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VLOGA PERIFITONSKIH ALG PRI DOLOČANJU EKOLOŠKO SPREJEMLJIVEGA PRETOKA VODE V TEKOČIH VODAH
THE ROLE OF PERIPHYTIC ALGAE IN THE DETERMINATION OF THE ECOLOGICALLY ACCEPTABLE FLOW IN RUNNING WATERS

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Pri določanju ekološko sprejemljivega pretoka (Qes) je treba poznati združbo perifitonskih alg, ker predstavljajo začetek prehranjevalne verige v tekočih vodah, se hitro odzivajo na spremembe v okolju in ponujajo podlago in zatočišče številnim vodnim organizmom. Vrednost Qes mora zagotavljati količino in kakovost vode, da ne pride do bistvenih sprememb v zgradbi in delovanju združbe perifitonskih alg. V različnih letnih obdobjih, v času nizkih pretokov vode v letih 1998-1999, smo v reki Savi Dolinki na območju odvzema vode za HE Moste, in v reki Soči, na območju odvzema vode za HE Doblar in HE Ajba, ocenili vpliv odvzema vode na združbo perifitonskih alg in na hidrološke značilnosti obeh rek ter opredelili vlogo perifitonskih alg pri Qes v tekočih vodah. Rezultati so pokazali na kakovostne in koločinske hidrološke, biološke, fizikalne in kemijske spremembe pod pregradami. Rezultati hidroloških analiz so pokazali na bistveno spremenjen hidrološki režim in prevladovanje prodnatih plavin s precejšnim deležem grobih zrn pod pregradami. Posledica odvzema vode je, da fizikalno in kemijsko sestavo vode pod pregradami ne uravnavajo več razmere v zgornjem delu porečja, temveč jo določajo dotoki pod mesti zajetja. Stalen pretok in redko pojavljanje visokih voda pod pregradami sta vzrok za veliko raznolikost perifitonskih alg in razlike v biomasi perifitonskih alg, v primerjavi s primerjalnimi mesti nad pregradami.

Ključne besede: *perifitonske alge, ekološko sprejemljiv pretok, odvzem vode*

To determine ecologically acceptable flow (EAF), it is vital to have knowledge of the periphyton community, since the algae represent the initial stage of the food chain in running waters, and respond quickly to environmental changes and act as substrata and refuges for a number of water organisms. The EAF value should assure such quantity and quality of water that substantial changes in the composition and functioning of the periphyton community do not occur. In different seasons of the years 1998-1999, during the period of low flows, the impact of abstractions on the periphyton community and on hydrological characteristics was assessed in the Sava Dolinka River in the abstraction section for the Moste power plant, and in the Soča River, in the abstraction sections for the Doblar and Ajba power plants. The role of periphytic algae in the determination of EAF in flowing waters was defined. Results of the study show qualitative and quantitative hydrological, biological, and physicochemical changes downstream of the dams. The results of the hydrological analyses show substantial changes in the hydrological regime and a predominance of gravel deposits with a considerable proportion of coarse grains downstream of the dams. Due to abstractions, the physicochemical composition of water downstream of the dams is no longer defined by conditions in the upper reaches of the river, but by tributaries downstream of the catchment area. A constant flow, as well as a rare occurrence of high waters downstream of the dams has given rise to a great diversity of periphyton and to differences in the periphyton biomass here, compared with reference sites upstream of the dams.

Key words: *periphytic algae, ecologically acceptable flow, water abstraction*

1. UVOD

Za ohranjanje dinamike naravnih procesov v vodotokih se je pojavila zahteva po zagotavljanju ekološko sprejemljivega pretoka vode (Qes). Definirali smo ga kot količino in kakovost vode, ki zagotavlja ohranitev naravnega ravnovesja v in ob vodotoku (Vrhovšek et al.,1994). Za določitev ekološko sprejemljivega pretoka vode (Qes) je, poleg hidroloških, morfoloških in krajinskih komponent vodnega ekosistema, potrebno med ekološkimi parametri tudi poznavanje perifitonskih alg. Perifitonske alge imajo velik pomen pri ekološkem ravnovesju rek, saj tvorijo organsko snov in imajo pomen pri pretoku snovi in energije. Perifitonske alge so najpomembnejši primarni producenti v majhnih vodotokih in so hkrati uporabni ekološki indikatorji stopnje onesnaženosti (Wilhm et al., 1978).

Čeprav so v večini raziskav določevanja Qes glavno vlogo namenjali ribam in nevretenčarjem, so pri določanju Qes na potoku Radurlsbach v Avstriji leta 1985 že upoštevali perifitonske alge (Jäger et al., 1985). Pri določitvi Qes za Alpbacher Ache v Avstriji so opravili analizo hidroloških, morfoloških in fizikalnih ter kemijskih parametrov, analizo sedimentov, med biološkimi parametri pa so vzorčevali perifitonske alge in večje vodne nevretenčarje (Pehofer et al., 1988). Rezultate analiz perifitonskih alg so upoštevali pri določanju Qes na vodotokih Töss, Schächenbach in Niemet v Švici (Bundi & Eichenberger, 1989). Na Hrvaškem pa so pri določanju Qes na reki Cetini (Mišetić et al., 1986) in na reki Žrnovici (Bonacci et al., 1998) opravili tudi analize perifitonskih alg. Pri določanju Qes v Sloveniji smo upoštevali rezultate perifitonskih alg, med drugim tudi na reki Soči (Vrhovšek et al., 1996a), Rižani (Smolar et al., 1997), Selščici (Smolar-Žvanut et al., 1999a), Meži (Smolar-Žvanut et al., 1999b) in Savi Dolinki (Vrhovšek et al., 1999).

1. INTRODUCTION

To maintain the dynamics of natural processes in watercourses, it is vital to ensure that the flow is ecologically acceptable. Ecologically acceptable flow (EAF) may be defined as such quantity and quality of water which preserves the ecological balance in a river and in the riparian zone (Vrhovšek et al., 1994). To determine EAF, not only data on hydrological, morphological, and landscape components of an aquatic ecosystem are needed, but also knowledge of periphyton. The algae play a major role in the maintenance of the ecological balance in rivers, since they produce organic matter and are of importance in the flow of matter and energy. They are the most significant primary producers in streams and can also be used as ecological indicators of pollution (Wilhm et al., 1978).

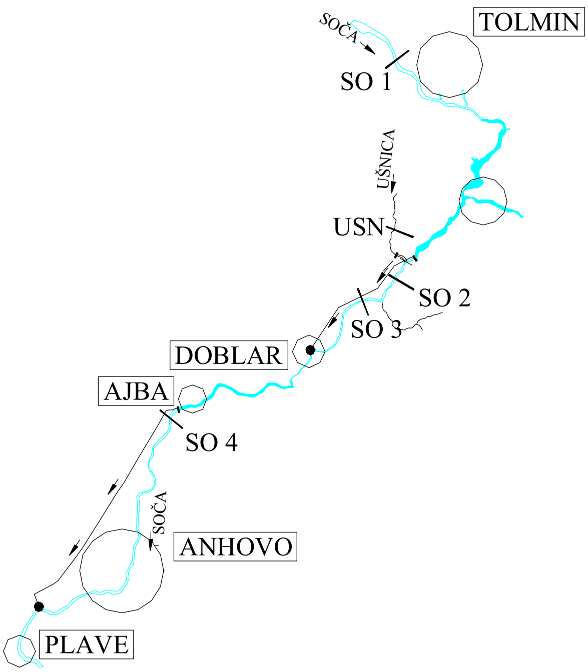
Most research on EAF determination deals mainly with fish and invertebrates. In 1985 a study was carried out to determine the EAF for the Radurlsbach Stream, in Austria, in which periphyton was taken into account (Jäger et al., 1985). The determination of the EAF for the Alpbacher Ache Stream in Austria included an analysis of hydrological, morphological, and physicochemical parameters, a sediment analysis and, among biological parameters, a sampling of periphyton and of macroinvertebrates (Pehofer et al., 1988). The periphyton was analysed when the EAF was determined for the Töss, Schächenbach, and Niemet rivers in Switzerland (Bundi & Eichenberger, 1989). In Croatia, periphyton analyses were carried out for the Cetina (Mišetić et al., 1986) and Žrnovica (Bonacci et al., 1998) rivers for the same purpose. In Slovenia, periphyton analyses were taken into account to determine the EAF for the Soča (Vrhovšek et al., 1996a), Rižana (Smolar et al., 1997), Selščica (Smolar-Žvanut et al., 1999a), Meža (Smolar-Žvanut et al., 1999b), and Sava Dolinka (Vrhovšek et al., 1999) rivers.

2. MESTO RAZISKAV

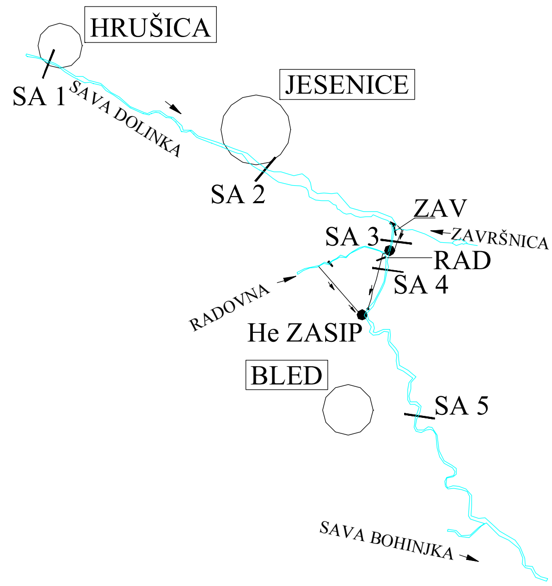
Na reki Soči smo izbrali območja odvzema nad pregrado (SO1) in pod pregrado Podsela (SO2, SO3), pod pregrado Ajba (SO4) ter na pritoku Ušnica (USN) (slika 1), na reki Savi Dolinki pa nad (SA1, SA2) in pod pregrado Moste (SA3, SA4, SA5) ter na pritokih Završnica (ZAV) in Radovna (RAD) (slika 2). Na vseh območjih odvzema smo vzorčevali perifitonske alge v različnih hidroloških okoljih (glede na hitrost in globino vode) ter merili hidrološke in fizikalno kemijske parametre. Na območju odvzema smo število odvzemnih mest izbrali glede na širino struge, strukturo habitatov, globino vode in hitrost vodnega toka. Območje odvzema je obsegalo prečni prerez od levega do desnega brega struge, v primeru zastajanja vode pa tudi najbližji gorvodni in dolvodni tolmun.

