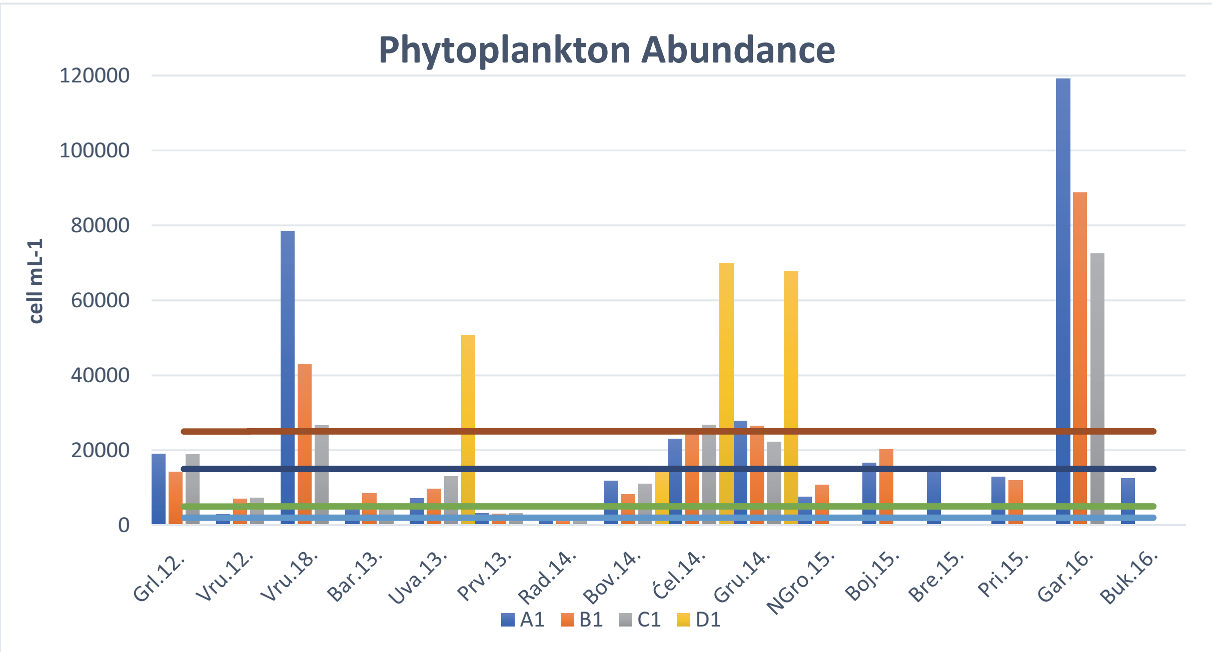
By heating the surface layers of water in the spring, there is a more intensive production of phytoplankton and an increase of the content of dissolved oxygen in the water. Surface populations of phytoplankton, with a predominance of silicate algae are characteristic. The spatial and temporal distribution of biocenoses depends on trophic status of the reservoir. In oligotrophic lakes, the available amount of primary nutrients, which control productivity, decreases sharply in the surface layers, which "pushes" phytoplankton populations to a refuge in the zone below the thermocline. Only a small amount of renewable primary nutrients remains in the surface layers, which enables the survival of the summer poor community at the surface (Laušević, 1995). Such situation was noted in the Radoinja reservoir, which belongs to oligotrophic-mesotrophic type, U mezotrofnim jezerima dovoljna količina primarnih ograničavajućih nutrijenata omogućava da dođe do pojave iscrpljivanja sekundarnih ograničavajućih nutrijenata (npr. silicijum, mikroelementi, vitamini) u površinskim slojevima nakon uspostavljanja stratifikacije. Populacije za čiji rast je neophodan sekundarni nutrijent prisiljene su na pomeranje iz epilimniona, ali se u njemu razvijaju značajne populacije vrsta koje ili ne zahtevaju, ili su prilagođene na rast u uslovima niske koncentracije sekundarnog nutrijenta i koje iscrpljuju od proleća preostalu količinu primarnih nutrijenata (Laušević, 1995). U mezotrofnim akumulacijama, kao što su Prvonek, Vrutci, Barje, Uvac (u delu kod brane), Nova Grošnica i Pridvorica dolazi do iscrpljivanja nutrijenata u epilimnionu od strane fitoplanktona i on se povlači u dublje slojeve vode, zauzimajući novu "ekološku nišu", u sloju metalimniona, gde vladaju uslovi slabijeg svetlosnog intenziteta, niže temperature, ali veće koncentracije nutrijenata. U većini mezotrofnih akumulacija, u letnjem periodu, zabeležen je metalimnionski pik razvoja algi, i to najčešće u donjem sloju metalimniona, debljine oko 50 cm, koji se graniči sa hipolimnionom (Grafik 5).

U sredini bogatoj nutrijentima ne postoje mehanizmi koji omogućavaju pojavu metalimnionskog maksimuma hlorofila. U proleće, velika količina epilimnionskih, površinskih nutrijenata stimuliše intenzivan razvoj fitoplanktona. Takav prinos fitoplanktona "ne pati" od nedostatka nutrijenata i najčešće aktivno raste tokom celog leta. Populacije koje su adaptirane na rast u površinskoj vodi postaju dominantne u sastavu fitoplanktona i konačno, svojom zasenom, uništavaju nišu subtermokline

where phytoplankton is characterized by uniform composition and low productivity. One maximum of development was occurred, in the summer period, with a weak peak in the zone below the thermocline, and the highest concentration of chlorophyll *a* was established at a depth of 9 m (Graph 5).

In mesotrophic lakes, a sufficient amount of primary limitative nutrients allows the depletion of secondary limitative nutrients (e.g. silicon, microelements, vitamins) in the surface layers after the establishment of stratification. Populations for which the growth of secondary nutrient is necessary are forced to move from the epilimnion, but significant populations of species developed in the epilimnion either do not require or are adapted to growth in conditions of low concentration of secondary nutrient and which deplete the remaining amount of primary nutrients from the spring period (Laušević, 1995). In mesotrophic reservoirs, such as Prvonek, Vrutci, Barje, Uvac (in the part near the dam), Nova Grošnica and Pridvorica, phytoplankton is depleted of nutrients in the epilimnion and it retreats into deeper layers of water occupying a new ecological niche in the metalimnion layer where prevailed conditions of lower light intensity, lower temperatures, but higher concentrations of nutrients. In most mesotrophic reservoirs, in the summer period, the metalimnion peak of algae development was observed, most often in the lower layer of metalimnion, cca. 50 cm thick bordering with hypolimnion (Graph 5).

In environment rich in nutrients, there are no mechanisms that enable the appearance of the metalimnion maximum of chlorophyll. In the



Grafik 6. Prosečne godišnje vrednosti abundance fitoplanktona na različitim lokalitetima u akumulacijama

Graph 6. Mean annual values of phytoplankton abundance at different sampling sites in the reservoirs

(Laušević, 1995). U eutrofnim akumulacijama, kao što su Gruža, Ćelije, Bovan, Grlište, Sjenica (u centralnom delu, u kanjonu i na ulazu u akumulaciju), Bojnik (Brestovac) i Bresnica, nutrijenata ima dovoljno tokom cele godine, tako da dominiraju površinske populacije algi, a sastav fitoplanktona u dubljim slojevima je siromašan (Grafik 6).

U akumulaciji Garaši, koja je prema svim pokazateljima eutrofnog tipa, maksimum hlorofila *a* i u prolećnom i u letnjem periodu (Grafik 5), izmeren je u metalimnionu na dubini od 5 m. Najverovatnije je da su autekološke osobine vrste *Planktothrix agardhii* (Gomont) Anagnostidis & Komárek, koja je "cvetala" u akumulaciji 2016. godine, uzrokovale ovu pojavu, jer su za ovaj tip jezera karakteristične površinske populacije algi i cijanobakterija. U akumulaciji Bukulja, koja je mezotrofnog tipa, konstatovane su neke karakteristike eutrofnih akumulacija, kao što su površinske populacije algi u letnjem periodu (Grafik 6).

