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THE IMPACT OF A SMALL HYDROPOWER PLANT (SHP) ON BENTHIC ALGAE, MACROINVERTEBRATE COMMUNITY AND ICHTHYOFAUNA OF THE PANJICA RIVER (SERBIA)

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ABSTRACT. The impact of a small hydropower plant (SHP) on aquatic communities (benthic algae, macroinvertebrates and ichthyofauna) and water quality was investigated in the Panjica River (Serbia). The field research was conducted at three localities in November 2024. The results showed differences in community composition between localities upstream and downstream of the SHP, with the greatest impact observed immediately downstream of the water intake. A decline in benthic diatom and macroinvertebrate diversity was observed. Non-diatom algae more clearly indicated the changes in habitat conditions caused by the SHP's operation, as evidenced by the excessive growth of the cyanobacterium *Microcoleus autumnalis*. The greatest impact was observed in the ichthyofauna, which was absent at the site immediately downstream of the SHP. The ecological status assessment based on diatoms showed no differences, while the macroinvertebrates indicated a deterioration in water quality downstream of the SHP. Long-term monitoring is recommended to better assess SHP's impact.

Keywords: flow regime, water level, cyanobacterial mats, water quality.

INTRODUCTION

Although small hydropower plants (SHPs) can represent a significant source of renewable energy, their ecological impact is becoming an increasingly important topic (ÁLVAREZ *et al.*, 2020). They can affect aquatic ecosystems through changes in hydrodynamic conditions, flow regimes, sedimentation and water quality, which may impact biological communities in rivers (ANDERSON *et al.*, 2015). Benthic algae and macroinvertebrates are sensitive to changes in water flow and nutrient availability, so an altered hydrological regime can affect their abundance and diversity, favoring certain species and reducing the abundance

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of others (XIAOCHENG *et al*., 2008; VAIKASAS *et al*., 2015; QI *et al*., 2024). Fish are the most visibly affected group of organisms when it comes to the impact of SHPs (GU *et al*., 2022). They are barriers to the migration of fish, and cause changes in water level and temperature which can have a negative impact on their reproduction and growth (NOONAN *et al.*, 2012). In addition, the reduced availability of suitable habitats can hinder the development of juvenile fish and lead to a decline in the populations of some species (POFF and ZIMMERMAN, 2010).

In the last decade, support for the development of SHPs has increased significantly (COUTO and OLDEN, 2018). In the Balkan region, a total of 1315 hydropower plants are planned for construction, with the majority located in Serbia and Bosnia and Herzegovina. By 2019, 101 medium and small hydropower plants had already been built in Serbia (HUĐEK *et al*., 2020). Despite the large number of SHPs, studies on their impact on aquatic organisms in Serbia remain limited. In recent years, research has focused on the effects of SHPs on benthic epilithic diatoms (JAKOVLJEVIĆ *et al*., 2022, 2024; MILIĆEVIĆ *et al*., 2022, 2024). The impact on all algal groups was only investigated by SIMIĆ *et al*. (2020), while MITROVIĆ *et al*. (2021) investigated SHPs as a threat factor to habitats of red algae. The effects of SHPs have also been studied on aquatic macroinvertebrate communities and fish (SIMIĆ *et al*., 2018, 2020, 2022; SIMONOVIĆ *et al*., 2021), amphibians and reptiles (CRNOBRNJA-ISAILOVIĆ *et al*., 2021).

Given the limited number of previous studies, we investigated the effects of the SHP on the composition of the benthic algal, macroinvertebrate and fish (ichthyofauna) communities in the Panjica River. We also assessed the impact on water quality (ecological status) using biological quality elements (epilithic diatoms and macroinvertebrates).

MATERIALS AND METHODS

Study area

The Panjica River originates from the confluence of several smaller streams, below the limestone cliff of Kukutnica (1382 m a.s.l.), and flows for 13.7 km before joining the Golijska Moravica, which is part of the Zapadna Morava Basin. Most of the river's course passes through the limestone gorge "Dobrača" (SAVOVSKI *et al*., 2024).