2. STUDY SITE

In the Soča River, sampling sites were selected upstream (SO1) and downstream (SO2, SO3) of the Podsela Dam, downstream of the Ajba Dam (SO4), and in the Ušnica Tributary (USN) (Figure 1). In the Sava Dolinka River, they were selected upstream (SA1, SA2) and downstream (SA3, SA4, SA5) of the Moste Dam, and in the Završnica (ZAV) and Radovna (RAD) (Figure 2) tributaries. At all the sampling sites, the periphyton was sampled in different hydrological environments (according to velocity and water depth), and hydrological and physicochemical parameters were measured. The number of sampling points at a sampling site was determined according to river bed width, habitat structure, water depth, and current velocity. A sampling site comprised a cross-channel transect from the left to the right bank and, in the case of stagnant water, the nearest upstream and downstream pools.



Slika 1. Odvzemna mesta v reki Soči in v potoku Ušnica.
Figure 1. Sampling points in the river Soča and in the stream Ušnica.



Slika 2. Odvzemna mesta v reki Savi Dolinki, v reki Radovni in v potoku Završnica.
Figure 2. Sampling points in the river Sava Dolinka, in the river Radovna and in the stream Završnica.

2.1 ZNAČILNOSTI HE MOSTE, HE ZAVRŠNICA IN HE ZASIP

HE Moste obratuje kot prva večja elektrarna na reki Savi Dolinki. Betonska, ločno-težnostna pregrada je s 60 m višine tudi najvišja pregrada v Sloveniji. HE Moste je akumulacijska elektrarna za proizvodnjo vršne energije. Vtočni objekt leži ob levem boku pregrade, od tam je speljan dovodni rov v dolžini 840 m do strojnice. V dovodni rov so speljane tudi zaledne vode iz potoka Završnica. HE Moste sestavlja, skupaj s HE Završnica na potoku Završnica, enoten energetski sistem. V HE Moste so bili prvotno vgrajeni trije agregati, s požiralnostjo 28.5 m^3/s. Sistem je bil dograjen leta 1977 z vgradnjo četrtega agregata v strojnici HE Moste, s požiralnostjo 6 m^3/s in s priključitvijo dovodnega cevovoda HE Završnica. Četrti agregat obratuje v pogojih vršnega obratovanja.

Obratovanje HE Moste je vezano na količino dotoka vode v akumulacijo in obratuje glede na potrebe energije v državi, običajno v dnevnih urah. V primeru, da je dotok vode v akumulacijo 14 m^3/s, obratuje HE Moste od 6. ure zjutraj do 22. ure zvečer, in sicer z odvzemom vode 20 m^3/s, razen v

2.1 CHARACTERISTICS OF THE MOSTE, ZAVRŠNICA, AND ZASIP POWER PLANTS

The Moste HPP is the first larger power plant which was built on the Sava Dolinka River. The concrete arch-gravity dam, 60 metres high, is the highest in Slovenia. The power plant is a reservoir generating peak energy. The intake structure is located on the left side of the dam, where a 840-metre long power tunnel leads to the power station. The Završnica Stream flows into the power tunnel. Along with the Završnica HPP, located on the Završnica Stream, the Moste HPP constitutes a uniform hydropower system. Initially, the Moste HPP had three generators with a design flow of 28.5 m^3/s. On completion of the system in 1977, the power station of the Moste plant was fitted with a fourth generator with a design flow of 6 m^3/s, and was connected with the power channel of the Završnica HPP. The fourth generator operates in peak energy conditions.

The operation of the Moste HPP depends on the quantity of the inflow into the reservoir. It is operative according to electricity requirements, usually during the daytime. If inflow into the reservoir is 14 m^3/s, the plant operates from 6 a.m. to 10 p.m., with abstractions of 20 m^3/s, except from 1 p.m. to času med 13. in 18. uro z odvzemom vode od 4 do 10 m^3/s. Na začetku obratovanja elektrarne se v povprečju v času dveh minut poveča količina vode iz 0 na 10 m^3/s oz. v petih minutah iz 0 na 20 m^3/s.

HE Moste v glavnem ne obratuje v sobotah in nedeljah, ker se voda nabira v akumulacijo, zato so pretoki na v.p. Blejski most takrat najnižji. Obratovanje HE Moste povzroča v dolvodni strugi Save Dolinke, na odseku od vtoka vode nazaj v Savo Dolinko do HE Mavčiče, hitro povečevanje in zmanjševanje pretokov.

Pod pregrado Moste se, zaradi zajezitve, zbira le voda iz drenaž, del vode iz Završnice in nekaj vode, ki se pretaka pod pregrado za HE Zasip na Radovni. V primeru, da HE Moste ne obratuje, doteka v strugo Save Dolinke pred Piškotarjevim mostom le voda, ki se pretaka pod pregrado HE Moste in Radovna iz HE Zasip. Zaradi odvzema vode za HE Moste je Sava Dolinka pod vplivom odvzema vode na dolžini 2470 m.

Za HE Zasip na reki Radovni je odvzem vode iz Radovne v višini 7.5 m^3/s. Zaradi puščanja jezu in zapornic se v strugi pretaka nekaj deset litrov vode. Dolžina odseka Radovne, ki je pod vplivom odvzema vode za HE Zasip, je 2175 m, dolžina Save Dolinke, ki je pod vplivom odvzema za HE Zasip pa je 1625 m.

2.2 ZNAČILNOSTI HE DOBLAR, HE AJBA, HE PLAVE

Soča je bila energetsko zanimiva že v času Avstro-Ogrske, ko so jo pričeli prvič intenzivneje preučevati, z namenom izrabe njene vodne moči. Kasneje so tudi Italijani nadaljevali s preučevanjem Soče in pritokov ter zgradili tudi prve elektrarne (HE Log, HE Plužna, 1930-1932). V letu 1939 je bila zgrajena HE Doblar in leta 1940 HE Plave. V letih od 1971 do 1975 je bila zgrajena HE Ajba na jezovnih zgradbah HE Plave, od leta 1984 pa je v pogonu tudi HE Solkan. Pod pregrado Podsela do državne meje zaradi energetske izrabe ni več naravnega pretočnega režima (Vrhovšek et al., 1996a).

6 p.m. when abstractions amount to from 4 to 10 m^3/s. When it starts to operate in the morning, the abstraction increases, on an average, from 0 to 10 m^3/s in two minutes, or from 0 to 20 m^3/s in five minutes.

The Moste HPP is not in operation, as a rule, on Saturdays and Sundays, when water flows into the reservoir. Therefore, flows at the Blejski most Gauging Station (g.s.) are lowest at that time. The operation of the power plant causes a rapid increase and decrease of flows downstream of the Sava Dolinka River, in the section from the inflow of water back into the Sava Dolinka River to the Mavčiče HPP.

Due to damming, downstream of the dam Moste, in the bed of the Sava Dolinka River, water is collected from the draining system, part of the water from the Završnica Stream, and some water flowing downstream of the dam to the Zasip HPP on the Radovna River. If the Moste HPP is not operational, then in the river bed, before the Bridge Piškotarjev most, water flows from downstream of the dam for the Moste HPP and from the Radovna River for the Zasip HPP. Thus, a 2470 m long section of the Sava Dolinka River is adversely affected by abstractions for the Moste HPP.

For the Zasip HPP on the Radovna River, there are abstractions of 7.5 m^3/s. Due to gate and sluice leakage, some tens of litres flow into the river bed. The abstractions for the Zasip HPP exert an effect on a 2175 m long section of the Radovna River and on a 1625 m long section of the Sava Dolinka River.

2.2 CHARACTERISTICS OF THE DOBLAR, AJBA, AND PLAVE HPP

The Soča River as a source of hydropower was already considered interesting at the time of the Austro-Hungarian Empire when this aspect of its use was more intensely investigated for the first time. Later, the Italians continued to study the Soča River and its tributaries for this purpose, and thus the first hydropower plants were built (Log, Plužna, 1930-1932). The Doblar and Plave power plants were constructed in 1939 and 1940 respectively. In 1971-1975, the Ajba HPP was built by means of the Plave HPP dams. The Solkan HPP has been operational since 1984. As a consequence of power utilisation, there is no natural flow regime downstream of the Podsela Dam to the Italian border (Vrhovšek et al., 1996a).

Pregrada Podsela za HE Doblar je betonska, ločno težnostna in je s 55 m višine druga najvišja pregrada v Sloveniji. Pregrada Ajba leži 4.5 km dolvodno od elektrarne Doblar. Odvzem vode med pregrado Podsela in HE Doblar je na dolžini 4320 m, med pregrado Ajba in HE Plave pa 7950 m.

Največji mogoč odvzem vode iz reke Soče na pregradi Podsela za potrebe HE Doblar je 96 m^3/s; v primeru, da so pretoki vode višji in se akumulacija ne polni, voda teče preko pregrade.

V letu 1998 se je pričela gradnja novih hidroelektraren HE Doblar II in HE Plave II, pri čemer bo skupen inštaliran pretok vode HE Plave I in II 180 m^3/s, HE Doblar I in II 180 m^3/s, HE Ajba, ki se nahaja v pregradi Ajba, pa bo ukinjena.

V strugi reke Soče pod pregrado Podsela se pretaka le voda iz potoka Ušnica in majhne količine vode, ki se precejajo skozi izpuste zapornic pregrade Podsela. Levi pritok Vogrščec v sušnem obdobju nima vode, ker je izrazito hudourniškega značaja s kraškimi značilnostmi.