Prosečne godišnje vrednosti abundance fitoplanktona su važan parametar za ocenu ekološkog potencijala akumulacija. Najveće vrednosti, koje odgovaraju lošem ekološkom potencijalu konstatovane su u akumulacijama Garaši, Gruža, Ćelije, Uvac (na ulazu u akumulaciju), i u akumulaciji Vrutci 2018. godine. Vrednosti koje odgovaraju slabom ekološkom potencijalu konstatovane su akumulacijama Grlište, Bojnik i Bresnica, a umerenom u akumulacijama Vrutci 2012. godine, Barje, Uvac (kod brane, u centralnom delu akumulacije i u kanjonu), Bovan, Nova Grošnica, Pridvorica i Bukulja. Akumulacije u kojima je prosečna vrednost abundance fitoplanktona, na godišnjem nivou, iznosila ispod 5000 ćel mL^{-1}, što odgovara dobrom i boljem ekološkom potencijalu, su Prvonek i Radoinja (Grafik 6).

Jedan od najvažnijih parametara za procenu ekološkog potencijala je i prisustvo cijanobakterija i njihova abundanca u akumulacijama. Poslednjih decenija na globalnom nivou primećeno je širenje "cvetanja" cijanobakterija u mnogim jezerima i akumulacijama.

Antropogeno obogaćivanje hranljivim materijama i hidrološke modifikacije, uključujući diverzije vode i izgradnju akumulacija su glavni pokretači širenja cvetanja. Klimatske promene, tj. zagrevanje, ekstremniji kišni događaji i suše deluju sinergistički sa ljudskim pokretačima kako bi pogoršali problem (Paerl, 2018). Cijanobakterijski rodovi koji formiraju cvate izuzetno su otporni na ekstremne sredine; poseduju ćelije za odmor (akinete), omotače i kapsule, fotoprotektivne pigmente i sposobnost klizanja i brzog kretanja po vodenom stubu, menjajući mobilnost i na taj način optimizirajući pristup svetlosti i hranjivim sastojcima. (Potts & Whitton, 2000; Reynolds, 2006 in Paerl, 2018). Neki rodovi mogu pristupiti ogromnom rezervoaru atmosferskog azota (N_2) putem azotofiksacije, koji

spring, a large amount of epilimnetic, surface nutrients stimulates the intensive development of phytoplankton. Such phytoplankton yield "does not suffer" from a lack of nutrients and usually actively grows during the whole summer. Populations that are adapted to growth in surface water become dominant in the composition of phytoplankton and finally, with their shade, destroy the niche of the subthermocline (Laušević, 1995). In eutrophic reservoirs, such as Gruža, Ćelije, Bovan, Grlište, Uvac (in the central part, in the canyon and at the entrance to the reservoir), Bojnik (Brestovac) and Bresnica, there are enough nutrients throughout the year, so that surface algae populations dominate, and the composition of phytoplankton in the deeper layers is poor (Graph 5).

In the Garaši reservoir, which is according to all indicators belongs to eutrophic type, the maximum of chlorophyll, both in the spring and in the summer period (Graph 5), was measured in the metalimnion at a depth of 5 m. It is most likely that the autecological characteristics of *Planktothrix agardhii* (Gomont) Anagnostidis & Komárek, which "bloomed" in the reservoir in 2016, caused this phenomenon, because this type of lake is characterized by the surface populations of algae and cyanobacteria. In the Bukulja reservoir, which belongs to mesotrophic type, some characteristics of eutrophic reservoir were found, such as surface populations of algae in the summer period (Graph 5).

Mean annual values of phytoplankton abundance are important parameter for assessing the ecological potential of reservoirs. The highest values, which correspond to bad ecological potential, were ascertained in the following reservoirs: Garaši, Gruža, Ćelija, Uvac (at the entrance to the reservoir), and in the Vrutci reservoir in 2018. The values correspond to poor ecological potential were found in the Grlište, Bojnik and Bresnica reservoirs, and moderate in the following reservoirs: Vrutci in 2012, Barje, Uvac (near the dam, in the central part of the reservoir and in the canyon), Bovan, Nova Grošnica, Pridvorica and Bukulja. The reservoirs in which the average value of phytoplankton abundance, on an annual level, was below 5000 cells mL-1, which corresponds to good and better ecological potential, are Prvonek and Radoinja reservoirs (Graph 6).

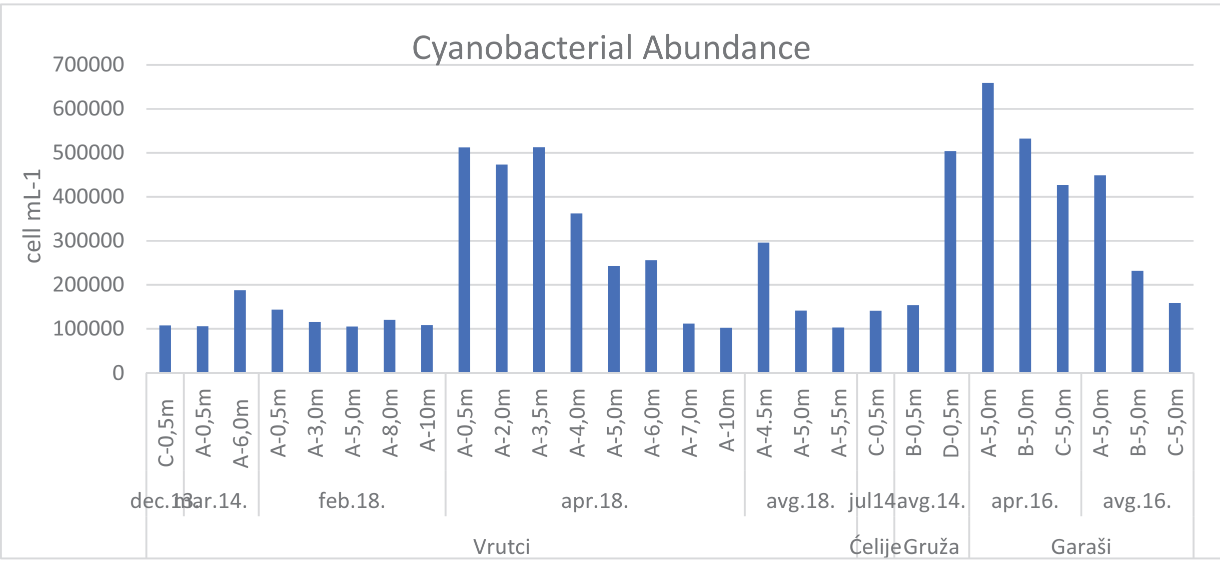
One of the most important parameters for assessing ecological potential is a presence of cyanobacteria and their abundance in the reservoirs. In recent decades, the spread of "blooming" of cyanobacteria in many lakes and reservoirs has been observed on a global level. Anthropogenic nutrient enrichment and hydrological modifications, including water diversions and reservoir construction, are major drivers of bloom expansion. Climate change, i.e., warming, more extreme rainfall events, and droughts, act može zaobići ograničenje azota (Gallon et al., 1992 u Paerl, 2018), sekvestrirano gvožđe izlučivanjem siderofora (Wilhelm & Trick, 1994 in Paerl, 2018), skladištenje fosfora, azota i drugih osnovnih hranljivih materija (Reynolds, 2006 in Paerl, 2018), proizvodnju sekundarnih metabolita, uključujući jedinjenja toksična za životinje i čoveka (Paerl et al., 1996), i suprotstavljaju se nepovoljnim i stresnim uslovima okruženja, uključujući fotooksidaciju, povišen salinitet i povezani osmotski stres (Paerl et al., 1996).

