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ECOLOGICAL IMPACTS OF COAL MINING AND PHOTOVOLTAIC POWER PLANT OPERATIONS ON THE MACROINVERTEBRATE COMMUNITY IN OSLOMEJ RESERVOIR AND TEMNICA RIVER (NORTH MACEDONIA)

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ABSTRACT
Coal mining and photovoltaic power plant operation significantly impact the macroinvertebrate communities in freshwater ecosystems due to changes in water quality and habitat structure resulting from dramatic erosion processes. Therefore, monitoring the macroinvertebrate community serves as an important indicator of ecological health. This study presents the ecosystem conditions in Oslomej reservoir and river Temnica based on the aquatic invertebrate community. The obtained results showed that Oslomej reservoir and river Temnica suffer habitat degradation and put up with different pollutants, introduced through the soil and sediment that entered the reservoir and the river during the construction of the PV Oslomej 3, as well as from previous acid mine drainage from the coal mine "Oslomej".

KEYWORDS: macroinvertebrates, biodiversity assessment, ecosystem health, N. Macedonia

EKOLOŠKI UTICAJI RUDNIKA UGLJA I FOTONAPONSKIH ELEKTRANA NA ZAJEDNICU MAKROBESKIČMENJAKA U AKUMULACIJI OSLOMEJ I RECI TEMNICA (R. SEVERNA MAKEDONIJA)

REZIME

Iskopavanje uglja i rad fotonaponskih elektrana značajno utiču na zajednice makrobeskičmenjaka u slatkovodnim ekosistemima zbog promena u kvalitetu vode i strukturi staništa koje su rezultat dramatičnih procesa erozije. Stoga, praćenje zajednice makrobeskičmenjaka služi kao važan indikator ekološkog zdravlja. Ova studija prikazuje uslove ekosistema u Oslomejskom akumulaciji i reci Temnici na osnovu zajednice vodenih beskičmenjaka. Dobijeni rezultati su pokazali da akumulacija Oslomej i reka Temnica trpe degradaciju staništa i trpe različite zagađivače, unete kroz zemljište i sediment koji su dospeli u akumulaciju i reku tokom izgradnje PV Oslomej 3, kao i prethodnim kiselim rudničkim odvodom iz rudnika uglja „Oslomej“.

KLJUČNE REČI: makrobeskičmenjaci, procena biodiverziteta, stanje ekosistema, S. Makedonija

INTRODUCTION

Many studies confirm that deforestation, mining activities, construction of facilities and other infrastructure projects lead to dramatic erosion processes that result in increased soil loss and sediment transport into reservoirs and other waterbodies (e.g. Dutta, 2016; Pacetti et al., 2020; Stefanović et al., 2024). Sediment particles that deposit into the reservoir after getting eroded from the catchment, significantly reduse the water storage capacity (Dutta, 2016) and contribute to chemical pollution of water with materials of both natural and anthropogenic origin (Stefanović et al., 2024).

This situation is really visible in areas that have been defforestated before the start of the coal mining operation where man-made reservoirs for wet storage of mine tailings have been created (Pacetti et al., 2020; Sowa et al., 2020). Chemical substances of natural origin, resulting from the decay of rocks, are transported into the hydrographic network through sediment erosion (Stefanović et al., 2024), while anthropogenic chemical pollution occurs due to the runoff of soil and sediment from mining areas into reservoirs (Pacetti et al., 2020). Acidic mine drainage (AMD) is an environmental pollutant that also contributes to the chemical pollution of the water resources in mining regions, becoming a focus of research for many scientists (Neculita et al., 2017). The ecological consequences of AMD pollution in freshwaters can be substantial, due to the very low pH (often below pH 3.0), high concentrations of dissolved metals, and metal precipitate accumulation in sediments (Hogsden and Harding, 2012). These complex effects lead to reductions in abundance, species loss and structural changes to macroinvertebrate community (He et al., 2015; Dean

et al., 2025), while also causing dominance of pollution-tolerant organisms (Quanz et al., 2021).
Benthic macroinvertebrates are sensitive to a broad range of environmental stressors and they have been widely used as indicators in water quality assessments because of their diversity and life-history characteristics (He et al., 2015; Tampo et al., 2021). However, to date, hydrobiological research on reservoirs and streams affected by coal acid mine drainage in North Macedonia have never been undertaken. Therefore, the aim of this study is to analyze ecological impacts of coal mining and photovoltaic power plant operations on the macroinvertebrate community in Oslomej reservoir and Temnica river (North Macedonia).