Pod pregrado Ajba se skozi zapornico spušča pretok vode 0.5 m^3/s, opredeljen v vodnogospodarskem dovoljenju za HE Plave. Na odseku od pregrade Ajba do izpusta vode iz HE Plave so manjši hudourniški pritoki (Vrhovšek et al., 1996a).

3. MATERIAL IN METODE DELA

3.1 ČAS VZORČEVANJA

Vzorčevanje perifitonskih alg, določanje biomase perifitonskih alg in merjenje hidroloških parametrov je potekalo v letih 1998 in 1999, v obdobju nizkih pretokov vode. Na Soči smo vzorčevali dne 3.2.1998, 20.5.1998, 25.8.1998 in 30.11.1998, na Savi Dolinki pa 9.2.1998, 3.6.1998, 24.8.1998 in 7.1.1999. Linijski odvzem vzorca plavin smo na Soči opravili dne 19.7.1999, na Savi Dolinki pa dne 6.7.1999. Meritve na območju odvzema SA5 (Blejski most) v Savi Dolinki so bile vedno izvedene v času, ko HE Moste ni obratovala, torej ni bilo povečanega pretoka vode, izmerjenega gorvodno od pregrade Moste.

The Podsela Dam for the Doblar HPP is a concrete arch-gravity dam, 55 metres in height, the second highest in Slovenia. The Ajba Dam is situated 4.5 km downstream of the Doblar HPP. The abstraction section from the Podsela Dam to the Doblar HPP is 4320 m long, and that from the Ajba Dam to the Plave HPP is 7950 m long.

At the Podsela Dam, the highest possible abstraction amount for the Doblar HPP is 96 m^3/s. If flows are higher and the reservoir is not being filled, water flows over the dam.

In 1998 the construction of the Doblar II and Plave II power plants began. Joint design flow for the Plave I and Plave II power plants will be 180 m^3/s, the same as the design flow for the Doblar I and Doblar II power plants. The Ajba HPP, situated within the Ajba Dam, will stop operating.

In the bed of the Soča River, downstream of the Podsela Dam, water flows from the Ušnica Stream and small quantities of water trickle through, due to gate leakage at the Podsela Dam. In the dry season, the left Vogrščec Tributary dries up because of its distinctively torrential character and karst features.

Downstream of the Ajba Dam, the flow through the gate is 0.5 m^3/s, according to the water management operating licence for the Plave HPP. In the section from the Ajba Dam to the discharge from the Plave HPP, there are smaller torrential tributaries (Vrhovšek et al., 1996a).

3. MATERIAL AND METHODS

3.1 SAMPLING

A sampling of periphyton, determination of periphyton biomass, and measurement of hydrological parameters was carried out in the period of low flows in 1998 and 1999. In the Sava River, the sampling was conducted on February 3, May 20, August 25, and November 30, 1998, and in the Sava Dolinka River, on February 9, June 3, August 24, 1998, and on January 7, 1999. The Wolman Count of sediment samples was performed in the Soča River on July 19, 1999, and in the Sava Dolinka River on July 6, 1999. Measurements conducted at sampling site SA5 (Blejski most Gauging Station) in the Sava Dolinka River were always carried out when the Moste HPP was not in operation. So there was no increase in flow measured upstream of the Moste Dam.

3.2 HIDROLOŠKI PARAMETRI

Hitrost vodnega toka in pretok vode smo merili s hidrometričnim krilom SEBA Mini Current Meter MI. Na vseh odvzemnih mestih, kjer smo vzorčevali, smo merili hitrost vodnega toka 3 cm nad dnom. Povprečno hitrost v merskih vertikalah nad odvzemnimi mesti smo izmerili na 0.4 globine vode, merjeno od dna struge. Čas meritve v posamezni točki je bil eno minuto.

Merjene hidrološke parametre ter podatke o vodostajih, ki smo jih povzeli po MOP - HMZ, smo obdelali z računalniškim programom (VGI, 1992) na Vodnogospodarskem inštitutu v Ljubljani.

Določili smo prispevno področje (F) za območja odvzema in s pomočjo računalniškega programa (VGI, 1992) izračunali vrednosti sQs (srednji pretok - je povprečje srednjih dnevnih pretokov v m^3/s za vsako leto v obravnavanem obdobju), sQn (srednji nizek pretok - je povprečje najnižjih pretokov v m^3/s v letu v obravnavanem obdobju), nQn (najmanjši nizek pretok- je najnižji zabeležen pretok v m^3/s v obravnavanem obdobju), vQv (največji pretok - je najvišji zabeležen pretok vode v m^3/s v obravnavanem obdobju), Q_{300d} (pretok, ki traja 300 dni na leto) in Q_{347d} (pretok, ki traja 347 dni na leto).

Cilj analize hidroloških podatkov je bila določitev hidroloških parametrov, ki kažejo rečni režim na odseku Soče pod pregrado Podsela in pod pregrado Ajba ter na odseku Save Dolinke od pregrade HE Moste do Blejskega mostu za posamezne hidrološke prereze, za naslednje vodne režime:

1. brez odvzema – pretoki pridobljeni s predpostavko, da na obravnavnem območju ni odvzema vode za hidroelektrarno
2. z odvzemom – pretoki, ki so na obravnavanem območju pri sedanjem obratovanju hidroelektraren oziroma odvzemih vode na Savi Dolinki, Završnici, Radovni in Soči.

3.2 HYDROLOGICAL PARAMETERS

Current velocity and flow were measured with a SEBA Mini Current Meter MI. At all the sampling points, the current velocity was measured 3 cm above the bottom. The average velocity was measured in measuring verticals above the sampling points at 0.4 of water depth from the bottom of the river bed. The duration of individual measurements was one minute per sampling point.

The results of the measurements of hydrological parameters, and the data on water levels according to the Ministry of Environment and Physical Planning were processed using a computer programme (VGI, 1992) at the Water Management Institute, Ljubljana.

The catchment area (F) of sampling sites was determined and the following values were calculated using a computer programme (VGI, 1992): sQs (mean flow – the average of mean daily flows in m^3/s for every year in the considered period); sQn (mean minimum flow - the average of minimum flows in m^3/s for every year in the considered period); nQn (minimum flow - the minimum flow in m^3/s in the considered period); vQv (maximum flow - the maximum flow in m^3/s in the considered period); Q_{300d} (the flow lasting for 300 days a year); and Q_{347d} (the flow lasting for 347 days a year).

The intent of an analysis of the hydrological data was to determine the hydrological parameters characteristic to the Soča River regime in the section downstream of the Podsela Dam and downstream of the Ajba Dam, and that of the Sava Dolinka River, in the section from the dam of the Moste HPP to the gauging station at Blejski most, for individual hydrological cross-sections under the following water regime:

1. without abstractions – the flows were determined on the supposition that there were no abstractions for the power plant in the sections under consideration,
2. with abstractions – the flows were determined for the present operation of power plants or for abstractions in the Sava Dolinka, Radovna, and Soča rivers and the Završnica Stream in the sections under consideration.

3.3 ANALIZA PLAVIN

Analizo plavin smo opravili z linijskim načinom odvzema vzorca s programom ZPP, napisanem v programskem okolju EXCEL (Mikoš, 1999). Izdelali smo krivuljo zrnavosti podlage in krovnega sloja s pomočjo preračuna linijske – številčne analize in togim sestavljanjem s Fullerjevo zrnavostno krivuljo. Iz vsotne zrnavostne krivulje je mogoče odčitati značilna zrna, kot so d_{90}, d_{84} in d_{16}. Končni rezultat računa v obliki preglednice je bila določitev aritmetičnega srednjega zrna prodnatih plavin d_m in 90-odstotnega zrna rinjenih plavin d_{90}.

3.3 SEDIMENT ANALYSIS

An analysis of the sediments was carried out with the use of the Wolman Count of samples with a ZPP computer programme prepared in the environment of EXCEL (Mikoš, 1999). A grain-sized distribution curve and a cover layer curve were designed by means of the Wolman Count-numerical analysis and a rigid combination with the Fuller grain-sized distribution curve. The cumulative grain-sized distribution curve displays characteristic grains such as d_{90}, d_{84}, and d_{16}. The final result of the calculation, in the form of a table, was the determination of the mean grain of the gravel deposits, d_m, and 90% of a bed load grain, d_{90}.

3.4 FIZIKALNI IN KEMIJSKI PARAMETRI

Električno prevodnost in temperaturo smo merili z instrumentom MA 5950 (Iskra), pH z instrumentom MA 5721 (Iskra), vsebnost raztopljenega kisika in nasičenost s kisikom pa z oksimetrom OM 8.

3.4 PHYSICOCHEMICAL PARAMETERS

Electrical conductivity and temperature were measured with an MA 5950 (Iskra), and the pH was measured with an MA 5721 (Iskra). The dissolved oxygen content and oxygen saturation were measured using an oxymeter OM 8.

3.5 BIOLOŠKI PARAMETRI

3.5.1 VZORČEVANJE PERIFITONSKIH ALG IN OBDELAVA VZORCEV

Vzorce perifitonskih alg za kvalitativno analizo smo pobirali tako, da smo postrgali površino prodnikov, kamnov, skal, peska, makrofitov in potopljenega lesa na območju odvzema. Vzorce perifitonskih alg smo že na terenu fiksirali tako, da je bila končna koncentracija formalina v vzorcih približno 5 odstotkov.

Vzorce za kvantitativno analizo perifitonske združbe smo pobirali samo s plavin premera 50 do 200 mm. V laboratoriju smo ovrednotili suho težo, organsko snov (suha teža brez pepela) po metodiki APHA.AWWA.WPCP (1992) in koncentracijo klorofila-*a* s filtriranjem skozi Watman GF/C filtre ter z ekstrahiranjem z vročim metanolom (Vollenweider, 1974). Vrednosti biomase perifitonskih alg smo preračunali na m^2 plavin.