The "Jovanovići" SHP is located on the lower reaches of the Panjica River, with the intake situated about 3.5 km from the confluence with Golijska Moravica (Figure 1). The SHP is of the diversion type, and the length of the pipeline from the intake to the powerhouse is approximately 1300 m. It began to operate in March 2020. An initial analysis of the algal community (phytoplankton), macroinvertebrates and fish fauna was conducted after the construction of the small hydropower plant (SHP) but prior to the start of its operation by RADULOVIĆ *et al*. (2019). About 80 m upstream from the SHP intake, there is a Californian trout farm (Figure 1), which also serves as a spawning center for the production of salmonid fish juveniles for stocking fishing waters. The farm uses water from the Panjica River.

Field research and sample collection of benthic algae, macroinvertebrates, and ichthyofauna were conducted in November 2024 at three localities along the Panjica River (L1, L2, L3).

L1 is located 500 m upstream of the SHP (N 43.6593014, E 20.0721090; 491.81 m a.s.l.) (Figure 1). The river is about 3.5 m wide and 0.1 to 0.6 m deep at this locality. The riverbed consists of coarse gravel and stones, and the water velocity was 1.2 m/s. The river banks remained unchanged. The geological substrate is limestone and the surrounding vegetation consists of deciduous forests dominated by hornbeam (Figure 1). No visible anthropogenic influences were observed at this site.

L2 is located between the water intake and the powerhouse of the SHP, more precisely in the area where the 1300 m long pipeline of the SHP runs (N 43.6608286, E 20.0744281;

491.23 m a.s.l.) (Figure 1). The width of the river varies between 1.5 and 2 m (up to 2.5 m), while the water depth was between 0.1 and 0.5 m. Both the banks and the riverbed have been altered, with 90% of the riverbed covered by large, broken stones deposited during the construction of the pipeline. The left bank is rocky and overgrown with woody shrubs. During the study period, the river had a slightly faster flow at this site compared to L1 due to the narrowed riverbed, but also to the steeper channel gradient. The water flow remained almost unchanged compared to other river sections, as the SHP was not in operation for several months (from July to November) prior to sampling due to low water levels (SIMIĆ *et al*., 2024).

L3 is located approximately 500 m downstream of the SHP (N 43.6632999, E 20.0893992; 427.54 m a.s.l.) (Figure 1). At this site, the river is a maximum of 5.5 m wide and between 0.1 and 0.7 m deep. The riverbed consists mainly of large stones (>250 mm). The riverbanks at this site are steep and overgrown with trees, mainly hornbeam. No visible anthropogenic influences were observed at this site.

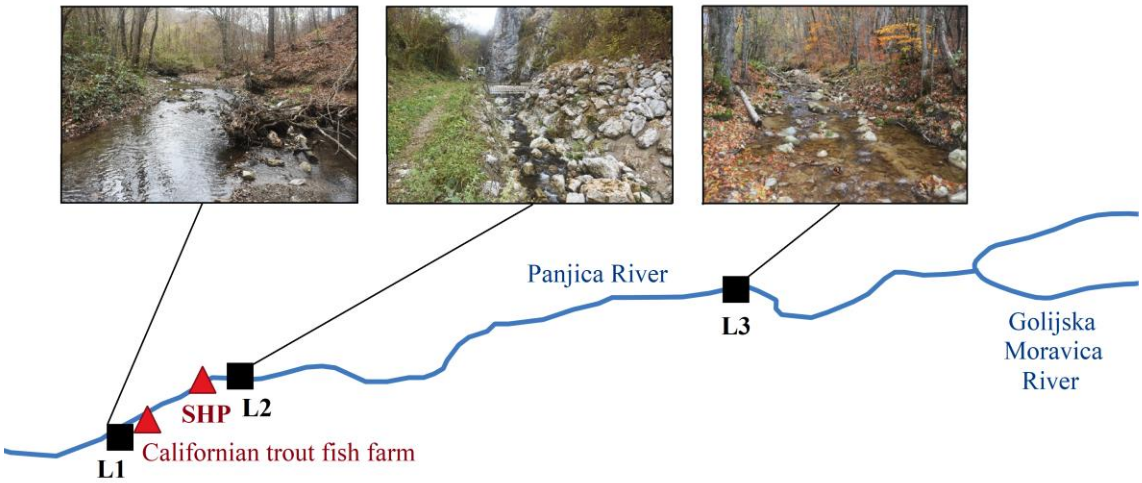

Figure 1. Location and appearance of the study sites along the Panjica River (L1, L2, L3).