MATERIALS AND METHODS

Study area

As a result of the mining activities of the coal mine "Oslomej" (near the town of Kicevo) in the past, depression was created for wet storage for mine tailings. Over surface waters were additionally filling up the depression and the Oslomej reservoir was created about 10-15 years ago (Figures 1; 2a). The reservoir has an area of over 30.000 m^2 and has a maximum depth of 15 m.

Figure 1. Map of the location of Oslomej reservoir, Temnica river and PV Oslomej 3.

Temnica river is located nearby the Oslomej reservoir (Figures 1; 2b). The mining activities in deforested mining area also contributed to soil contamination and erodibility and consequently to reservoir and river silting. Also, there are discharges to the reservoir from the Oslomej coal mine area located on the north of the location. In more recent time, both ecosystems additionally suffered from high sedimentation due to construction activities of the nearby photovoltaic power plant (PV) Oslomej 3 – South (Figure 1). On the southern side, the PV location borders with the Oslomej reservoir, while on the west side runs Temnica river and the west coal mining and ash dumpsite. There are the discharges of rainwater to Oslomej reservoir and Temnica river from PV Oslomej 3 – South (Figure 2c).

Macroinvertebrates sampling and analyses

Macroinvertebrates sampling was conducted on 20th of July 2024 on 6 selected sampling sites on the Oslomej reservoir and 2 sampling sites on Temnica river. More detailed information on the sampling sites is given in Table 1.

Table 1. List of visited sampling sites on Oslomej reservoir and Temnica river.

Code of sampling site	Locality	Habitat	GPS	Date	Comment
T1	Oslomej reservoir (next to the reservoir shore)	reservoir	41.552054,21.011439	20.07.2024	right side of the reservoir
T2	Oslomej reservoir (middle of the reservoir)	reservoir	41.552016,21.009785	20.07.2024	right side of the reservoir
T3	Oslomej reservoir (near the reservoir shore)	reservoir	41.550371,21.009520	20.07.2024	right side of the reservoir
T4	Oslomej reservoir (middle of the reservoir)	reservoir	41.551094,21.004717	20.07.2024	left side of the reservoir
T5	Oslomej reservoir (near the reservoir shore)	reservoir	41.552655,21.003144	20.07.2024	left side of the reservoir
T6	Oslomej (near the reservoir shore, at the confluence of the streams)	reservoir	41.554081,21.012043	20.07.2024	/
T7	River Temnica (near the PV)	river	41.559157,21.002187	20.07.2024	/
T8	River Temnica (approximately 500 m below sampling site T7, right after the PV)	river	41.559778,21.002343	20.07.2024	/

Macroinvertebrate samples from Oslomej reservoir were obtained using Ekman grab, suitable method designed for collecting sediment samples from lake bottom (Figure 3 a). Additionally, Kick sampling method was also apllied in order to disturb the submerged aquatic vegetation and encourage organisms to fall in the 500 µm mesh net (Figure 3 b). The macroinvertebrate samples from river Temnica (Figure 3 c) were collected from different microhabitats (aquatic vegetation, stones and other hard substrates) using Kick sampling method (EN ISO 10870: 2012).

a) b) c)

Figure 2. a) Oslomej reservoir; b) Temnica river; c) discharges of rainwater to Temnica river from PV Oslomej 3 – South

All biological material collected during the fieldtrip was preserved in plastic sample containers using 96% ethanol and transferred to the Laboratory of Invertebrates in the Institute of Biology at the Faculty of Natural Sciences and Mathematics in Skopje. Further processing of the material included sorting of macroinvertebrates into groups for additional identification, preserving, preparation of microscope slides (for aquatic worms Oligochaeta), as well as, adequate handling, labelling, and documentation of the sorted material.

Macroinvertebrates prepared for taxonomic identification were identified using Nikon SMZ750 stereomicroscope following appropriate taxonomic to the lowest possible taxonomic level (mostly species level). After identification, list of detected taxa was produced and the species richness was determined as number of taxa at the sampling localities (Table 2).