3.5 BIOLOGICAL PARAMETERS

3.5.1 PERIPHYTON SAMPLING AND PROCESSING

Periphyton samples intended for a qualitative analysis were taken by scraping off the surface area of pebbles, stones, rocks, sand, macrophytes, and sunken wood found at a sampling site. The samples were treated with formaline in the field, so that the concentration of formaline in the samples was around 5%.

Samples intended for a quantitative analysis of the periphyton community were taken from deposits 50 mm to 200 mm in diameter. Dry weight and organic matter (ash-free dry weight) were assessed in the laboratory using the APHA.AWWA.WPCP technique (1992). The chlorophyll-a concentration was determined with the use of filtration through Watman GF/C filters and extraction with hot methanol (Vollenweider, 1974). The values of periphyton biomass were calculated per square meter of deposits.

V laboratoriju smo perifitonske alge pregledali pod svetlobnim mikroskopom, s fazno kontrastno optiko pri povečavah do 1000-krat. Pri pregledu vzorcev smo ocenili pogostost posameznih taksonov (vrst) perifitonskih alg (Grbović, 1994).

3.6 STATISTIČNE ANALIZE

Za posamezna območja odvzema smo izračunali Pantle - Buckov saprobni indeks. Primerjavo združb perifitonskih alg med odvzemnimi mesti in med območji odvzema smo izvršili s pomočjo podatkov vrstnega sestava in relativne pogostosti prisotnih vrst. Podobnost oziroma različnost združb perifitonskih alg smo vrednotili z multivariantno klastersko analizo (Bray - Curtisov koeficient podobnosti) (Clarke in Warwick, 1990), s pomočjo podatkovnega sistema "DABA".

4. REZULTATI IN DISKUSIJA

4.1 HIDROLOŠKI PARAMETRI

Rezultati hidroloških meritev in analiz so pokazali na bistveno spremenjen hidrološki režim na Soči, pod pregradama Podsela in Ajba, in na Savi Dolinki, pod pregrado Moste, ki se odraža v zmanjšanju pretokov vode, hitrosti vodnega toka in globini vode, nadalje v spremenjeni krivulji trajanja pretokov vode ter predvsem zastajanju in odlaganju plavin nad pregradami ter s tem povzročeno t.i. dolvodno erozijo (Smolar-Žvanut, 2000). Vsi merjeni hidrološki parametri so pokazali, da pod pregradama Podsela in Moste niso bile zagotovljene vrednosti Qes.

Do največjih razlik v Savi Dolinki je prišlo v vrednostih najmanjših nizkih pretokov vode nQn na območjih odvzema SA3 in SA4, saj je voda tekla preko pregrade le nekaj dni na leto. Manjše razlike v vrednosti sQs so bile izračunane na območju odvzema SA5, ker vrednost ne kaže nihanja v pretoku vode zaradi delovanja HE Moste in HE Završnica. Območje odvzema SA5 je namreč izpostavljeno urnim in dnevnim spremembam v pretoku vode, zaradi obratovanja HE Moste

In the laboratory, periphytic algae were examined under a light microscope by means of phase contrast optics for magnifications of x 1000 in order to assess the frequency of individual taxa (species) (Grbović, 1994).

3.6 STATISTICAL ANALYSES

The Pantle-Buck Saprobic Index was calculated for individual sampling sites. A comparison of periphyton communities within individual sampling points and within sampling sites was made with the use of data on species composition and the relative frequency of species found. Similarities and differences among periphyton communities were assessed by means of a multivariate cluster analysis (Bray-Curtis coefficient of similarity) (Clark and Warwick, 1990) and the DABA data system.

4. RESULTS AND DISCUSSION

4.1 HYDROLOGICAL PARAMETERS

Results of the hydrological measurements and analyses show substantial changes in the hydrological regime of the Soča River downstream of the Podsela and Ajba dams, and of the Sava Dolinka River, downstream of the Moste Dam. The changes concerned reduced flows, a decrease in current velocity and, in water depth, an altered flow duration curve, and, particularly, the stagnation and deposition of sediments upstream of the dams, resulting in erosion downstream (Smolar-Žvanut, 2000). All the measurements suggest that downstream of the Podsela and Moste dams, the flow was not ecologically acceptable.

In the Sava Dolinka River, the most substantial differences were found in the values of the minimum flow (nQn) at sampling sites SA3 and SA4, since water was flowing over the dam just a few days a year. Less substantial differences in the values of the mean flow (sQs) were calculated at sampling site SA5, since they show no fluctuations in flows due to the operation of the Moste and Završnica power plants. For the latter site is subjected to hourly and daily changes in flow induced by the operation of the power plants.

in HE Završnica. Zaradi odvzema vode za HE Zasip na Radovni se je vrednost srednjega nizkega pretoka (za obdobje od 1961 do 1995) na območju odvzema RAD iz 1.68 m^3/s zmanjšala na 0, oz. Radovna je zaradi obratovanja HE Zasip občasno presahnila (preglednica 1).

Owing to abstractions for the Zasip HPP on the Radovna River, the values of the mean minimum flow (sQn) for the period 1961-1995 were reduced from 1.68 m^3/s to 0 at sampling site RAD; that is, the Radovna River periodically dried up due to the operation of the Zasip HPP (Table 1).

Preglednica 1. Glavni hidrološki parametri za Savo Dolinko in Radovno za obdobje od 1961 do 1995 za vodni režim brez odvzema vode oz. z odvzemom vode.
Table 1. Hydrological parameters for the Sava Dolinka River and the Radovna River for the period 1961-1995 for water regimes with and without water abstraction .

hidrološki prerez *Hydrological cross-section*	območje odvzema *Sampling site*	F (km^2)	sQs (m^3/s)	sQn (m^3/s)	nQn (m^3/s)	vQv (m^3/s)	Q300d (m^3/s)	Q347d (m^3/s)
Sava Dolinka v.p. Jesenice *Sava Dolinka River at g.s. Jesenice*	SA1	257.6	10.65	4.12	2.46	261	5.65	4.43
Sava Dolinka pregrada Moste – brez odvzema *Sava Dolinka River at the dam Moste - without abstractions*	/	300.1	13.53	5.97	3.62	310	8.22	6.44
Sava Dolinka pod Završnico – brez odvzema *Sava Dolinka River downstream of the confluence with the Završnica Stream - without abstractions*	SA3	325.9	14.70	6.48	3.93	337	8.94	7.01
Sava Dolinka pod Završnico – z odvzemom *Sava Dolinka River downstream of the confluence with the Završnica Stream - with abstractions*	SA3	325.9	0.63	0.11	0.048	337	0.17	0.13
Radovna izliv – brez odvzema *Outfall of the Radovna River - without abstractions*	RAD	170.4	8.03	1.68	1.02	113	2.77	1.90
Radovna izliv – z odvzemom *Outfall of the Radovna River - with abstractions*	RAD	170.4	3.47	0.00	0.00	113	0.0005	0.00
Sava Dolinka pod Radovno – brez odvzema *Sava Dolinka River downstream of the confluence with the Radovna River - without abstractions*	SA4	496.8	22.74	8.42	5.03	450	12.12	9.09
Sava Dolinka pod Radovno – z odvzemom *Sava Dolinka River downstream of the confluence with the Radovna River - with abstractions*	SA4	496.8	4.11	0.11	0.048	450	0.17	0.13
Sava Dolinka v.p. Blejski most – brez odvzema *Sava Dolinka River at g.s. Blejski most - without abstractions*	SA5	505.4	22.96	8.47	5.06	453	12.20	9.18
Sava Dolinka v.p. Blejski most – z odvzemom *Sava Dolinka River at g.s. Blejski most - with abstractions*	SA5	505.4	22.96	2.87	0.70	453	10.12	6.08

Preglednica 2. Glavni hidrološki parametri za Sočo in Ušnico za obdobje od 1961 do 1990 za vodni režim, brez odvzema vode oz. z odvzemom vode.
Table 2. Hydrological parameters for the Soča River and the Ušnica Tributary for the period 1961-1995 for water regimes with and without water abstraction.

hidrološki prerez *Hydrological cross-section*	območje odvzema *Sampling site*	F (km^2)	sQs (m^3/s)	sQn (m^3/s)	nQn (m^3/s)	vQv (m^3/s)	Q_{300d} (m^3/s)	Q_{347d} (m^3/s)
Soča v.p. Kobarid *Soča River at g.s. Kobarid*	/	434.7	34.1	7.96	4.59	664	12.10	8.96
Soča pregrada Podsela *Soča River at the Podsela Dam*	/	1244	80	16	10	2140	27.43	20.04
Ušnica pri pregradi Ušnik *Ušnica stream at the Ušnik Dam*	USN	9.43	0.60	0.03	0.02	2140	/	/
Soča pod pregrado Podsela – brez odvzema *Soča River downstream of the Podsela Dam - without abstractions*	SO2	1254	80.6	16.03	10.0	2140	27.47	20.08
Soča pod pregrado Podsela – z odvzemom *Soča River downstream of the Podsela Dam -* with abstractions	SO2	1254	22.5	0.13	0.12	2140	0.64	0.25
Soča pod pregrado Ajba – brez odvzema *Soča River downstream of the Ajba Dam - without abstractions*	SO4	1345	86.2	17.8	10.5	> 2140	29.70	21.22
Soča pod pregrado Ajba – z odvzemom *Soča River downstream of the Ajba Dam -with abstractions*	SO4	1345	33.1	1.0	1.0	> 2140	1.41	1.12

Primerjava hidroloških parametrov za Sočo za obdobje 1961-1990 na območjih odvzema je pokazala, da je na območju odvzema SO2 in SO4, zaradi odvzema vode za HE Doblar, prišlo do zmanjšanja vrednosti sQn in nQn za več kot 90 odstotkov (preglednica 2).