Sampling, processing and analysis of benthic algae

Different methods were used to collect benthic algae, depending on morphological form and substrate type. Epilithic diatoms were collected in accordance with the EN 13946 (2015) standard, while other algal groups (non-diatoms), including both micro- and macroalgae, were sampled following the EN 15708 (2011) standard. All collected algal samples were immediately fixed and preserved in a 4% formaldehyde solution.

For the analysis of the collected benthic algae samples, both temporary and permanent algal slides were made. The permanent diatom slides were prepared according to the EN 13946 standard (2015), while the temporary slides were used for the observation of non-diatom algae. The morphological parameters of the algae were analyzed using a Motic BA310 light microscope with a digital camera (Bresser 9MP). The taxa found were identified using appropriate identification keys: KOMÁREK and ANAGNOSTIDIS (2005), ELORANTA *et al.* (2011), JOHN *et al.* (2011), WEHR and SHEATH (2015), and LANGE-BERTALOT *et al*. (2017).

The quantitative analysis of non-diatom macroscopic aggregations was based on the determination of the percentage coverage of thalli along a 10 m transect (RAMIREZ-RODRIGUEZ *et al*. 2007). The quantitative analysis of epilithic diatoms was based on the determination of the relative abundance (%) of the species in the sample (EN 14407: 2014).

Based on the qualitative and quantitative diatom analysis, the Shannon-Wiener diversity index and the IPS diatom index were calculated using the OMNIDIA software (LECOINTE *et al*. 1993).

Sampling, processing and analysis of benthic macroinvertebrates

Benthic macroinvertebrates were also collected at the selected sites (L1, L2, L3) using a manual benthic net (Surber benthic net) with dimensions of 30×30 cm following standard EN 10870 (2012). The samples were fixed with a 70% ethanol solution. The macroinvertebrates were identified using a binocular magnifier (NIKON SZM-800), an Eclipse E-100 microscope and appropriate identification keys: CONCI and NILSEN, 1956; ROZKOŠNÝ, 1980; ELLIOTT *et al*., 1988; DOBSON, 2013. The evaluation of the ecological characteristics was carried out with the software ASTERICS 4.04 (AQEM CONSORTIUM, 2002).

Sampling and processing of ichthyofauna

The fish community and fish stock were assessed by sampling and catching fish using the electrofishing method (Aqutech IG 1300 and IG 4000 electrofishing devices). The electrofishing transect was 50 m long. The qualitative analysis of the fish community was carried out according to KOTTELAT and FREYHOF (2007), while the quantitative analysis was expressed as the number of individuals (N) per kilometer of river (N/km). The age structure was determined by the number of age classes of each fish species. For each individual caught, the total length (LT) (cm), standard length (LS) (cm) and weight (W) (g) were measured in the field. The mean value of standard length (LM) (cm) was used for the analysis of fish population characteristics.

In addition to the qualitative and quantitative analysis of the fish community, biomass, actual production (AP) (kg/km), and potential production (PP) (kg/km) were also estimated. The real production was estimated according to the CHAPMAN (1971) method, while potential production was estimated according to the methods of HUET (1949, 1964, 1970) and NĂSTASE *et al*. (2018).

Indicative ecological status assessment

The ecological status assessment based on the biological quality elements (phytobenthos – epilithic diatoms and macroinvertebrates) was carried out following Serbian national regulations (ANONYMOUS 2011, 2023). The Panjica River was classified as a TYPE 6 water body (small rivers outside the Pannonian Basin that do not fall under types 3 and 4). For the assessment of the ecological status of TYPE 6 rivers, the above-mentioned regulations prescribe the use of the IPS (*Pollution Sensitivity Index*) (COSTE, 1982) diatom index.