Intenzitet "cvetanja" cijanobakterija u nekim akumulacijama za vodosnabdevanje dostiže zabrinjavajuće razmere. U različitim periodima ispitivanja, na pojedinim dubinama, iznosi preko 100 000 ćel mL^{-1} (Grafik 7), što je prema preporukama Svetske zdravstvene organizacije, za prisustvo cijanobakterija u vodi za vodosnabdevanje, opasnost visokog rizika po zdravlje stanovništva (Chorus & Bartham, 1999). Ova pojava je konstatovana u akumulaciji Gruža 2014. godine, gde su na ulazu u akumulaciju formirane površinske agregacije usled "cvetanja" azotofiksatorske vrste *Aphanizomenon flosaquae* Ralfs ex Bornet & Flahault. Ova vrsta potencijalno može da luči nekoliko vrsta cijanotoksina (saksitoksin i neosaksitoksin, koji prema tipu toksičnosti, pripadaju grupi neurotoksina, i mikrocistin koji pripada grupi hepatoksina).

U akumulaciji Vrutci, u decembru 2013. godine, primećena je pojava "cvetanja vode" izazvana hepatoksičnom filamentoznom vrstom *Planktothrix rubescens* (De Candolle ex Gomont) Anagnostidis & Komárek. Brojnost cijanobakterija iznosila je preko 90000 *ćel* mL^{-1}, da bi u martu 2014. došlo do još veće proliferacije *P. rubescens* sa preko 100000 *ćel* mL^{-1}.

synergistically with human drivers to exacerbate this problem (Paerl, 2018). Bloom-forming cyanobacterial genera are remarkably resistant to environmental extremes; They possess heat- and desiccation-tolerant resting cells (akinetes), sheaths and capsules, photoprotective pigments, and the ability to glide and rapidly move throughout the water column by altering their buoyancy, and thereby optimizing access to light and nutrients (Potts & Whitton, 2000; Reynolds, 2006; Paerl, 2018). Some genera can access the vast reservoir of atmospheric nitrogen via nitrogen (N_2) fixation, which can circumvent nitrogen limitation (Gallon et al., 1992 in Paerl, 2018), sequester iron by secreting siderophores (Wilhelm & Trick, 1994 in Paerl, 2018), store phosphorus, nitrogen, and other essential nutrients (Reynolds, 2006 in Paerl, 2018), produce secondary metabolites including compounds toxic to animals, including humans (Paerl et al., 1996), and counter adverse and stressful environmental conditions including photooxidation, elevated salinity, and related osmotic stress (Paerl et al., 1996).

The intensity of of cyanobacterial "blooming" in some reservoirs for water supply was reached worrying proportions. In different investigation periods, at certain depths, it amounts to over 100 000 cells mL^{-1} (Graph 7), which is, according of the World Health Organization (WHO) recommendations, for the presence of cyanobacteria in water supply, a high risk to public health (Chorus & Bartham, 1999). This phenomenon was observed in the Gruža reservoir in 2014, where surface aggregations were formed at the entrance to the reservoir due to the "blooming" of the nitrogen-fixing species *Aphanizomenon*



Grafik 7. Akumulacije u kojima je brojnost cijanobakterija u različitim periodima ispitivanja i na različitim dubinama iznosila preko 100 000 ćel. mL-1

Graph 7. The reservoirs in which cyanobacterial abundance was more than 100 000 cell mL-1 in different investigation periods and at different depths

Ponovnim ispitivanjem akumulacije Vrutci u aprilu 2018. konstatovana je brojnost *P. rubescens* preko 500000 *ćel* mL^{-1}, a u letnjem periodu vrsta se povlači u metalimnion na dubinu između 4,5 i 5,5 m (Grafik 7).

U akumulaciji Garaši 2016. godine, "cvetanje vode" izazvala je druga vrsta roda *Planktothrix*. Radi se, takođe, o hepatoksičnoj vrsti *Planktothrix agardhii* (Gomont) Anagnostidis & Komárek. Proliferacija vrste je veoma intenzivna u aprilu mesecu na dubini od 5 m (preko 600 000 *ćel* mL^{-1}) (Grafik 7). Intenzitet "cvetanja" se nastavlja i tokom letnjih meseci. *Planktothrix agardhii* je dominantna vrsta u mnogim plitkim eutrofnim jezerima. Obe vrste roda *Planktothrix* su potencijalno veoma opasne jer mogu da produkuju mikrocistin, toksin jetre. Jezera u kojima dominira *Planktothrix* imaju značajno veće koncentracije mikrocistina po jedinici cijanobakterijske biomase od jezera u kojima dominiraju druge vrste cijanobakterija (Briand et al., 2002). Pored praćenja dinamike cijanobakterija, Agencija za zaštitu *životne* sredine pratila je i dinamiku mikrocistina u akumulacija Vrutci 2018. godine. Utvrđeno je prisustvo tri vrste mikrocistina: MC-LR, MC-RR i MC-YR. Najtoksičnija forma je mikrocistin-LR. Utvrđene su veoma visoke koncentracije ukupnih mikrocistina u aprilu 2018. u površinskim slojevima vode, sa najvećom vrednosti na 4 m dubine (10,9 µg L^{-1}). Prema kriterijumu EPA (US) ove vrednosti odgovaraju visokom nivou upozorenja (>1,6 µg L^{-1}). Ovaj trend se nastavlja i u avgustu 2018., ali se vrsta povlači u metalimnion; koncentracije ukupnog mikrocistina niže su nego u aprilu, ali su opet veoma povišene (2,58 µg L^{-1}). Najveća koncentracija utvrđena je za MC-RR. U novembru 2018. godine koncentracije sve tri forme mikrocistina su ispod granice kvantifikacije (<0,1 µg L^{-1}). S obzirom da je Svetska zdravstvena organizacija (SZO) dala preporučenu koncentraciju samo za MC-LR (1 µg L^{-1}), koncentracije MC-LR su u svim periodima ispitivanja bile ispod propisanih vrednosti. Pojava "cvetanja" cijanobakterija uvek je posledica dugogodišnjeg negativnog antropogenog uticaja i povećane eutrofikacije, koja u kombinaciji sa fizičkim faktorima, kao što su temperatura vode i stabilnost vodenog stuba, dovodi do favorizovanja jedne ili nekoliko vrsta. Globalno zagrevanje i klimatske promene na regionalnom nivou, koje utiču na povećanje temperature vodenih ekosistema predstavljaju sve veću pretnju. Povećanje temperature vode može promeniti hidrodinamiku jezera i produžiti period stratifikacije vode. Klimatske promene se smatraju potencijalnim uzrokom daljeg širenja "cvetanja" štetnih cijanobakterija, naročito u eutrofnim vodama sa porastom temperature, povećanom stratifikacijom, dužim retencionim vremenom i velikim uticajem nutrijenata koji favorizuju dominaciju cijanobakterija (O'Neil et al., 2012).

Okvirna direktiva o vodi EU predviđa i ispitivanje zajednica fitobentosa u jezerima i akumulacijama.

flosaquae Ralfs ex Bornet & Flahault. This species could potentially excrete several types of cyanotoxin (saxitoxin and neosaxitoxin, which according to the type of toxicity, belong to the group of neurotoxins, and microcystin, which belongs to the group of hepatoxins).

In the Vrutci reservoir in December 2013, the phenomenon of "water bloom" caused by the hepatotoxic filamentous species *Planktothrix rubescens* (De Candolle ex Gomont) Anagnostidis & Komárek was observed. The number of cyanobacteria was over 90 000 cells mL^{-1}, and in March 2014 there was an even greater proliferation of *P. rubescens*, with over 100 000 cells mL-1. In April 2018, the repeated examination of the Vrutci reservoir revealed the number of *P. rubescens* was over 500 000 cells mL^{-1}, and in the summer 2018 the species retreated into the metalimnion, to a depth between 4.5 and 5.5 m (Graph 7).