Merjeni pretoki Save Dolinke pod pregrado Moste na območju odvzema SA3 in SA4 so v času naših meritev zaradi odvzemov vode za HE Moste, HE Završnica in HE Zasip dosegali največ 5.9 % pretoka Save Dolinke, merjenega na primerjalnem območju odvzema SA1, medtem ko so bili pretoki na Soči pod pregrado Podsela vsaj za 97.6 % in pod pregrado Ajba vsaj za 81.3 % nižji od pretokov na primerjalnem območju SO1 (Smolar-Žvanut, 2000). Posledično so bile na območjih odvzema pod pregradami izmerjene tudi nižje lokalne hitrosti ob dnu in povprečne hitrosti vodnega toka. Zaradi nizkih pretokov vode je voda pod pregradami tudi zastajala.

Vsi merjeni hidrološki parametri so pokazali na zmanjšanje raznolikosti vodnih habitatov za vodne organizme. Zaradi odvzema vode je na odseku z zmanjšanim pretokom vode prišlo do opaznega zmanjšanja v velikosti in številu brzic, podobno kot na reki Töss v Švici (Bundi et al., 1990). Vrednotenje pretočnih hitrosti vode je pomembno tudi kot del določanja Qes (Mikoš, 1996).

A comparison of hydrological parameters for the Soča River for the period 1961-1990 shows a decrease in the values of the mean minimum flow (sQn) and the minimum flow (nQn) at sampling sites SO2 and SO4 by over 90%, which can be attributed to abstractions for the Doblar HPP (Table 2).

In the Sava Dolinka River, flows measured downstream of the Moste Dam at sampling sites SA3 and SA4 attained, at the most, 5.9 % of the flows measured at reference site SA1 due to abstractions for the Moste, Završnica, and Zasip power plants. In the Soča River, on the other hand, flows measured downstream of the Podsela Dam were at least 97.6 %, and those measured downstream of the Ajba Dam were at least 81.3 %, lower than flows measured at reference site SO1 (Smolar-Žvanut, 2000). Hence, lower local current velocities at both the bottom and lower average current velocitities were measured at the above sampling sites downstream of the dams. Owing to low flows, water stagnated downstream of the dams.

All the hydrological parameters show a decrease in the diversity of aquatic habitats for water organisms. As a result of the abstractions, a discernible decline in the size and number of rapids occurred in sections with reduced flow, as was also reported for the Töss River, Switzerland (Bundi et al., 1990). Flow velocity assessment is thus of importance to EAF determination (Mikoš, 1996).

4.2 PLAVINE

Zajezitev in odvzem vode iz vodotoka običajno povzroči značilno zmanjšanje pretokov visokih voda dolvodno (Ward in Stanford, 1995, Erskine et al., 1999), kar vodi do zmanjšanega transporta plavin (Ward in Stanford, 1995). Razlog za zmanjšanje transporta plavin na Soči in Savi Dolinki je predvsem v prekinitvi prodonosnosti, ne pa v spremenjeni krivulji trajanja pretokov voda v tistem delu, ki vpliva na prodni premik.

4.2 SEDIMENTS

The damming of watercourses and abstractions usually give rise to a considerable decrease in the flows of high waters downstream (Ward and Stanford, 1995; Erskine et al., 1999), which in turn leads to reduced sediment transport (Ward and Stanford, 1995). In the case of the Soča and Sava Dolinka rivers, reduced sediment transport may mainly be attributed to the disruption of sediment transport, rather than to changes in the flow duration curve at the section influencing sediment transport.

Preglednica 3. Rezultat linijske-številčne analize in togega sestavljanja s Fullerjevo zrnavostno krivuljo v prostorninski vzorec za Savo Dolinko.
Table 3. Results of the Wolman Count-numerical analysis and rigid combination with the Fuller grain-size distribution curve for a volume pattern of the Sava Dolinka River.

odvzemno mesto *Sampling point*	d_{16}(mm)	d_{84}(mm)	d_{90}(mm)	d_m (mm)	raztros zrnavosti *Grain-size distribution*
SA1P1	5	170	214	81	6
SA1P2	4	100	119	57	5
SA3P1	8	200	226	98	5
SA4P1	10	160	175	86	4
SA4P2	15	377	454	187	5

Preglednica 4. Rezultat linijske-številčne analize in togega sestavljanja s Fullerjevo zrnavostno krivuljo v prostorninski vzorec za Sočo.
Table 4. Results of the Wolman Count-numerical analysis and rigid combination with the Fuller grain-size distribution curve for a volume pattern of the Soča River.

odvzemno mesto *Sampling point*	d_{16}(mm)	d_{84}(mm)	d_{90}(mm)	d_m (mm)	raztros zrnavosti *Grain-size distribution*
SO1P1	4	125	138	59	5
SO1P2	5	163	183	72	6
SO2P1	7	184	219	92	5
SO2P2	14	324	359	155	5
SO3P1	11	280	301	134	5
SO3P2	6	165	210	84	5

Po dolgih letih obratovanja HE se pod pregrado izoblikuje stabilna struga, vendar pride do povečanja raznolikosti habitatov z naraščanjem pretoka vode (Gore, 1994). Na Soči, pod pregrado Podsela in Ajba, ter na Savi Dolinki, pod pregrado Moste, so pregrade prekinile normalen dotok plavin in tako ustvarile nezasičeni vodni tok in tudi bistveno okrnile pretok lebdečih plavin. To je tudi razlog, da so pod pregradami Moste, Podsela in Ajba prevladovale prodnate plavine s precejšnjim deležem grobih zrn in določili smo večje srednje aritmetično zrno plavin d_m kot nad pregradami (preglednica 3 in preglednica 4). Podobno je pod pregrado na reki Fontauliere v Franciji, zaradi sprememb v režimu premeščanja plavin, v povezavi s spremenjeno hidravliko prišlo do stabilne struge (Sear, 1995).

Rezultati so pokazali, da je bilo povprečno zrno rinjenih plavin v Savi Dolinki in Soči na vseh območjih odvzema večje od povprečnega srednjega zrna rinjenih plavin v podobnih prodonosnih vodotokih v Sloveniji, ki je od 35 do 40 mm. Vrednost d_m nad 100 mm kaže na zelo grobo in zelo sprano dno, kar kažejo rezultati pod pregradami Moste, Podsela in Ajba.

If a hydropower plant has been in operation for a number of years, then a stable river bed is formed downstream of the dam, but there is also an increase in the diversity of habitats, along with an increase in flow (Gore, 1994). In the Soča River, downstream of the Podsela and Ajba dams, and in the Sava Dolinka River, downstream of the Moste Dam, the dams interrupted the normal increase in sediments, creating an unsaturated current, and substantially reduced the transport of floating sediments. This is also the reason why gravel deposits with a high percentage of coarse grains prevailed downstream of the Moste, Podsela and Ajba dams, and a larger mean grain, d_m, was determined here than upstream of the dams (Tables 3 and 4). Similar findings were reported for the Fontauliere River, France, downstream of the dam, where changes in the regime of sediment transport, combined with altered hidraulics, gave rise to a stable river bed (Sear, 1995).

Results of this study show that, at all the sampling sites in the Sava Dolinka and Soča Rivers, the average bed load grain was larger than the average mean bed load grain in watercourses with a similar sediment transport in Slovenia, that is 35-40 mm. The value d_m of over 100 mm suggests a very coarse and highly washed out bottom with no fine grains, as is shown by the results obtained downstream of the Moste, Podsela, and Ajba dams.

4.3 FIZIKALNI IN KEMIJSKI PARAMETRI

Spremenjene vrednosti fizikalnih in kemijskih parametrov pod pregradama Moste in Podsela so odraz prevelikega odvzema vode, ki je v primerjavi s primerjalnim mestom še posebej izraženo v Soči; merjene vrednosti kažejo, da pod pregradama niso bile zagotovljene ustrezne vrednosti Qes.

Poleti, ko je bila temperatura vode na primerjalnem odvzemnem mestu SO1 13.5 ºC, je bila temperatura vode na odseku, kjer je bil odvzem vode, višja za 6.7 ºC (Smolar-Žvanut, 2000). Podobno so pokazali rezultati raziskav na reki Schächenbach v Švici (Bundi in Eichenberger, 1989), kjer je na odseku odvzema vode prišlo do povišanja temperature vode za 6 ºC. Do manjših razlik

4.3 PHYSICOCHEMICAL PARAMETERS

The altered values of the physicochemical parameters downstream of the Moste and Podsela dams are the result of excessive abstractions, which are particularly evident in the case of the Soča River, compared to the reference site. The obtained values show that downstream of the two dams, appropriate EAF values were not assured.

In the summer, when the water temperature at the reference site SO1 was 13.5°C, water temperature in the abstraction section was higher by 6.7°C (Smolar-Žvanut, 2000). Similar findings were reported for the Schächenbach River in Switzerland (Bundi and Eichenberger, 1989), where an increase in water temperature of 6°C was found in the abstraction section. Smaller differences in water temperature among individual sampling sites were observed in the Sava v temperaturi vode med območji odvzema je prihajalo v Savi Dolinki, kjer je temperaturni režim takoj pod pregrado Moste določal pritok Završnica, nižje pa pritok Radovna.

Posledica odvzema vode je, da fizikalno in kemijsko sestavo vode na odseku, ki je pod vplivom odvzema vode, ne določajo več razmere v zgornjem delu porečja, temveč jo določajo dotoki pod mestom zajetja (Bundi in Eichenberger, 1989), kar kažejo tudi naši rezultati.

4.4 BIOLOŠKI PARAMETRI

4.4.1 VRSTNI SESTAV

V Savi Dolinki in Soči je bila velika raznolikost združbe perifitonskih alg, ki je v primeru Save Dolinke s pritokoma Završnico in Radovno vključevala 128 taksonov, v primeru Soče in pritoka Ušnice pa 127 taksonov. V vseh vzorcih smo določili največje število vrst iz skupine kremenastih alg, podobno kot pri drugih raziskavah alg v slovenskih rekah (Kosi, 1988, Smolar, 1992, 1997, Vrhovšek et al., 1994, 1996a, 1996b).