The following parameters were used to assess the ecological status based on the macroinvertebrate community: Zelinka and Marvan Saprobic Index (ZELINKA and MARVAN, 1961), Biological Monitoring Working Party (BMWP) Score (CHESTER, 1980), Shannon-Weaver Diversity Index (SHANNON, 1948), the total number of recorded taxa, Balkan Biotic Index (BNBI) (SIMIĆ and SIMIĆ, 1999), percentage of Oligochaeta/Tubificidae in the total macroinvertebrate community, and the number of taxa from the Ephemeroptera, Plecoptera and Trichoptera (EPT), calculated using the ASTERICS 4.04 software package. The parameter values were compared with the threshold values from the regulation (ANONYMOUS, 2011), and the ecological status was determined by the parameter indicating the lowest class (ČAĐO *et al*., 2021).

The assessed ecological status can be: high (class I), good (class II), moderate (class III), poor (class IV), or bad (class V) (ČAĐO *et al*., 2021).

RESULTS AND DISCUSSION

Benthic algal community

The qualitative analysis of the benthic algal community revealed a total of 58 taxa, which were divided into five algal groups: Cyanophyta (4), Rhodophyta (1), Xanthophyceae (Heterokontophyta) (1), Bacillariophyceae (Heterokontophyta) (49) and Chlorophyta (3). The highest number of species was recorded at L1 and the lowest at L3 (Table 1).

Table 1. Qualitative and quantitative analysis (%) of benthic algae at the investigated sites of the Panjica River (+ - species present)

	Locality		
Taxa	**L1**	**L2**	**L3**
Cyanophyta			
Microcoleus autumnalis (Gomont) Strunecky, Komárek & J.R. Johansen		30	
Phormidium tergestinum (Rabenhorst ex Gomont) Anagnostidis & Komárek	+		
Phormidium spp.			+
Nostoc sp.		<5	
Rhodophyta			
Audouinella sp.	+		
Xanthophyceae (Heterokontophyta)			
Vaucheria sp.	+	<5	15
Bacillariophyceae (Heterokontophyta)			
Achnanthidium minutissimum (Kützing) Czarnecki	6.5	13.25	5.5
Achnanthidium sp.	5.75	3.25	1
Amphipleura pellucida (Kützing) Kützing			0.25
Amphora sp.	4.75	0.5	4.75
Cocconeis pediculus Ehrenberg	1.5	0.25	
Cocconeis placentula Ehrenberg	6.75	1.25	2.5
Craticula sp.		+	1.75
Cymbella affinis Kützing	3.5	0.25	2
Cymbella compacta Østrup		2.5	2.25
Cymbella sp.		0.25	
Cymbella tumida (Brébisson) Van Heurck	1.75	2	2.5
Diatoma moniliformis (Kützing) D.M.Williams	0.75		0.75
Diatoma vulgaris Bory	3.25	17	0.25
Encyonema brevicapitatum Krammer	4.5	9.25	
Encyonema leibleinii (Agardh) Silva et al.	1		1
Encyonema minutum (Hilse) D.G. Mann	7	8.5	2
Encyonema silesiacum (Bleisch) D.G. Mann	0.5		
Encyonema ventricosum (C.Agardh) Grunow	12.5		
Encyonopsis subminuta Krammer & E. Reichardt	0.25		0.25
Fallacia subhamulata (Grunow) D.G. Mann			4.75
Fragilaria sp.			0.25
Frustulia vulgaris (Thwaites) De Toni	1	0.25	0.25
Geissleria decussis (Østrup) Lange-Bertalot & Metzeltin		0.25	
Gomphonella olivacea (Hornemann) Rabenhorst	0.5	0.25	