In the Garaši reservoir in 2016, the water blooming was caused by another species of the genus *Planktothrix*. It is also a hepatotoxic species, *Planktothrix agardhii* (Gomont) Anagnostidis & Komárek. In April 2016, the proliferation of this species was very rapid at a depth of 5 m (over 600 000 cells mL^{-1}) (Graph 7). The intensity of "blooming" continued during the summer months. *Planktothrix agardhii* is a dominant species in many shallow eutrophic lakes. Both species of the genus *Planktothrix* are potentially very dangerous because they can produce microcystin, a liver toxin. The lakes dominated by *Planktothrix* have significantly higher concentrations of microcystins per unit of cyanobacterial biomass than lakes dominated by other species of cyanobacteria (Briand et al., 2002). Besides monitoring of the dynamics of cyanobacteria, the Serbian Environmental Protection Agency also monitored the dynamics of microcystins in the Vrutci reservoir in 2018. The presence of three types of microcystins was determined: MC-LR, MC-RR and MC-YR. The most toxic form is microcystin-LR. Very high concentrations of total microcystins were found in April 2018 in the surface layers of water, with the highest value in 4 m depth (10.9 µg L^{-1}). According to the EPA (US) criterion, these values correspond to a high-risk level (> 1.6 µg L^{-1}). Such trend was continued in August 2018 as well, but the species was retreated into metalimnion; the concentrations of total microcystin were lower than in April 2018, but very increased (2.58 µg L^{-1}). The highest concentration was determined for MC-RR. In November 2018, the concentrations of all three forms of microcystins were below the limit of quantification (<0.1 µg L^{-1}). Since the World Health Organization (WHO) proposed the recommended concentration for MC-LR only (1 µg L^{-1}), the MC-LR concentrations were below proposed values in all investigation periods. The occurrence of cyanobacterial "blooming" is always a consequence of long-term negative anthropogenic impact and

Akcenat je na ispitivanju bentosnih dijatoma. Iako su dijatomni indeksi već decenijama nezaobilazan "alat" za procenu ekološkog stanja potoka i reka, njihova primena u proceni ekološkog statusa/ potencijala jezera i akumulacija je novijeg datuma. Parametar koji se, prema Pravilniku, koristi za procenu ekološkog potencijala akumulacija je IPS ("Indice de pollutio-sensibilite") dijatomni indeks (Coste in Cemagref, 1982). Rezultati ispitivanja pokazuju da je ekološki potencijal akumulacija, na osnovu IPS indeksa, za jednu ili čak dve klase bolji nego što pokazuju ispitivanja zajednica fitoplanktona ili makroinvertebrata. U epilitskim zajednicama, bilo da su prirodne ili veštački postavljene podloge za prikupljanje dijatoma, veoma često dominiraju kosmopolitske, alkalifilne vrste kao što su *Cocconeis placentula* Ehrenberg ili *Achnanthidium minutissimum* (Kützing) Czarnecki. To su brzorastuće, "pionirske" vrste koje su u stanju da brzo kolonizuju ogoljene podloge, imaju širok ekološki spektar i javljaju se u širokom opsegu pH vrednosti, u uslovima od oligotrofije do eutrofije. Često su veoma tolerantne na organsko zagađenje i imaju široku ekološku valencu kada su u pitanju koncentracije nutrijenata. Osim toga, neki radovi ukazuju i da je epipelna zajednica dijatoma u obalskom pojasu većine nizijskih jezera relativno homogena, često dominiraju sitni *Fragilaria* (sensu lato) taksoni. Ovi taksoni koriste povoljne svetlosne uslove u plitkoj litoralnoj zoni, ali su loši indikatori kvaliteta vode, jer imaju široku toleranciju na koncentracije nutrijenata (npr. Bennion et al., 2001). Njihova niska osetljivost sugeriše da verovatno neće biti pogodni za razvoj "alata"za klasifikaciju (King et al., 2006).

Vrednosti IPS indeksa koje odgovaraju slabom ekološkom potencijalu utvrđene su u akumulaciji Grlište, umerenom u akumulacijama Bovan, Gruža, Bojnik (Brestovac) i Garaši na ulazu u akumulaciju, a vrednosti koje odgovaraju dobrom i boljem ekološkom potencijalu u svim ostalim akumulacijama.

Ispitivanjem zajednice akvatičnih makroinvertebrata akumulacije Grlište 2012. godine na lokalitetu na ulazu u akumulaciju u septembru mesecu ukupno je zabeleženo 16 taksona. Procentualna zastupljenost maločekinjastih crva (Oligochaeta) u zajednici bila je 39,33%. Iz klase puževa (Gastropoda) bile su prisutne 4 vrste: *Radix labiata* (Rossmässler, 1835), *Physella acuta* (Dreparnaud, 1805), *Viviparus viviparus* (Linnaeus, 1758) i *Viviparus acerosus* (Bourguignat, 1862), a iz klase školjki (Bivalvia) samo jedna vrsta: *Dreissena polymorpha* (Pallas, 1771). Na osnovu prisustva pojedinih taksona bioindikatora konstatovano je umereno organsko opterećenje akumulacije. Predstavnici insekatskih redova Ephemeroptera, Plecoptera i Trichoptera su odsustovali. Na osnovu svih paramatara relevantnih za zajednicu akvatičnih makroinvertebrata, prema Pravilniku, ekološki potencijal akumulacije Grlište

increased eutrophication, which in combination with physical factors, such as water temperature and water column stability, leads to favoring of one or several species. At the regional level, global warming and climate change affected increasing a temperature of aquatic ecosystems, and becoming a high threat. An increase in water temperature could change a lake hydrodynamic and prolong the period of water stratification. Climate change is considered a potential cause of further spread of "blooming" of harmful cyanobacteria, especially in eutrophic waters with rising temperature, increased stratification, longer retention time and high impact of nutrients that favor cyanobacterial dominance (O'Neil et al., 2012).

The EU Water Framework Directive also proposes examination of phytobenthos community in lakes and reservoirs. The emphasis is on the examination of benthic diatoms. Although diatoms indices have been an indispensable "tool" for decades for assessing the ecological status of streams and rivers, their use in assessing the ecological status/ potential of lakes and reservoirs has been dated from recently. The parameter used, according to the Regulation, to assess the ecological potential of reservoirs is the IPS ("Indice de pollutio-sensibilite") diatom index (Coste in Cemagref, 1982). The results of investigation showed that the ecological potential of the reservoirs, based on the IPS index, is one or even two classes better compared to the studies of phytoplankton or macroinvertebrate community. In epilithic communities, whether natural or artificially laid substrates for collecting diatoms, usually dominated by cosmopolitan, alkaliphylic species, such as *Cocconeis placentula* Ehrenberg or *Achnanthidium minutissimum* (Kützing) Czarnecki. These fast-growing pioneer species that are able to rapidly colonize bared substrates, and have a wide ecological spectrum occurring in a wide range of pH values, in conditions from oligotrophy to eutrophy. They are often very tolerant to organic pollution and have a wide ecological valence related to nutrient concentrations. Furthermore, some studies indicate that epipelic diatom community in littoral zone of most lowland lakes is relatively homogeneous, often dominated by small *Fragilaria* (sensu lato) taxa. These taxa take advantage of the favourable light conditions in the shallow water of littoral zones, but are poor indicators of water quality, having a broad tolerance to nutrient concentrations (e.g. Bennion et al., 2001). Their low sensitivity suggests that they are unlikely to be suitable for classification "tool" development (King et al, 2006).