Zaradi stabilnosti ekoloških dejavnikov pod pregradami Moste in Podsela (konstanten pretok in redko pojavljanje visokih voda), nizkih do srednjih hitrosti vodnega toka, ki omogočajo naselitev zelenih alg, katere predstavljajo podlago za naseljevanje kremenastih alg in dobri osvetljenosti, smo določili večje število perifitonskih alg kot nad pregradama.

Znano je, da je diverziteta perifitonskih alg zelo majhna v vodotokih, kjer se povišani pretoki vode pogosto pojavljajo (Clausen in Biggs, 1997). Hiter vodni tok namreč odtrga perifitonske alge od podlage, mehansko premikanje večjih zrn plavin pa privede do poškodb alg. Rod *Oscillatoria* predstavlja slab substrat za kremenaste alge zaradi majhne površine in izpostavljenosti vodnemu toku (Koudelkova, 1999). To je tudi eden izmed razlogov za manjšo raznolikost perifitonskih alg v Savi Dolinki nad pregrado Moste in v Soči nad pregrado

Dolinka River, where the temperature regime immediately downstream of the Moste Dam is defined by the Završnica Tributary, and further downstream by the Radovna Tributary.

Due to abstractions, the physicochemical composition of water in the section influenced by the abstractions is no longer defined by conditions in the upper reaches, but by inflows downstream of the catchment site (Bundi and Eichenberger, 1989). This statement is supported by the results of the present study.

4.4 BIOLOGICAL PARAMETERS

4.4.1 SPECIES COMPOSITION

The Sava Dolinka River and the Soča River are distinguished by a great diversity of periphyton community. So 128 taxa were determined in the Sava Dolinka River and its tributaries, the Završnica and the Radovna, and 127 taxa in the Soča River and its tributary, the Ušnica. In all the samples, the highest number of species were found to belong to Bacillariophyta, as was also reported by other investigations of algae in Slovenian rivers (Kosi, 1988; Smolar, 1992, 1997; Vrhovšek et al., 1994, 1996a, 1996b).

The stability of ecological factors downstream of the Moste and Podsela dams (constant flow and rare occurrence of high waters), the low to moderate current velocities which make possible the colonisation of green algae, a substratum of Bacillariophyta, and adequate light, all of these factors result in the fact that a greater number of periphyton was determined here than upstream of the dams.

It is known that periphyton diversity is highly limited in watercourses with a frequent increase in flow (Clausen and Biggs, 1997). For periphyton will be torn from substratum by fast flows, and damage to algae will be caused by the transport of larger sediment grains. The genus *Oscillatoria* is an inadequate substratum for Bacillariophyta due to its small surface area, and hence the exposure to the current (Koudelkova, 1999). This is also one of the reasons for the limited periphyton diversity in the Sava Dolinka River upstream of the Moste Dam, and in the Soča River, upstream

Podsela. V obdobju pogostega pojavljanja cianobakterij v poletnem času smo v Savi Dolinki in Soči nad pregradami Moste in Podsela izmerili nižjo temperaturo vode, medtem ko se zelene alge pogosteje pojavljajo pri višjih temperaturah vode, ki so bile izmerjene pod pregradami. Vpliv odvzema vode na pojavljanje vrste *Hydrurus foetidus* se je pokazal tako v Savi Dolinki kot v Soči. Množično se je ta vrsta pojavljala le v zimskem času na območju odvzema SA1 v Savi Dolinki in območju odvzema SO1 v Soči ter na pritokih Radovna in Završnica. To lahko pripišemo nizkim zimskim temperaturam vode in konstantnemu pretoku vode (Ward, 1974; Valentin s sod., 1995; Smolar, 1997). Traaen in Lindstrøm (1983) sta ugotovila, da se je 90 odstotkov alg *Hydrurus foetidus* pojavljalo pri hitrostih, večjih od 80 cm/s (hitrost, merjena 1 cm nad dnom), podobno kot so pokazali rezultati naše raziskave.

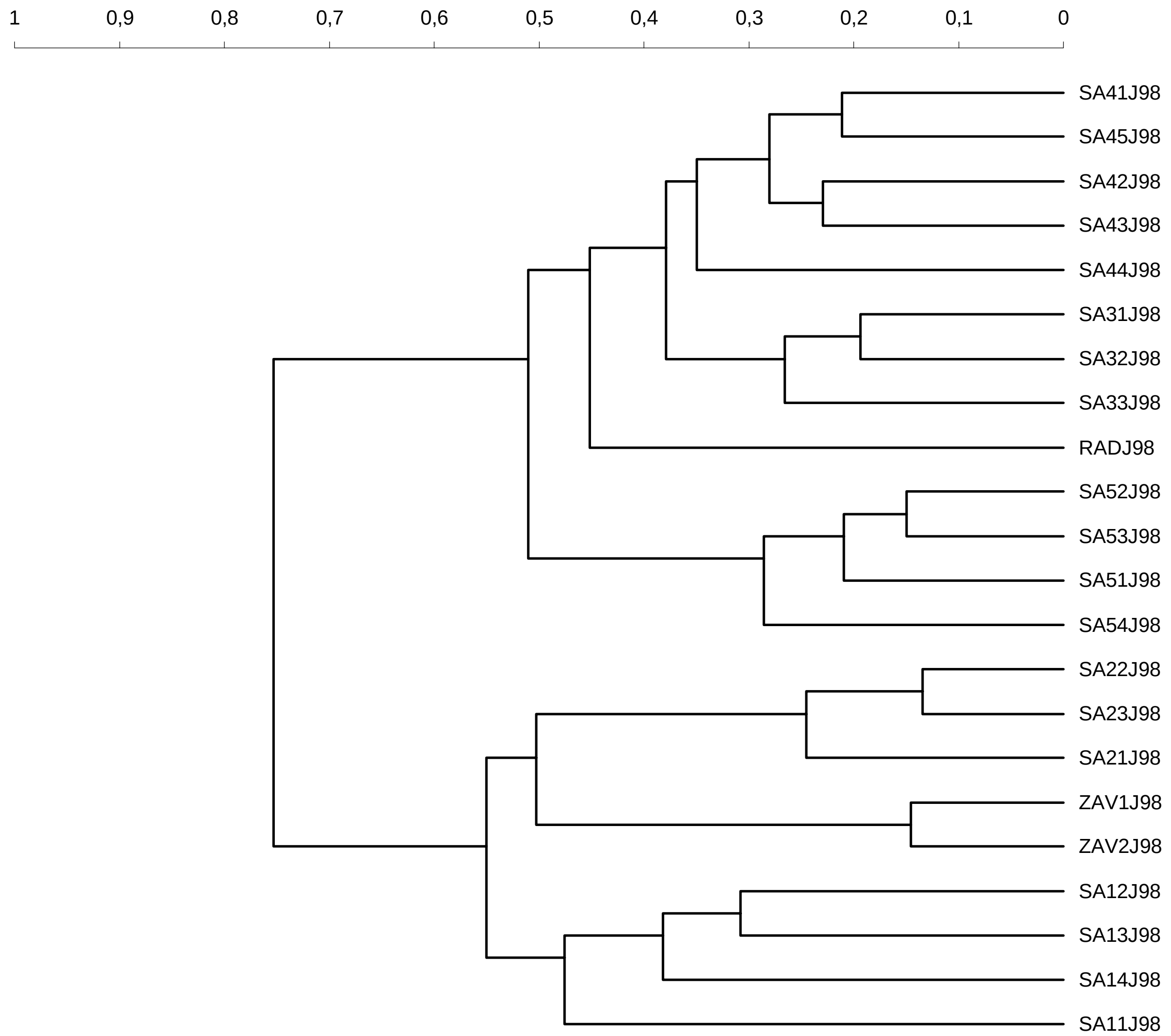
Bray - Curtisov koeficient podobnosti kaže kakovostne spremembe v strukturi združbe in zagotavlja hiter in preprost pregled podobnosti in različnosti med združbami. Večja podobnost v hidroloških in fizikalno-kemijskih razmerah nad pregrado Podsela in pod pregrado Ajba se je odražala v večji podobnosti med vzorci teh območij odvzema. Torej lahko ugotovimo, da je zaradi odvzema vode pod pregrado Podsela prišlo do spremembe v vrstni sestavi in pogostosti perifitonskih alg. Tudi v Savi Dolinki je bila vidna krajevna odvisnost med območji odvzema, in sicer je bila največja podobnost v vzorcih med območji odvzema, ki so bila pod vplivom odvzema vode za HE Moste, v drugi skupini pa so bili vzorci iz območij odvzema nad pregrado Moste (slika 3).

Velikost sprememb v združbi perifitonskih alg pod pregrado Podsela in pregrado Moste je dokaz, da pod pregradama ni bil zagotovljen Qes.

of the Podsela Dam. At the time of the frequent occurrence of Cyanophyta in the summer, a lower water temperature was measured in the Sava Dolinka River and the Soča River, upstream of the Moste and Podsela dams, while green algae occured more often at the higher water temperatures which were measured downstream of the dams. The effect of abstractions on the occurrence of the species *Hydrurus foetidus* was observed in the Sava Dolinka River as well as in the Soča River. The species proliferated only in winter at sampling site SA1 in the Sava Dolinka River, at sampling site SO1 in the Soča River, and in the Radovna and Završnica tributiaries. This may be ascribed to low water temperatures in the winter and to constant flow (Ward, 1974; Valentin et al., 1995; Smolar, 1997). Traaen and Lindstrom (1983) reported that 90 % of the algae *Hydrurus foetidus* occurred at velocities of over 80 cm/s (measured 1 cm above the bottom), which is in agreement with the results of this study.

The Bray-Curtis coefficient of similarity shows qualitative changes in the structure of a community, providing a fast and simple survey of similarities and differences among communities. The hydrological and physicochemical parameters measured upstream of the Podsela Dam and downstream of the Ajba Dam show closer similarities among samples taken at these locations. Thus, it can be concluded that abstractions downstream of the Podsela Dam gave rise to changes in species composition and periphyton frequency. In the Sava River, too, a local interdependence of abstraction sections was evident. So the closest similarities were found among samples taken at locations influenced by abstractions for the Moste power plant, while the second group of samples comprised those taken at locations upstream of the Moste Dam (Figure 3).