Table 1.continued

Gomphonema acuminatum Ehrenberg	0.25	0.25	
Gomphonema parvulum (Kützing) Kützing		1.25	
Gomphonema pumilum (Grunow) E. Reichardt & Lange-Bertalot	0.75		
Gomphonema sp.	+	+	
Gomphonema truncatum Ehrenberg	2	1	
Gomphonema ventricosum W. Gregory		0.25	
Gyrosigma obtusatum (Sullivant & Wormley) C.S. Boyer	4		9.25
Luticola goeppertiana (Bleisch) D.G. Mann ex Rarick, S. Wu, S.S. Lee & Edlund		+	
Melosira varians C. Agardh	6.5	5	0.75
Navicula cryptocephala Kützing	0.5		
Navicula cryptotenella Lange-Bertalot	0.75		
Navicula gregaria Donkin		+	
Navicula rostellata Schmidt	+		
Navicula tripunctata (O.F. Müller) Bory	5.5	11	24.25
Navicula trivialis Lange-Bertalot			1
Navicula viridula (Kützing) Ehrenberg	0.25		
Nitzschia dissipata (Kützing) Rabenhorst	6.5	4.5	6
Nitzschia fonticola (Grunow) Grunow	3.75	7.5	10
Nitzschia linearis W. Smith	5	5	9
Rhoicosphenia abbreviata (C. Agardh) Lange-Bertalot	6		
Surirella angusta Kützing	2.5	1	
Surirella lacrimula J.D. English		1	3.75
Surirella librile (Ehrenberg) Ehrenberg		0.5	
Tryblionella apiculata W. Gregory	0.25		
Ulnaria ulna (Nitzsch) Compère	1.75	2.5	4
Chlorophyta			
Cladophora glomerata (L.) Kützing		< 5	+
Ulothrix zonata (F. Weber & Mohr) Kützing		+	
Closterium sp.		+	
Total number of taxa	**37**	**34**	**29**

At all three investigated localities (L1, L2, L3), the most diverse group was Bacillariophyceae (diatoms) (33, 28, 26 recorded taxa, respectively). Among them, dominant species with an abundance of over 10% included *Encyonema ventricosum* (L1), *Diatoma vulgaris* (L2), *Achnanthidium minutissimum* (L2), *Navicula tripunctata* (L2, L3) and *Nitzschia fonticola* (L3) (Table 1). The diatom species occurring at the sites downstream of the SHP and the fish farm (L2, L3) are known as indicators of meso-eutrophic (*D. vulgaris*, *N. fonticola*) and eu-polytrophic waters (*N. tripunctata*) (ROTT *et al.*, 1999). There are conflicting reports for *A. minutissimum*, with some studies suggesting that it is sensitive to pollution and typically occurs as the dominant species in oligotrophic waters (ROTT *et al.*, 1999; PONADER and POTAPOVA, 2007), while others claim that it is widespread in both clean and polluted waters (JÜTTNER *et al.*, 2022). The presence of diatom species indicating meso- to polytrophic conditions at localities L2 and L3 could be related to nutrient-rich discharges from fish farm that entered the river during the low-flow period from July to November. The highest diatom diversity was observed at L1, upstream of the SHP, while it was lower downstream at L2 and L3 (Table 2). A decrease in diatom diversity and number of species directly downstream of SHPs was also observed by MILIĆEVIĆ *et al.* (2024) on the Ljubovića River and JAKOVLJEVIĆ *et al*. (2024) on the Prištavica River.

Table 2. Values of Shannon-Wiener diatom diversity index at the investigated sites of the Panjica River

Locality	L1	L2	L3
Diversity index	4.57	3.85	3.84

In addition to benthic epilithic diatoms, visible macroscopic aggregations of non-diatom algae were found at sites L2 and L3. At L1, only traces of the red alga *Audouinella* sp., thalli of *Vaucheria* sp. and trichomes of the cyanobacterium *Phormidium tergestinum* were found in the material (Table 1). At L2, thick, leathery, green-black coatings formed by the intertwining of homocytic thalli of the cyanobacterium *Microcoleus autumnalis* (basionym *Phormidium autumnale* Gomont) (Figure 2) were observed. They covered about 30% of the rocky substrate at the site (Table 1). Colonies of the cyanobacterium *Nostoc* sp., cushion-like green mats of *Vaucheria* sp. and filaments of the green alga *Cladophora glomerata* were found on the stones. These algae covered less than 5% of the riverbed (Table 1). Microscopic examination also revealed individual filaments of the green alga *Ulothrix zonata* (Table 1).