The valorization of aquatic macroinvertebrate diversity was done according the national and international conventions and legislatives for protection of endangered species on European and global level. Additionally, all of the taxa went under detailed biodiversity assessment in order to ensure if any present species can be considered to trigger PBF and CH criteria according to the EBRD Performance Requirement 6: Biodiversity conservation and sustainable management of living natural resources (Guidance note, 2023).

a) b) c)

Figure 2. Field work: a) Ekman grab; b) and c) Kick sampling method.

RESULTS AND DISCUSSION

The laboratory analyses of the samples obtained during the field trip in July 2024 on Lake Oslomej and River Temnica showed presence of total number of 19 aquatic invertebrate taxa (Table 2).

The aquatic invertebrate fauna at the bottom of Oslomej reservoir includes 10 taxa, more precisely 1 aquatic snail (Gastropoda), one aquatic worm (Clitellata), two crustaceans (Malacostraca), 4 taxa of true flies (Diptera), one species of mayflies (Ephemeroptera) and one damselfly (Odonata) (Table 2). The macroinvertebrate community in the shallower part of the Oslomej reservoir, near the reservoir shore (T1, T3, T5, T6) was characterised with significantly low abundance of aquatic invertebrates presented with scarce populations of aquatic mollusks (*Peregriana peregra*), aquatic worms (*Limnodrilus hoffmeisteri*), crustaceans (*Gammarus balcanicus* and *Astacus astacus*), chironomids (*Orthocladius thienemanni*, *Tanypus punctipennis*, *Cladotanytarsus mancus* and *Chironomus plumosus*), mayflies (*Cloeon dipterum*) and damselflies (*Lestes virens*) (Table 2, Figure 4). The community was even more reduced in the deeper part of the reservoir (middle of the reservoir), as only one specimen of the tolerant *L. hoffmeisteri*, *C. mancus* and *C. plumosus* were recorded at the sampling locality T2 (Table 2, Figure 3). These taxa are well know as highly tolerant of organic pollution, registered in other reservoir in N. Macedonia (Slavevska-Stamenković et al., 2012). Moreover, no macroinvertebrate taxa were registered on the sampling locality T4 (Table 2, Figure 4).

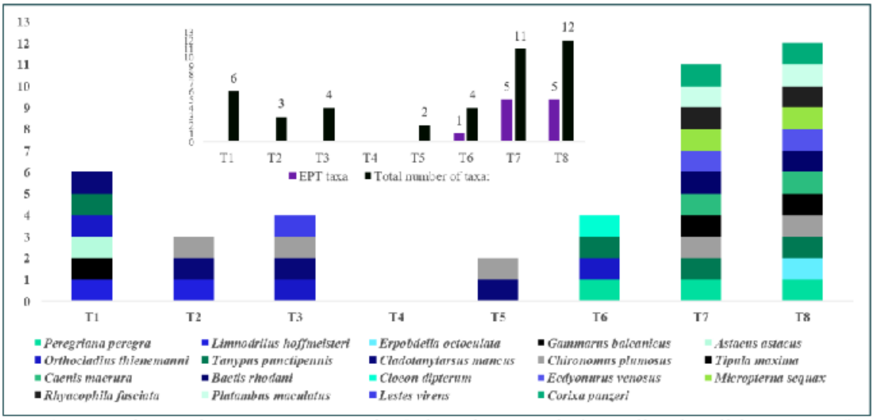

Figure 4. Macroinvertebrate taxa present in Oslomej reservoir (sampling localities T1 – T6) and Temnica river (sampling localities T7 – T8).