The values of the IPS index, corresponding to poor ecological potential, were obtained in the Grlište reservoir, moderate in the following reservoirs: Bovan, Gruža, Bojnik (Brestovac) and Garaši at the entrance to the accumulation, whilst the IPS index values correspond to good and better ecological potential in all other reservoirs.

u 2012. godini mogao bi se okarakterisati kao slab. U narednom ispitivanju akumulacije Grlište, nakon pet godina, u avgustu i novembru 2017. godine, analizom zajednice akvatičnih makroinvertebrata na lokalitetu kod brane ukupno je konstatovano 13 taksona, a na lokalitetima u centralnom delu akumulacije i na ulazu u akumulaciju po 16 taksona. Izračunate vrednosti BMWP skora na lokalitetima kod brane i na ulazu odgovaraju III klasi (umeren ekološki potencijal), a na sredini akumulacije II klasi (dobar ekološki potencijal). Vrednosti Shannon-Weaver indeksa diverziteta na sva tri lokaliteta odgovaraju II klasi (dobar ekološki potencijal). Visoko procentualno učešće maločekinjastih crva Oligochaeta/Tubificidae u zajednici makroinvertebrata zabeleženo je na sva tri lokaliteta akumulacije (najviše na lokalitetu na ulazu u akumulaciju; 39.22%). Prisutni su pojedini taksoni insekatskih redova Ephemeroptera, Plecoptera i Trichoptera. Na osnovu svih parametara relevantnih za zajednicu akvatičnih makroinvertebrata, prema Pravilniku, ekološki potencijal akumulacije Grlište u 2017. godini je ocenjen kao slab. Poređenjem bioloških parametara zajednice makroinvertebrata akumulacije Grlište u oba ispitivanja, u 2012. i 2017. godini, konstatovano je da nije došlo do značajnih promena stanja akumulacije (slab ekološki potencijal).

Analizama zajednice akvatičnih makroinvertebrata na lokalitetu kod brane i na ulazu u akumulaciju Barje u avgustu mesecu 2013. godine, ukupno je zabeleženo 11 taksona. Maločekinjasti crvi (Oligochaeta) su odsustvovali u zajednici. Puževi (Gastropoda) zastupljeni su sa 6 vrsta: *Radix labiata* (Rossmässler, 1835), *Radix balthica* (Linnaeus, 1758), *Physella acuta* (Dreparnaud, 1805), *Borysthenia naticina* (Menke, 1845), *Valvata piscinalis* (O. F. Müller, 1774) i Viviparus acerosus (Bourguignat, 1862), a školjke (Bivalvia) sa dve vrste: *Anodonta anatina* (Linnaeus, 1758) i *Unio pictorum* (Linnaeus, 1758). Na osnovu svih bioloških parametara ocene ekološkog potencijala za akvatične makroinvertebrate, prema Pravilniku, ekološki potencijal akumulacije Barje u 2013. godini ocenjen je kao umeren. U narednom ispitivanju akumulacije Barje, nakon pet godina, u avgustu 2018. godine, na lokalitetu kod brane ukupno je zabeleženo 14, u centralnom delu akumulacije 12, a na ulazu u akumulaciju 11 taksona. Maločekinjasti crvi (Oligochaeta) su bili prisutni na svim tačkama akumulacije, a najviše na ulazu u akumulaciju (19.05%). Prilikom ovog ispitivanja, zabeženo je 4 taksona iz reda Odonata: *Ischnura elegans* (Vander Linden, 1820), *Sympetrum* sp., *Coenagrion* sp. i *Lestes* sp., u odnosu na 2013. godinu kada je zabeležena samo jedna vrsta - *Onychogomphus forcipatus* (Linnaeus, 1758). Takođe, zabeleženo je dva taksona reda Coleoptera - *Helochares lividus* (Forster, 1771) i *Halipus* sp.; predstavnici ovog reda odsustvovali su u prethodnom ispitivanju. Na osnovu svih parametara relevantnih za zajednicu akvatičnih makroinvertebrata, prema Pravilniku, ekološki potencijal akumulacije Barje u

Investigation of the aquatic macroinvertebrate community of the Grlište reservoir, in September 2012, at the site at the entrance to the reservoir, revealed a total of 16 taxa. The percentage of participation sludge worms (Oligochaeta) in the total community was 39.33%. From the class of snails (Gastropoda), a four species were present: *Radix labiata* (Rossmässler, 1835), *Physella acuta* (Dreparnaud, 1805), *Viviparus viviparus* (Linnaeus, 1758) and *Viviparus acerosus* (Bourguignat, 1862), and from the class of mussels (Bivalvia) only one species, *Dreissena polymorpha* (Pallas, 1771). Based on the presence of certain bioindicator taxa, a moderate organic pollution in the reservoir was ascertained. The representatives of Ephemeroptera, Plecoptera and Trichoptera insect orders were absent. Based on all parameters relevant to aquatic macroinvertebrate community, according to the Regulation, ecological potential of the Grlište reservoir in 2012 could be characterized as a poor. In the next investigation of the Grlište reservoir, after five years, in August and November 2017, the analyses of the aquatic macroinvertebrate community at the site near the dam revealed a total of 13 taxa; 16 taxa at the site in the central part of the reservoir, and 16 taxa and at the entrance to the reservoir. The calculated values of the BMWP score at the sites at the dam, and at the entrance, correspond to class III (moderate ecological potential), and in the middle of the reservoir to class II (good ecological potential). The values of the Shannon-Weaver diversity index correspond to class II (good ecological potential) at all three localities. A high percentage of Oligochaeta/Tubificidae worms in the macroinvertebrate community was recorded at all three sites of the reservoir (mostly at the site at the entrance to the reservoir; 39.22%). The representatives of Ephemeroptera, Plecoptera and Trichoptera insect orders were present. Based on all parameters relevant to the aquatic macroinvertebrate community, according to the Regulation, ecological potential of the Grlište reservoir in 2017 was assessed as a poor. Comparing biological parameters of the macroinvertebrate community of the Grlište reservoir in both studies, in 2012 and 2017, it was concluded that there were no significant changes in state of the reservoir (poor ecological potential).

The analyses of aquatic macroinvertebrate community at the site near the dam, and at the entrance to the Barje reservoir in August 2013, revealed a total of 11 taxa. Sludge worms (Oligochaeta) were absent from the community. Snails (Gastropoda) are represented by 6 species: *Radix labiata* (Rossmässler, 1835), *Radix balthica* (Linnaeus, 1758), *Physella acuta* (Dreparnaud, 1805), *Borysthenia naticina* (Menke, 1845), *Valvata piscinalis* (O. F. Müller, 1774) and *Viviparus acerosus* (Bourguignat, 1862), and mussels (Bivalvia) with two species: *Anodonta anatina* (Linnaeus, 1758) and *Unio pictorum* (Linnaeus, 1758). Based on all biological parameters of the ecological potential assessment for aquatic macroinvertebrates, according to the

2018. godini je ocenjen kao umeren. Poređenjem bioloških parametara zajednice makroinvertebrata akumulacije Barje u oba ispitivanja, u 2013. i 2018. godini, konstatovano je da nije došlo do značajnih promena stanja akumulacije (umeren ekološki potencijal).