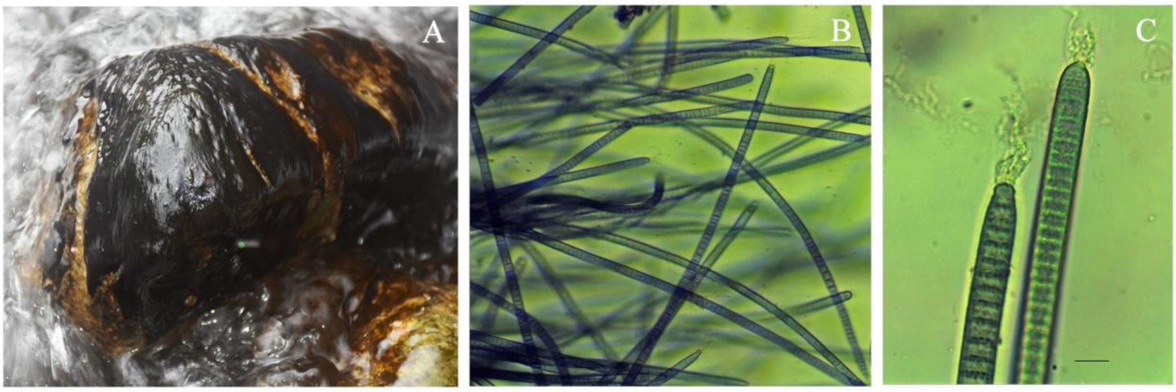

Figure 2. A – Cyanobacterial mats of *Microcoleus autumnalis* on rocks at site L2 (photo by V. Simić, 2024);
B, C – *M. autumnalis* under the microscope (bar scale=10 µm) (photos by S. Simić and K. Markeljić, 2024)

The occurrence and growth of cyanobacterial mats of *M. autumnalis* are becoming increasingly common in streams and rivers worldwide (WOOD *et al*., 2014, 2020). The factors influencing their proliferation and blooming are not yet fully understood and the available literature contains contradictory results. However, these cyanobacteria were found to develop most frequently on stable large stones in moderate-fast flowing waters, in riffles with fluctuating water levels and high light exposure (ECHENIQUE-SUBIABRE *et al.* 2018; MCALLISTER *et al*., 2020), which is consistent with our findings. Also, an increase in the abundance of *Phormidium* has been observed downstream of SHP (WU *et al*., 2010), suggesting that hydrological alterations may play a role in their proliferation. In terms of nutrients, some authors state that *M. autumnalis* forms mats in waters with low concentrations of dissolved reactive phosphorus (<0.01 mg/L) and elevated concentrations of dissolved inorganic nitrogen (>0.1–0.2 mg/L) (WOOD and YOUNG, 2012; WOOD *et al*., 2014), while according to ROTT *et al*. (1999), it is an indicator of mesotrophic waters. The occurrence of *M. autumnalis* at site L2 confirms that its development is favored by occasional nutrient inputs from the fish farm into this part of the river. It is also important to mention that in recent years special attention has been paid to benthic cyanobacteria, as they are known to produce cyanotoxins. *Microcoleus autumnalis* has been found to produce anatoxin, homoanatoxin and their derivatives (Wood *et al*., 2007; Heath *et al*., 2011; Bouma-Gregson *et al*., 2018). These toxins can affect aquatic macroinvertebrates (Anderson *et al*., 2018) and possibly other aquatic organisms and animals that use the river water for drinking (Wood *et al*., 2020). For these reasons, the occurrence of these mats needs to be monitored in the future. At L3, macroscopic, cushion-like mats of *Vaucheria* sp. were observed covering about 15% of the riverbed (Table 1).

Benthic macroinvertebrate community

The highest number of macroinvertebrate taxa was recorded at L1 (Table 3).

Table 3. Qualitative and quantitative composition of the macroinvertebrate community at the studied sites of the Panjica River