The extent of changes in the periphyton community downstream of the Podsela and Moste dams provides convincing proof that here the EAF was not assured.



Slika 3. Bray-Curtisov koeficient podobnosti za reko Savo Dolinko, reko Radovno in potok Završnico, dne 3.6.1998.
Figure 3. Bray-Curtis coefficient of similarity for the river Sava Dolinka, the river Radovna and the stream Završnica, on 3rd of June 1998.

4.4.2 PANTLE-BUCKOV SAPROBNI INDEKS

Vrednost Qes mora zagotavljati tako količino kot kakovost vode, da se vrednosti Pantle-Buckovih saprobnih indeksov na območju odvzema vode ne povečajo (Smolar-Žvanut, 2000).

Razlog za nekoliko višje vrednosti Pantle - Buckovega saprobnega indeksa na območju odvzema pod pregrado Podsela na območjih odvzema SO2 in SO3 v Soči (2. kakovostni razred) je verjetno v manjši hitrosti vodnega toka, ki se odraža v spremenjenih fizikalnih in kemijskih razmerah v vodi in v povečani onesnaženosti. Območje odvzema SO1 smo lahko v vseh obdobjih uvrstili v 1. oz. 1.-2. kakovostni razred. Ker razmere v Savi Dolinki pod pregrado Moste določajo pritoki kot sta Završnica in Radovna, je bilo onesnaženje pod pregrado manjše in vrednosti Pantle-Buckovih saprobnih indeksov pod pregrado Moste so bile v večini primerov nižje glede na vrednost indeksov primerjalnega območja odvzema SA1 (Smolar-Žvanut, 2000).

4.4.3 BIOMASA PERIFITONSKIH ALG

Vrednost Qes naj bi zagotavljala tako količino kot kakovost vode, pri kateri naj, v primerjavi s primerjalnim mestom ne bi prišlo do bistvenega povečanja biomase perifitonskih alg, vendar rezultati kažejo ravno to.

Vrednosti parametrov suhe teže in organske snovi perifitonskih alg so bile v Savi Dolinki in pritokih Završnica in Radovna najvišje v predelih struge z upočasnjenim tokom vode. V času konstantnega pretoka vode dosegajo perifitonske alge običajno visoko biomaso na velikih prodnikih in kamnih, posebej zaradi majhne gibljivosti plavin na dnu vodotoka. Visoka biomasa perifitonskih alg pa se lahko razvije šele, če je dovolj dolgo obdobje stabilnosti habitata (Biggs, 1996). Nizki pretoki vode, ugodne svetlobne razmere in velikost plavin so bili dejavniki, ki so omogočali tako bohotno rast alg v Savi Dolinki in Soči.

4.4.2 PANTLE-BUCK SAPROBIC INDEX

The EAF value should assure such quantity and quality of water that the values of the Pantle-Buck Saprobic Index do not increase in the abstraction section (Smolar-Žvanut, 2000).

The reason for the slightly higher values of the Pantle-Buck Saprobic Index determined in the Soča River downstream of the Podsela Dam, at sampling sites SO2 and SO3 (2nd category of water quality) may probably be lower current velocity, which results in the altered physicochemical conditions of water and in increased pollution. Sampling site SO1 was classified, in the whole investigation period, into the 1st or 1st-2nd category. Since conditions in the Sava Dolinka River, downstream of the Moste Dam, are defined by tributaries such as the Završnica Stream and the Radovna River, the pollution downstream of the dam was less severe and values of the Pantle-Buck Saprobic Index were, in most cases, lower, compared with those at reference site SA1 (Smolar-Žvanut, 2000).

4.4.3 PERIPHYTON BIOMASS

In keeping with the EAF value, such quantity and quality of water should be assured that, in comparison with the reference site, the periphyton biomass does not increase considerably. Yet results of this study show that this was what happened.

In the Sava Dolinka River and in the Završnica and Radovna tributaries, the values of dry weight and the organic matter of the periphyton were the highest in sections with a slower current. At the time of constant flow, periphyton usually attains a high biomass on large pebbles and stones, particularly due to limited sediment transport at the bottom of the watercourse. High biomass of periphyton can develop only after an extended period of habitat stability (Biggs, 1996). Low flows, favourable light, and appropriate sediment size were factors that made the proliferation of algae possible in the Sava Dolinka and Soča rivers.

Preglednica 5. Vrednosti suhe teže, organske snovi in klorofila-*a* v Savi Dolinki, Završnici in Radovni.
Table 5. Values of dry weight, organic matter, and chlorophyll-a for the Sava Dolinka and Radovna Rivers, and the Završnica Stream.

	suha teža (g/m^2) *Dry weight*			organska snov (g/m^2) *Organic matter*			klorofil-*a* (mg/m^2) *Chlorophyll-a*		
območje odvzema *Sampling site*	min Min.	maks Max.	povp Average	min Min.	maks Max.	povp Average	min Min.	maks Max.	povp Average
SA1	12	139	56	5	37	19	17	398	107
SA2	54	356	139	5	91	34	58	379	179
ZAV	76	218	168	10	161	51	117	373	194
SA3	49	514	219	<1	144	56	21	243	118
RAD	37	388	153	16	71	35	9	166	64
SA4	29	413	208	27	103	48	19	342	121
SA5	38	182	78	13	66	32	45	579	207

Preglednica 6. Vrednosti suhe teže, organske snovi in klorofila-*a* v Soči in Ušnici.
Table 6. Values of dry weight, organic matter, and chlorophyll-a for the Soča River and the Ušnica Stream.

	suha teža (g/m^2) *Dry weight*			organska snov (g/m^2) *Organic matter*			klorofil-*a* (mg/m^2) *Chlorophyll-a*		
območje odvzema *Sampling site*	min Min.	maks Max.	povp Average	min Min.	maks Max.	povp Average	min Min.	maks Max.	povp Average
SO1	9	324	56	5	67	16	6	153	42
USN	28	45	38	8	22	14	34	147	91
SO2	5	352	85	2	72	24	24	283	89
SO3	14	283	114	4	84	40	25	260	123
SO4	12	76	37	5	21	13	11	130	57

Nizke vrednosti suhe teže in organske snovi nad pregrado Moste na primerjalnem območju odvzema SA1 (preglednica 5), a relativno visoke vrednosti klorofila-*a* lahko pojasnimo s tem, da je bilo zaradi velikih hitrosti vodnega toka, manjše usedanje organskih delcev in da je v združbi, zaradi stalnega odnašanja odmrlih celic, večji delež živih celic. Zaradi vpliva drugih ekoloških dejavnikov, je bilo veliko rast alg v Savi Dolinki nemogoče pojasniti le z nizkimi pretoki vode, temveč tudi s količino hranilnih snovi, svetlobo in strukturo

Low values of dry weight and organic matter, but relatively high values of chlorophyll-a were determined upstream of the Moste Dam at reference site SA1 (Table 5). This may have been caused by the fact that, due to high current velocities, fewer organic particles settled at the bottom of the river bed, and that there was a higher proportion of living cells in the community, since dead cells were constantly swept away. Because of the effect of other ecological factors, the proliferation of algae in the Sava Dolinka River may be attributed, not only to low flows, but also to the quantity of nutrients, light, and sediment structure.

usedlin. Hidrološke razmere vplivajo na spremembe v biomasi perifitona, zato priporočajo, da se pri raziskavah upoštevajo prejšnje hidrološke razmere (Biggs in Close, 1989).

V poletnem obdobju smo na območjih odvzema SA3 in SA4 pod pregrado Moste izmerili visoke vrednosti suhe teže in organske snovi, kar lahko zaradi ugodnih svetlobnih in temperaturnih razmer, nizkih hitrosti vodnega toka, nizkih strižnih hitrosti, negibljivosti podlage in redkega pojavljanja povišanih pretokov voda, pripišemo množičnemu pojavljanju alge *Spirogyra sp.* Na območju odvzema SA5 pri Blejskem mostu pa smo, tako v zimskem kot v poletnem obdobju, izmerili nižje vrednosti suhe teže in organske snovi in višje vrednosti klorofila-*a*. Zaradi urnega spreminjanja v vodostajih se odplavljajo vsi organski delci in odmrle celice. Pri tem moramo upoštevati, da je to območje odvzema popolnoma zasenčeno, kar ima lahko za posledico večje količine klorofila-*a* v celicah. Na tem območju odvzema sta se pogosto pojavljali alga *Hydrurus foetidus* (zaradi nizkih temperatur vode tudi poleti) in alga *Cladophora sp.*

Z odvzemom vode iz Soče je pod pregrado Podsela prišlo do hidroloških, fizikalnih in kemijskih sprememb v vodotoku, kar se je odražalo v povečani biomasi perifitonskih alg (Preglednica 6). Preraščanje dna vodotoka z nitastimi algami je najbolj opazen vidni znak bioloških sprememb na odseku odvzema vode in to ima nadaljnje posledice za vodni živalski svet (Bundi in Eichenberger, 1989).

Visoka biomasa perifitonskih alg, izražena kot klorofil-*a* in organska snov, je bila opažena takoj pod pregradami tudi drugje (Lowe, 1979; Bundi in Eichenberger, 1989; Smolar, 1997; Koudelkova, 1999), podobno kot v Soči. Glavni razlog je lahko v manjših nihanjih temperature vode, pretoku vode brez večjega sezonskega nihanja in v naraščanju koncentracije hranilnih snovi ter njihovega prevzema v alge (Koudelkova, 1999) in v velikih negibljivih plavinah. Poleg hitrosti vodnega toka je pogoj za

Hydrological conditions exert an influence on changes in the periphyton biomass. Therefore, it is recommended that former hydrological conditions should be taken into account when such investigations are conducted (Biggs and Close, 1989).