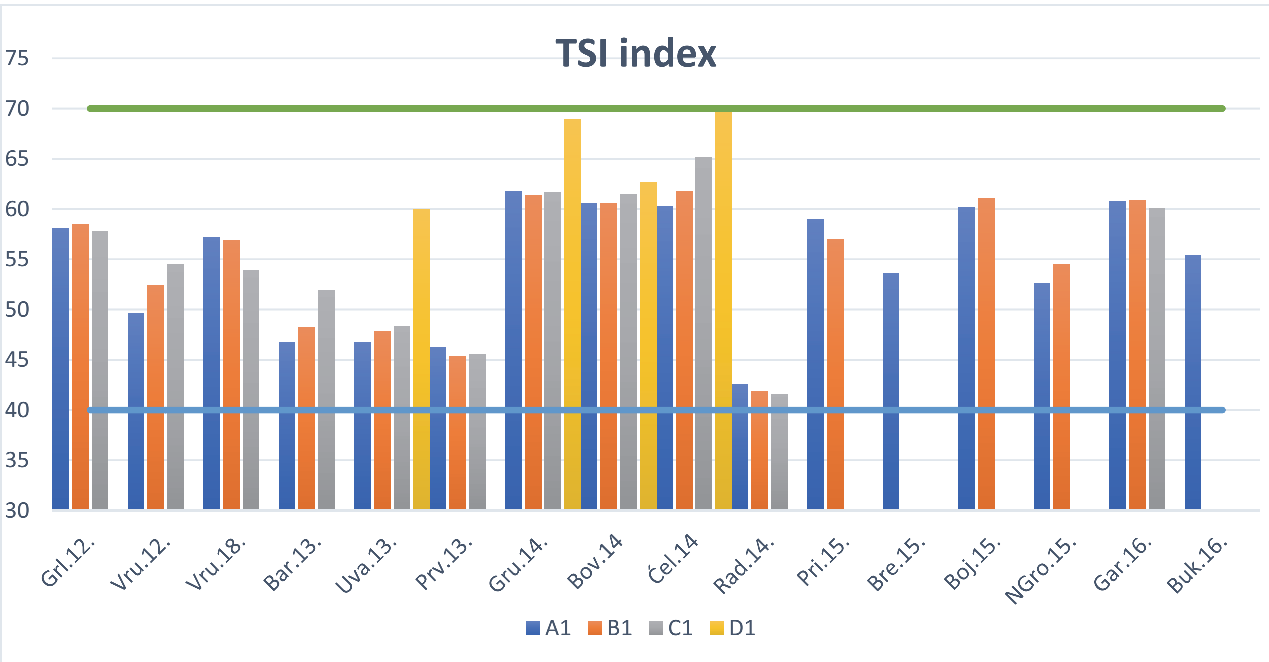
Ekološki potencijal akumulacije Uvac (Sjenica) 2013. godine na osnovu svih parametara relevanthih za zajednicu akvatičnih makroinvertebrata, prema Pravilniku, ocenjen je kao slab, a u 2014. godini akumulacije Radoinja kao umeren, akumulacije Bovan kao slab, a akumulacija Ćelije i Gruža kao loš. U 2015. godini, ekološki potencijal, na osnovu parametara zajednice akvatičnih makroinvertebrata, na akumulacionom jezeru Bresnica i Brestovac (Bojnik) bio je umeren, na Pridvorici slab, a na Novoj Grošnici loš. U 2016. godini akumulacija Bukulja imala je u umeren, a akumulacija Garaši slab ekološki potencijal. U 2018. godini akumulacija Vrutci imala je slab ekološki potencijal na osnovu zajednice akvatičnih makroinvertebrata.

Prosečne vrednosti trofičkog indeka - TSI (Grafik 8), prema Pravilniku, na svim lokalitetima u akumulacijama odgovaraju umerenom ekološkom potencijalu, osim na ulazu u akumulaciju Gruža (D_1) odgovaraju slabom potencijalu. Napominjemo da je širok dijapazon graničnih vrednosti TSI indeksa za umeren ekološki potencijal i da je neophodno revidirati Pravilnik.

Konačno, uzimajući u obzir sve elemente kvaliteta, umeren ekološki potencijal konstatovan je u akumulacijama: Radoinja, Prvonek, Vrutci 2012., Barje

Regulation, ecological potential of the Barje reservoir in 2013 was assessed as a moderate. In the next investigation of the Barje reservoir, after five years, in August 2018, a total of 14 taxa were recorded at the site near the dam, 12 in the central part, and 11 at the entrance to the reservoir respectively. Sludge worms (Oligochaeta) were present at all points of the reservoir, but mostly at the entrance to the reservoir (19.05%). During this examination, a four taxa from the order Odonata were recorded: *Ischnura elegans* (Vander Linden, 1820), *Sympetrum* sp., *Coenagrion* sp. and *Lestes* sp. compared to 2013, when only one species was recorded - *Onychogomphus forcipatus* (Linnaeus, 1758). Also, a two taxa from the order Coleoptera have been recorded - *Helochares lividus* (Forster, 1771) and *Halipus* sp.; the representatives of this order were absent in the previous examination. Based on all parameters relevant to the aquatic macroinvertebrate community, according to the Regulation, the ecological potential of the Barje reservoir in 2018 was assessed as a moderate. Comparing biological parameters of the macroinvertebrate community of the Barje reservoir in both studies, in 2013 and 2018, it was concluded that there were no significant changes in the state of the reservoir (moderate ecological potential).

Ecological potential of the Uvac (Sjenica) reservoir in 2013, based on all parameters relevant to the aquatic macroinvertebrate community, according to the Regulation, was assessed as a poor, in 2014 of the Radoinja as a moderate, of the Bovan as a poor, and of the Ćelije and Gruža reservoirs as a bad. In 2015 ecological potential based on parameters of aquatic macroinvertebrate community was moderate in the



Grafik 8. Prosečne vrednosti indeksa trofičnosti (TSI) na različitim lokalitetima u akumulacijama

Graph 8. Mean annual values of the Trophic State Index (TSI) at different localities in the reservoirs i Bukulja. Akumulacije Radoinja i Prvonek se nalaze u umerenom potencijalu samo zbog parametara trofičkog statusa; svi ostali parametri i parametri bioloških elemenata kvaliteta odgovaraju dobrom i boljem ekološkom potencijalu. Ovo je još jedan od brojnih razloga koji zahteva izmenu Pravilnika. Neke akumulacije pokazuju razlike u ekološkom potencijalu po lokalitetima. To su akumulacija Uvac (Sjenica), koja ima umeren ekološki potencijal kod brane, slab u centralnom delu akumulacije i u kanjonu a loš na ulazu u akumulaciju; akumulacija Grlište koja ima slab ekološki potencijal kod brane i na ulazu u akumulaciju, a loš u centralnom delu, i akumulacija Bovan koja ima umeren potencijal na svim lokalitetima osim u centralnom delu, gde je potencijal slab. Akumulacije sa slabim ekološkim potencijalom su: Bojnik (Brestovac), Bresnica i Pridvorica. Loš ekološki potencijal (V klasa) karakteriše akumulacije Ćelije, Gružu i Garaše. Akumulacija Vrutci je 2012. bila u umerenom ekološkom potencijalu, ali nakon intenzivnog "cvetanja" cijanobakterija 2013., 2014. i 2018. njen ekološki potencijal se pogoršava i prelazi u loš. Ekološki potencijal akumulacije Nova Grošnica, prema Pravilniku i prema kriterijumima ODV je loš, iz razloga što su konstatovane velike promene strukture i funkcije zajednice makroinvertebrata. Specifična hidromorfologija akumulacije Nova Grošnica, sa slabom diferencijacijom mikrostaništa za taksone specijaliste, uslovila je oskudnost zajednice bentosnih beskičmenjaka, sa dominacijom vrsta iz familije Chironomidae i Tubificidae u plićim delovima akumulacije. Stoga parametri koji su relevantni za zajednicu bentosnih beskičmenjaka ukazuju na loš ekološki potencijal akumulacije, ali se ne mogu uzeti kao reprezentativni u konačnoj oceni ekološkog potencijala imajući u vidu specifičnu hidromorfologiju i veliku starost akumulacije. Ekspertska procena na osnovu rezultata ostalih elemenata kvaliteta je da je ekološki potencijal akumulacije umeren.