Taxa **Locality**	**L1**	**L2**	**L3**
Gastropoda			
Lymnaea sp.	0	0	1
Amphipoda			
Gammarus balcanicus Schäferna (1922)	9	88	5
Ephemeroptera			
Ephemera Danica Müller (1764)	9	4	7
Ecdyonurus sp. Eaton (1868)	17	5	1
Epeorus assimilis Eaton (1885)	7	16	1
Baetis sp. Leach (1815)	1	0	0
Baetis rhodani Pictet (1843)	0	29	13
Paraleptophlebia submarginata Stephens (1835)	15	17	0
Plecoptera			
Perla marginata Panzer (1799)	5	2	1
Perlodes microcephalus Pictet (1833)	0	1	0
Leuctra sp. Stephens (1836)	1	0	1
Trichoptera			
Sericostoma sp. Latreille (1825)	0	1	0
Sericostoma flavicornis Pictet (1834)	7	36	5
Hydropsyche sp. Pictet (1834)	5	124	13
Odontocerum albicorne Scopoli (1763)	4	0	0
Rhyacophila sp. Pictet (1834)	12	0	2
Rhyacophila tristis Pictet (1834)	1	0	1
Philopotamus montanus Donovan (1813)	0	6	0
Potamophylax sp. Wallengren (1891)	0	0	1
Diptera			
Tipula sp. Linnaeus (1758)	1	1	0
Diptera sp. Linnaeus (1758)	0	0	3
Eukiefferiella sp. Thienemann (1926)	0	3	0
Brillia sp. Kieffer (1913)	0	1	0
Coleoptera			
Ibisia marginata Fabricius (1794)	3	4	8
Pomatinus substriatus Müller (1806)	5	19	10
Total number of taxa	**17**	**16**	**15**

The densest populations in this river section are represented by sensitive taxa *Ecdyonurus* sp., *Paraleptophlebia submarginata* (Ephemeroptera) and *Rhyacophila* sp. (Trichoptera). At site L2, the structure of the macroinvertebrate community differs from site L1. A pronounced dominance of *Hydropsyche* sp. larvae is observed. The highest abundance at L3 had the widespread larvae of *Baetis rhodani* (Ephemeroptera) and larvae *Hydropsyche* sp. (Trichoptera) (Table 3). Compared to the macroinvertebrate study presented in the 2019 report (RADULOVIĆ *et al*., 2019), notable changes were detected only at L2, primarily due to a higher abundance of *Hydropsyche* sp.—a genus tolerant to moderate organic pollution and fluctuating water flow (FICSÓR and CSABAI, 2021). This increase could be related to the prolonged low-flow water conditions, which probably favoured the accumulation of organic matter from the upstream fish farm.

Analysis of ichthyofauna

Four fish species were recorded at the studied sites of the Panjica River: *Salmo trutta* L. (1758) (brown trout), *Barbus balcanicus* Kotlík, Tsigenopoulos, Ráb & Berrebi (2002) (danube barbel), *Alburnoides bipunctatus* Bloch (1782) (spirlin) and *Phoxinus phoxinus* L. (1758) (common minnow). The results of the fish community structure at the studied sites are presented in Tables 4, 5, and 6.

Table 4. Fish community structure at L1 of the Panjica River

Fish species	N/km	Age structure (%)					LM (cm)	Biomass (kg/km)	AP (kg/km)	PP (kg/km)
		0+	1+	2+	3+	4+				
Brown trout	400	25	62.5	12.5	0	0	12.4	6.45	3.57	4.5
Total values	400	0	0	0	0	0	0	6.45	3.57	4.5

The results for the fish populations at the Panjica River sites clearly show the negative effects of SHP through changes in structure, abundance, biomass and fish production. At site L1, only species brown trout was found with an abundance of 400 N/km (Table 4). Among the sampled brown trout, the younger age classes dominated (Table 4). The absence of older individuals contributed significantly to the decline in biomass and fish production at site L1 compared to 2019 (RADULOVIĆ *et al*., 2019). While the actual fish production of 3.57 kg/km shows slightly lower measured values, the potential production with calculated values of 4.5 kg/km indicates a slightly higher capacity. These results show that the sustainability of brown trout has decreased over the years. Several factors have contributed to the absence of older individuals, most notably the construction of SHP, which led to habitat fragmentation and permanently divided the brown trout population. In addition, the increasing frequency of drought years with low rainfall has led to a decrease in water levels in the rivers, which in turn favors illegal fishing and overfishing (ADÁMEK and JURAJDA, 2001; FETTE *et al.,* 2007; JURAJDA *et al.,* 2020).