In summer, high values of dry weight and organic matter were measured at sampling sites SA3 and SA4, downstream of the Moste Dam. This may be ascribed to the proliferation of the alga *Spirogyra sp.*, as a result of favourable conditions such as light and temperature, low current velocity, low shear velocity, substratum immobility, and the rare occurrence of increased flow. At sampling site SA5, at the gauging station at Blejski most, lower values of dry weight and organic matter, and higher chlorophyll-a values were measured in the summer, similarly as in winter. Due to hourly changes in the water level, all organic particles and dead cells were swept away. But it must be taken into account that this abstraction section is totally shaded, which may give rise to higher quantities of chlorophyll-a in the cells. At this location, *Hydrurus foetidus* (due to low water temperatures in the summer as well) and *Cladophora sp.* were often found.

Abstractions in the Soča River, downstream of the Podsela Dam, resulted in hydrological, physicochemical changes in the watercourse, which in turn led to an increased periphyton biomass (Table 6). Biological changes were most strikingly evident in the overgrowth of the bottom with green algae at this location, which will have a further impact on the aquatic fauna (Bundi and Eichenberger, 1989).

The high periphyton biomass, expressed as chlorophyll-a and organic matter, found immediately downstream of the dams was reported by other studies as well (Lowe, 1979; Bundi and Eichenberger, 1989; Smolar, 1997; Koudelkova, 1999). This may be primarily attributed to minor fluctuations in the water temperature, flows without more distinct seasonal fluctuations, an increase in the concentration of nutrients and their absorption by algae (Koudelkova, 1999), and to large immobile sediments. In addition to current velocity, at locations with low veliko biomaso perifitonskih alg na območju nizkih hitrosti vodnega toka, pomembna v nezasenčenih vodotokih tudi kakovost vode, ki je bila pod pregrado Podsela slabša. Alge *Cladophora glomerata*, *Mougeotia sp.* in *Ulotrix zonata* so prispevale velik delež k biomasi spomladi in poleti na območjih odvzema SO2 in SO3 v Soči pod pregrado Podsela, medtem ko so bile v istem obdobju na območju odvzema SO1 izmerjene najnižje vrednosti biomase perifitonskih alg. To je zaradi velikih hitrosti vodnega toka in velike gibljivosti podlage.

Alga *Cladophora* je sposobna dosegati veliko biomaso pri visokih hitrostih vodnega toka ($\overline{v}_v$ > 0.7 m/s) (Stevenson, 1996), v Soči pa je največ prispevala k biomasi perifitonskih alg, pri nizkih hitrostih vodnega toka pod pregrado Podsela ($\overline{v}_v$ < 0.3 m/s).

Nobena izmed zelenih alg pa se ni množično pojavljala na območju odvzema SO1 v Soči nad pregrado Podsela, kar je rezultat gibljive podlage, velikih hitrosti vodnega toka, v pojavu visokih voda in manjši onesnaženosti.

V primerjavi s Sočo je vpliv odvzema vode na zelene alge v Savi Dolinki manjši, kar lahko pripišemo dotoku manj onesnažene vode pod pregrado in nižjim temperaturam vode v poletnem času.

5. ZAKLJUČEK

Rezultati vpliva odvzema vode pri že zgrajenih HE Moste, HE Doblar in HE Ajba so pokazali velike spremembe v hidroloških, fizikalno-kemijskih in bioloških parametrih pod pregradami, ki so posledica prenizkih pretokov vode pod pregradami. Z zagotavljanjem Qes do tako velikih sprememb, posebej pod pregrado Podsela, ne bi smelo prihajati.

Po svetu uporabljajo različne metode določanja Qes v tekočih vodah, vendar jih le malo upošteva združbo perifitonskih alg kot enakovreden parameter. Na podlagi pregleda literature, rezultatov vpliva odvzema vode iz Tržiške Bistrice (Smolar, 1997), Soče in Save Dolinke lahko povzamemo, da je pri

current velocities in unshaded watercourses, a high periphyton biomass also depends on the water quality, which was of a lower category downstream of the Podsela Dam. The algae *Cladophora glomerata*, *Mougeotia sp.* and *Ulotrix zonata* contributed substantially to the biomass in spring and summer at sampling sites SO2 and SO3 in the Soča River, downstream of the Podsela Dam, while in the same period, lower values of periphyton biomass were measured at sampling site SO1. This resulted from high current velocities and a mobile substratum.

The alga *Cladophora* can attain a high biomass at high current velocities ($\overline{v}_v$ > 0.7 m/s) (Stevenson, 1996). But in the Soča River, the alga contributed most to the periphyton biomass at low current velocities downstream of the Podsela Dam ($\overline{v}_v$ < 0.3 m/s).

No species of green algae proliferated at sampling site SO1 in the Soča River, downstream of the Podsela Dam, which is the result of a mobile substratum, high current velocities, the occurrence of high waters, and less severe pollution.

Unlike the Soča River, the abstractions do not have such a noticeable effect on the green algae in the Sava Dolinka River. This may be attributed to less polluted inflowing water downstream of the dam and to lower water temperatures in summer.

5. CONCLUSION

The analysis of the effects of the abstractions for the Moste, Doblar, and Ajba hydropower plants shows substantial changes in the hydrological, physicochemical and biological parameters downstream of the dams resulting from the excessively low flows here. Such changes would not have occurred if the EAF had been assured.

To determine EAF in flowing waters, different methods have been applied, but only some investigations have taken into account the periphyton community as an equivalent parameter. Based on reports in the literature and on the analysis of the effects of the abstractions for the Tržiška Bistrica (Smolar, 1997), Soča, and Sava Dolinka določanju Qes nujno poznavanje združbe perifitonskih alg, ker predstavljajo začetek prehranjevalne verige v tekočih vodah, hitro odgovarjajo na spremembe v okolju ter ponujajo podlago in zatočišče številnim vodnim organizmom.

Rezultati naših raziskav in pregled literature so pokazali, da so za razumevanje pojavljanja perifitonskih alg med hidrološkimi parametri pomembni: pretok vode in njegova dinamika, nihanje vodne gladine, lokalna hitrost vodnega toka nad odvzemnim mestom, globina vode, velikost in gibljivost plavin, med fizikalno-kemijskimi parametri: temperatura, vsebnost kisika, nasičenost s kisikom, vsebnost hranilnih snovi ter onesnaženje in morfologija vodotoka.

Pri določanju Qes je potrebno poznavanje vrstnega sestava in biomase perifitonskih alg v različnih tipih habitatov obravnavanega odseka vodotoka v različnih letnih časih.

Vrednost Qes mora zagotavljati količino in kakovost vode, da:

- - ne pride do prevelikega preraščanja dna s perifitonskimi algami in da se ne pojavlja biomasa, neznačilna za tip vodotoka,
- ne prevladuje le ena oziroma le nekaj vrst perifitonskih alg,
- se vrstni sestav ne spremeni bistveno glede na primerjalno mesto,
- ne pride do poslabšanja kakovosti vode,
- ohranimo diverziteto različnih tipov habitatov (glede na globino vode, hitrost vodnega toka, osenčenost, strukturo in velikost plavin),
- ne pride do zastajanja vode (zagotoviti moramo hitrost vodnega toka v posameznih habitatih nad 30 cm/s),
- preprečimo nenehne spremembe v pretoku vode, npr. zaradi vršnega obratovanja vodnih elektrarn,
- se občasno zagotavljajo pretoki visoke vode (dovoljeno le ob naravnem nastopu visokih voda)
- ne pride do prevelikih sprememb v fizikalnih in kemijskih lastnostih vode, takih, ki niso značilne za odsek vodotoka pod vplivom odvzema vode.

rivers, it can be concluded that the knowledge of the periphyton community is vital for the EAF determination, since the algae represent the beginning of the feed chain in running water, respond quickly to environmental changes, and act as substrata and refuges for a number of aquatic organisms.

The results of this study and a survey of the literature indicate that the following hydrological parameters, among others, are of importance for an understanding of periphyton occurrence: flow, flow fluctuations, fluctuations in water level, local current velocity above the sampling site, water depth and size and mobility of the sediments, along with the following physicochemical parameters: temperature, oxygen content, oxygen saturation, content of the nutrients, pollution, and the morphology of the watercourse.

To determine the EAF, it is vital to have a knowledge of species composition and the periphyton biomass in different types of habitats of the section under consideration in different seasons.

The EAF value should ensure such quantity and quality of water that

- the excessive overgrowth of the bottom with periphyton and a biomass uncommon for a particular type of watercourse do not occur,
- merely one or just a few periphyton species do not predominate,
- species composition does not change substantially when compared with the reference site,
- the water quality does not deteriorate,
- the diversity of different habitat types is preserved (with regard to water depth, current velocity, the extent of the shade and the structure and size of the sediments),
- the water does not stagnate (the current velocity in individual habitats should be over 30 cm/s),
- constant changes in flow, e.g. owing to the peak operation of a hydropower plant, are prevented,
- flows of high waters are occasionally ensured (only if high waters occur naturally), and that
- radical changes in the physicochemical properties of the water do not occur; that is, changes that are uncommon for the section of a watercourse influenced by the abstractions.

Potrebne pa so nadaljnje raziskave, da bomo lahko količinsko bolj podrobno opredelili zgoraj naštete zahteve.

Rezultati naših raziskav so pokazali, da v času konstantnega pretoka vode pod pregradami dosegajo perifitonske alge običajno visoko biomaso na velikih prodnikih in kamnih, predvsem zaradi majhne gibljivosti plavin v dnu vodotoka. Zato je treba, poleg zagotavljanja Qes na odseku pod pregrado za odvzem vode, ohranjati naravno dinamiko pretokov visokih voda na tem odseku in zagotavljati pretok plavin v odsek pod pregrado.

Further research is needed to define quantitatively, in more detail, the above statements.

Results of the study show that, at the time of the constant flow downstream of a dam, periphytonic algae usually attain a high biomass on large pebbles and stones, primarily owing to the limited mobility of sediments at the bottom of a watercourse. Therefore, it is vital - in addition to ensuring EAF downstream of the dam intended for abstractions - to preserve the natural dynamics of the flows of high waters at this location, and to ensure sediment transport into the section downstream of the dam.

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