Ovakvo stanje akumulacija je pre svega posledica dugogodišnjeg negativnog antropogenog uticaja i narušavanja prirodnih procesa koji vladaju u vodenim ekosistemima. Starost mnogih akumulacija je preko 30 i 40 godina. Mnoge akumulacije imaju morfometrijske karakteristike koje pogoduju eutrofikaciji, veliku površinu, a malu dubinu, a u mnogima nije urađena zaštita od erozije, oko mnogih se nalaze obradive površine u neposrednoj blizini, sa kojih se vrši spiranje u akumulacije, zatim nekontrolisana upotreba veštačkih đubriva, nedozvoljena izgradnja stambenih i turističkih objekata u užoj zoni sanitarne zaštite. I na kraju visok priliv nutrijenata, organskog zagađenja i specifičnih zagađujućih materija koje se direktno ispuštaju u reke i dospevaju u akumulacije.

ZAKLJUČAK

Monitoring bioloških elemenata (BQEs), pratećih fizičko-hemijskih elemenata (PHQEs)

Bresnica and the Brestovac (Bojnik) reservoirs, poor in the Pridvorica, and bad in the Nova Grošnica. In 2016 the Bukulja reservoir had a moderate and the Garaši reservoir a poor ecological potential. In 2018 the Vrutci reservoir had a poor ecological potential based on aquatic macroinvertebrate community.

The average values of the trophic index - TSI (Graph 8), according to the Regulation, at all localities in the reservoirs correspond to moderate ecological potential, except at the entrance to the reservoir Gruža (D_1) where correspond to poor potential. We noted that there is a wide range of TSI index limit values for moderate ecological potential and that is necessary to revise the Regulation.

Finally, taking into consideration all quality elements, a moderate ecological potential was found in the following reservoirs: Radoinja, Prvonek, Vrutci 2012, Barje and Bukulja. The Radoinja and Prvonek reservoirs were in moderate potential only due to the parameters of trophic status; all other parameters and parameters of biological quality elements correspond to good and better ecological potential. This is another of the many reasons requiring the amendment of the Regulation. Some reservoirs show differences in ecological potential by localities. These are the Uvac (Sjenica) reservoir, which had a moderate ecological potential at the dam, poor in the central part of the reservoir and in the canyon, and poor at the entrance to the reservoir; the Grlište reservoir which had a poor ecological potential at the dam and at the entrance to the reservoir, and poor in the central part, and the Bovan reservoir which had a moderate potential in all localities except the central part, where the potential was poor. The reservoirs with poor ecological potential are: Bojnik (Brestovac), Bresnica and Pridvorica. Bad ecological potential (V class) characterized the reservoirs Ćelije, Gruža and Garaši. The Vrutci reservoir had a moderate ecological potential in 2012, but after the intensive "blooming" of cyanobacteria in 2013, 2014 and 2018, its ecological potential worsened and corresponded to a bad. The ecological potential of the Nova Grošnica reservoir, according to the Regulation and the WFD criteria, is poor, due to the fact that large changes in the structure and function of the macroinvertebrate community have been evidenced. The specific hydromorphology of the Nova Grošnica reservoir, with poor differentiation of microhabitats for the specialist taxa, conditioned the scarcity of the benthic invertebrate community, with the dominance of species from Chironomidae and Tubificidae families in more shallow parts of the reservoir. Therefore, the parameters relevant to the benthic invertebrate community indicate poor ecological potential of the reservoir, but cannot be taken as a representative in the final ecological potential assessment of considering specific hydromorphology and long age of the reservoir. Expert assessment based on the i specifičnih zagađujućih supstanci za potrebe određivanja ekološkog potencijala akumulacija za vodosnabdevanje sprovela je Agencija za zaštitu životne sredine Srbije od 2012. godine prema zahtevima ODV. Sve ispitivane akumulacije pripadaju dimiktičkom tipu jezera umereno kontinentalne zone i odlikuje ih više ili manje izražena termička stratifikacija vode u prolećnom i letnjem periodu. Stratifikacija i cirkulacija vode kontrolišu dva najvažnija faktora u ekologiji fitoplanktona: dostupnost svetlosti i nutrijenata. Sadržaj rastvorenog kiseonika u većini akumulacija, u letnjem periodu, opada već u metalimnionu i njegov deficit je evidentan u hipolimnionu, osim u akumulacijama Prvonek i Radoinja. Vrednost C10 (10-percentil) za rastvoreni kiseonik na godišnjem nivou u mnogim akumulacijama odgovara slabom ili lošem ekološkom potencijalu. Prema Pravilniku, konstatovane su povećane prosečne godišnje koncentracije ortofosfata i ukupnog fosfora u akumulacijama: Grlište, Bovan, Ćelije, Gruža i Garaši, i one odgovaraju umerenom ekološkom potencijalu. Prema OECD klasifikaciji radi se o velikom povećanju ovih nutrijenata u svim akumulacijama, koje odgovara eutrofnim i hipereutrofnim uslovima, osim akumulacije Prvonek koja ima mezotrofan status. Prosečne godišnje vrednosti ukupnog organskog ugljenika (TOC) su, takođe, povećane u nekim akumulacijama. Od trofičkog statusa akumulacija zavisi prostorna i vremenska distribucija životnih zajednica. Najvažniji biološki element kvaliteta u jezerima i akumulacijama je fitoplankton; on najbrže reaguje, naročito svojom brojnošću i biomasom, na promene životnih uslova. Prosečne vrednosti abundance fitoplanktona su povećane u većini akumulacija i odgovaraju slabom ili lošem ekološkom potencijalu. Eutrofikacija je poslednjih decenija na globalnom nivou, jedan od najozbiljnijih problema koji utiče na kvalitet vode. Jedna od posledica eutrofikacije je "cvetanje" cijanobakterija koje dostiže zabrinjavajuće razmere. One potencijalno mogu da produkuju širok spektar toksina koji mogu da izazovu oboljenja ljudi i životinja. Intenzitet "cvetanja" cijanobakterija u nekim akumulacijama iznosi >100000 ćel mL^{-1}, što je prema preporukama Svetske zdravstvene organizacije, za prisustvo cijanobakterija u vodi za vodosnabdevanje, opasnost visokog rizika po zdravlje stanovništva. To su akumulacije: Vrutci, Ćelije, Gruža i Garaši. I u drugim akumulacija brojnost cijanobakterija, u pojedinim periodima je povišena, ali iznosi <100000 ćel mL^{-1}, što je, prema preporukama Svetske zdravstvene organizacije, opasnost srednjeg rizika po zdravlje stanovništva. U akumulacijama Vrutci i Garaši "cvetanje" su izazvale dve filamentozne, hepatoksične vrste roda *Planktothrix* (*P. rubescens* i *P. agardhii*), koje imaju značajno veće koncentracije mikrocistina po jedinici cijanobakterijske biomase od drugih vrsta cijanobakterija. U akumulaciji Vrutci 2018. godine praćene su i koncentracije cijanotoksina.

results of other quality elements is that the ecological potential of the reservoir is moderate.

Such state of the reservoirs is primarily a consequence of the long-term negative anthropogenic impact and disruption of natural processes prevailing in aquatic ecosystems. The age of many reservoirs is over 30 and 40 years. Many reservoirs have morphometric characteristics affecting eutrophication, large area and small depth, and many have not been protected from erosion, around many there are arable land in the surrounding area, from which rinsing into reservoirs is occurred, then uncontrolled use of fertilizers, illegal construction of residential and tourist facilities in the narrow zone of sanitary protection. And finally, a high nutrient influx, organic pollution and specific pollutants discharged directly into rivers and reach reservoirs.