Table 5. Fish community structure at L2 of the Panjica River

Fish species	N/km	Age structure (%)					LM (cm)	Biomass (kg/km)	AP (kg/km)	PP (kg/km)
		0+	1+	2+	3+	4+				
Total values	0	0	0	0	0	0	0	0	0	0

No fish species were detected at site L2 (Table 5), which comprises the section between the intake and the powerhouse. The absence of brown trout in this section of the river can be directly linked to the operation of the SHP, which affects water flow, increases temperature, reduces oxygen concentration, and increases nutrient levels, negatively affecting sensitive species such as brown trout, which require stable ecological conditions (MACEDA-VEIGA and SOSTOA, 2011; BENEJAM *et al.*, 2014). Compared to the other sites, L2 has the highest measured values for potential production, indicating good habitat potential. Although the periphyton and benthic fauna communities are well developed as the first links in the food chain at site L2, fish populations have not been able to recover. The availability of sufficient fish food is not the decisive factor, as the ecological conditions of the habitat play a crucial role in the production potential (DWIRASTINA and DITYA, 2021).

Table 6. Fish community structure at L3 of the Panjica River

Fish species	N/km	Age structure (%)					LM (cm)	Biomass (kg/km)	AP (kg/km)	PP (kg/km)
		0+	1+	2+	3+	4+				
Danube barbel	267	0	50	50	0	0	10.69	3.18	2.32	2.54
Spirlin	33	0	0	100	0	0	9.5	0.30	0	0.24
Common minnow	67	0	0	100	0	0	8.5	0.27	0	0.21
Total values	367	0	0	0	0	0	0	3.75	2.32	3

The greatest diversity of fish species was found at site L3 (Table 6), located downstream of the SHP. The danube barbel was the dominant species, accompanied by common minnow and spirlin (Table 6). This site also showed a stable ratio of biomass and production; however, brown trout was not recorded. In contrast, RADULOVIĆ *et al*. (2019) reported the presence of both brown trout and danube barbel at this site. They stated that the presence of danube barbel is probably secondary and originates from the Golijska Moravica River located downsteam.

Indicative ecological status assessment

According to the epilithic diatom community (IPS index), a high-good ecological status was assessed (Table 7). This parameter was not sensitive to changes caused by the operation of the SHP, as previously noted (SIMIĆ *et al*. 2021; JAKOVLJEVIĆ *et al*. 2024; MILIĆEVIĆ *et al*. 2024).

Table 7. Indicative assessment of the ecological status of the Panjica River localities based on epilithic diatoms and macroinvertebrate parameters

Parameter / Locality	L1	L2	L3
	Epilithic diatoms		
IPS index	15.4	16.6	13.9
Ecological status assessment			
	Benthic macroinvertebrates		
Saprobic Index (Zelinka and Marvan)	1.408	1.719	1.95
Total number of taxa	17	16	15
BNBI	4	3.5	3.6
Diversity (Shannon-Wiener-Index)	2.572	1.952	2.362
Oligochaeta [%]	0	0	0
EPT-Taxa [%]	79.245	67.507	63.014
Ecological status assessment			

High ecological status (class I) Good ecological status (class II) Moderate ecological status (class III)

On the other hand, the assessment using aquatic macroinvertebrates indicated a good to moderate ecological status at the investigated sites (Table 7). Thus, there was a decline in water quality by one class downstream of the SHP. According to the Shannon-Wiener diversity index of macroinvertebrates, it was lower at the site below the SHP (L2) compared to L1 (Table 7).

CONCLUSION

The analysis of aquatic communities (benthic algae, macroinvertebrates, ichthyofauna) revealed certain differences upstream of the SHP (L1) and downstream (L2, L3), with the greatest impact observed immediately downstream of the water intake (L2). This is also a section of the river where nutrients and organic matter from the fish farm flow through. A decline in the number of species and diversity of benthic diatoms and macroinvertebrates was observed. However, the non-diatom algal community better reflected the effects of the altered habitat conditions caused by the operation of the hydropower plant, as there was extensive growth of the potentially toxic cyanobacterium *Microcoleus autumnalis*. The most pronounced changes were observed in the fish community, which was completely absent at L2, probably because the water level was below the prescribed biological minimum for long periods or completely absent in short intervals. The assessment of ecological status based on diatoms showed no significant differences between sites, in contrast to the assessment based on macroinvertebrates, which indicated a deterioration in water quality downstream of the hydropower plant. As the conclusions are based on a one-off survey, continuous monitoring is required.

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