CONCLUSIONS

Since 2012 monitoring of biological elements (BQEs), accompanying physico-chemical elements (PHQEs) and specific pollutants for the purpose of determining the ecological potential of reservoirs intented for water supply according to the WFD requirements has been conducted by the Serbian Environmental Protection Agency. All investigated reservoirs belong to dimictic type of lake of the temperate continental climates, and characterized by more or less pronounced thermal stratification of water in the spring and summer period. Stratification and water circulation control two most important factors in phytoplankton ecology: the availability of light and nutrients. The content of dissolved oxygen in most reservoirs, in the summer period, decreases yet in the metalimnion and its deficit is evident in the hypolimnion, except in the Prvonek and Radoinja reservoirs. The value of C10 (10th percentile) for dissolved oxygen on annual level in many reservoirs corresponds to a poor or bad ecological potential. According to the Regulation, the increased mean annual concentrations of orthophosphate and total phosphorus in the following reservoirs: Grlište, Bovan, Ćelije, Gruža and Garaši have been ascertained corresponding to a moderate ecological potential. According to the OECD classification, there is a large increase in these nutrients in all reservoirs, which corresponds to eutrophic and hypereutrophic conditions, except for the Prvonek reservoir which had mesotrophic status. Mean annual values of total organic carbon (TOC) had also increased in some reservoirs. The spatial and temporal distribution of biocenoses depends on the trophic status of the reservoirs. The most important biological quality element in lakes and reservoirs is phytoplankton; it reacts the fastest to changes in living conditions, particularly with its number and biomass. The mean values of phytoplankton abundance were increased in most reservoirs and correspond to

U aprilu su utvrđene visoke koncentracije ukupnih mikrocistina koje su činili: MC-LR, MC-RR i MC-YR. Te koncentracije (10,9 μg L^{-1}) prema kriterijumu EPA (US) odgovaraju visokom nivou upozorenja. U avgustu 2018. *P. rubescens* se povlači u metalimnion, snižavaju se koncentracije ukupnih mikrocistina, ali i dalje ostaju na visokom nivou. Tek u novembru su njihove vrednosti ispod granice kvantifikacije. Mikrocistin-LR, koji je najtoksičnija forma od ove tri, bio je ispod propisane vrednosti koncentracije koje je dala Svetska zdravstvena organizacija (SZO) samo za ovu formu mikrocistina (1 μg L^{-1}). Klimatske promene i globalno zagrevanje dodatno pogoršavaju situaciju i smatraju se potencijalnim uzrokom daljeg širenja "cvetanja" štetnih cijanobakterija.

Ispitivanje bentosnih dijatoma i primena dijatomnih indeksa (IPS) za određivanje ekološkog potencijala akumulacija je novijeg datuma. Zbog prisustva kosmopolitskih vrsta koje imaju široku ekološku valencu, rezultati pokazuju da je ekološki potencijal za jednu ili dve klase bolji nego što pokazuju ispitivanja fitoplanktona i makroinvertebrata.

U zajednici akvatičnih makroinvertebrata, na organsko opterećenje ispitivanih akumulacija uglavnom ukazuje povećana brojnost taksona maločekinjastih crva (Oligochaeta), predstavnika pijavica (podklasa Hirudinea), kao i predstavnika familje Chironomidae. Postavlja se pitanje ocene poor or bad ecological potential. In recent decades eutrophication has been a global problem, one of the most serious problems affecting water quality. One of the consequences of eutrophication is "blooming" of cyanobacteria, which reaches worrying proportions. Cyanobacteria can potentially produce a wide range of toxins that can cause disease in humans and animals. The intensity of "blooming" of cyanobacteria in some reservoirs was >100 000 cells mL^{-1}, which, according to the the World Health Organization (WHO) recommendations, for the presence of cyanobacteria in water supply, is a threat of high risk to public health. These are the following reservoirs: Vrutci, Ćelije, Gruža and Garaši. In other reservoirs, the number of cyanobacteria is increased in some periods, but it amounts <100 000 cells mL^{-1}, which is, according to the the WHO recommendations, a threat of medium risk to the health of population. In the Vrutci and Garaši reservoirs, the "blooming" was caused by two filamentous, hepatotoxic species of the genus *Planktothrix* (*P. rubescens* and *P. agardhii*), which have significantly higher concentrations of microcystins per unit of cyanobacterial biomass than other cyanobacterial species. In 2018 in the Vrutci reservoir, cyanotoxin concentrations were also monitored. In April, high concentrations of total microcystins were found, consisting of: MC-LR, MC-RR and MC-YR. These concentrations (10.9 μg L^{-1}) according to the EPA (US) criterion correspond to a

Slika 1. Akumulacija Vrutci – Opština Užice, 2014 (foto: SEPA)

Figure 1. The Vrutci reservoir – Municipality of Užice, 2014 (photo: SEPA)

indikativnosti zajednice makroinvertebrata u oceni ekološkog statusa i potencijala jezera i akumulacija, s obzirom da je na pojedinim akumacijama prisutan veći broj neindikatorskih, neosetljivih, invazivnih i neustonskih taksona, a fluktuacije vodostaja, velike količine padavina i nanosa u akumulacije driftom donose i organizme iz obližnjih potoka i reka, koje ne pripadaju stalnim makrozoobentocenozama akumulacionih jezera.

Konačna ocena pokazuje da su akumulacije: Radoinja, Prvonek, Vrutci 2012. godine, Barje, Bukulja, Nova Grošnica, Uvac (Sjenica) na lokalitetu kod brane i Bovan kod brane i na ulazu u akumulaciju, imale umeren ekološki potencijal. Slab ekološki potencijal imale su akumulacije: Grlište kod brane i na ulazu u akumulaciju, Bovan u centralnom delu, Bojnik (Brestovac), Bresnica i Pridvorica. Loš ekološki potencijal imale su akumulacije: Ćelije, Gruža, Garaši, Grlište u centralnom delu i Vrutci 2018. godine, nakon višegodišnjeg cvetanja cijanobakterija.

high level of warning. In August 2018, *P. rubescens* withdrawed into the metalimnion, the concentrations of total microcystins decreased, but still remained at a high level. Only in November their values are below the limit of quantification. Microcystin-LR, which is the most toxic form of these three, was less to proposed concetration value given by the World Health Organization (WHO) only for this form of microcystin (1 μg L^{-1}). Additionally, climate change and global warming deteriorate the state, considered as a potential cause of the further spread of "blooming" harmful cyanobacteria.

The examination of benthic diatoms and the use of diatom indices (IPS) to determine the ecological potential of the reservoir has been dated from recently. Due to the presence of cosmopolitan species that have a wide ecological valence, the results showed the ecological potential is one or even two classes better compared to the studies of phytoplankton or macroinvertebrate community.

In aquatic macroinvertebrate community, the increased number of sludge worms taxa (Oligochaeta), the leech representatives (subclass Hirudinea), as well as the representatives of the family Chironomidae, mainly indicate organic load in the investigated reservoirs. The indicativeness of macroinvertebrate community in assessing ecological status and potential of lakes and reservoirs is questionable bearing in mind a high number of non-indicative, insensitive, invasive and neuston taxa are present in some reservoirs, and water-level fluctuations drifted organisms into reservoir from nearby streams and rivers, which do not belong to regular macrozoobenthocenosis of reservoir.

The final assessment showed that the following reservoirs: Radoinja, Prvonek, Vrutci in 2012, Barje, Bukulja, Nova Grošnica, Uvac (Sjenica) at the site near the dam, and Bovan near the dam and at the entrance to the reservoir, had a moderate ecological potential. The reservoirs had a poor ecological potential are: Grlište near the dam and at the entrance to the reservoir, Bovan in the central part, Bojnik (Brestovac), Bresnica and Pridvorica. The reservoirs had a bad ecological potential are: Ćelije, Gruža, Garaši, Grlište in the central part, and Vrutci in 2018, after many years of cyanobacterial "blooming".

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