The presence of tolerant taxa of aquatic invertebrate species recorded in the Oslomej reservoir during the summer aspect of the study is certainly dictated by the organic loading. However, the fact that all detected taxa were noted in scarce populations or even completely absent in the deeper part of the lake, indicates that Oslomej reservoit underlies several stressors. Macroinvertebrate communities are devastated in severely impacted reservoirs and streams by AMD; either only a few individuals remain or macroinvertebrates are completely absent (He et al., 2015). Probably, the present ecosystem condition as well as the low values of diversity and density of macroinvertebrates are a consequence of the Oslomej reservoir origin and the impacts of its surrounding. As a result of the mining activities in the past, depression was created for dry storage for mine tailings at first, and for wet storage later. Namely, the waste water generated from the operation of the coal mine Oslomej was discharged in the created depression. In coal mining areas, the most common mineral is iron pyrite (FeS2) (Zipper & Skousen, 2014).). When the pyrite (iron sulphide) is exposed to air reacts with oxygen and water and forms sulphuric acid (H2SO4) and dissolved iron – iron(II) sulphate (ferrous state). Soluble iron, or iron(II) sulphate is then subsequently oxidised to form insoluble iron of iron(III) sulphate (Fe2(SO4)3 – ferric state. As the acidic water flows away from the mine, the pH changes and cause iron and other heavy metals to precipitate out of solution. The change in pH also causes the soluble iron(II) sulphate to form insoluble ferric iron or iron(III)hydroxide which is red, orange, or yellow colloid that percipitates and covers the bottom of reservoirs and streams (Neculita et al., 2007; Chikanda et al., 2021). The orange colour of the sediment extracted especially from the deeper parts of Oslomej resevoir serves as present-day evidence that these processes occurred in the past. Over the time, surface water was additionally filling up the depression and the reservoir Oslomej reservoir was created.

Since the reservoir was created in a previously defforestated mining area the mining activities in the past also contributed to soil contamination and erodibility and consequently to reservoir silting. In more recent time, the reservoir probably suffered from high sedimentation due to construction activities of the nearby PV Oslomej 3 and lack of erosion control works in operational phase especially at the parts of defforestated lake shore. Sediment and water also enter the reservior through the outlets from the rain water collecting ducts. However, bearing in mind that nowadays the coal mine Oslomej is inactive and there is no acid mine drainage, it is expected that erosion control works will reduce the transport of solids in Oslomej reservoir, gradually improve water quality and obtain more suitable conditions for collonisation of more macroinvertebrate species. The aquatic vegetation developed in the reservoir poses a significant part in the improvement of the water quality due to its physiological ability to accumulate metals from soil and water (phytomelioration). This was previously proven in numerous research studies (Mishra & Shukla, 2016; Ali et al., 2020; Tyndyk et al., 2024) where aquatic plants were used in the treatment process for reducing or limiting wastewater pollution.

Significant result of the field research conducted during the summer period within this study presents the notation of the noble crayfish *Astacus astacus*. This species is found in rivers, lakes, ponds, and reservoirs, in both lowlands and hills, where shelter availability is high (Souty-Grosset et al. 2006; Kalayda & Bogatyrev, 2019). This includes stones, logs, roots and aquatic and marginal vegetation. This species prefers soft bottoms with some sand and is not usually found in water bodies with a muddy substrate. In streams and lakes, the noble crayfish is keystone species of the freshwater ecosystem due to its habitat-modifying behaviour, substantial size, omnivorous feeding and often high abundance (Lovrenčić et al., 2022). Its feeding plasticity is especially evident in populations from different habitats, which adapted their feeding strategy to local resources. The noble crayfish can tolerate polluted environments more than the stone crayfish (*Austropotamobius torrentium*) and bioaccumulate pollutants in water especially heavy metals in their tissues (Kouba et al., 2010). In general, for all crayfish species, the concentration of metals in the environment is not sufficient to be a direct cause of death. Furthermore, crayfish are considered to be highly resistant to environmental metal contamination (Simon, 2000), which make them suitable as bioindicators of heavy metals in the environment (Kouba et al., 2010).

Concerning the survey on Oslomej reservoir, only two male specimens of the species were collected. Since the population seems to be much bigger according to the local fishermen, additional investigations on the population size, mortality, sex ratio and presence of juvenile specimens, as well as way of introduction of the noble crayfish in Oslomej reservoir are nessecary as soon as possible.

Table 2. List of taxa noted during the field survey on Oslomej reservoir and Temnica river.

	Oslomej reservoir						River Temnica	
Taxa	T1	T2	T3	T4	T5	T6	T7	T8
Mollusca								
Gatropoda								
Peregriana peregra **(O.F.Müller, 1774)**						+	+	+
Annelida								
Clitellata								
Tubificida								
Limnodrilus hoffmeisteri **Claparède, 1862**	+	+						
Arhynchobdellida								
Erpobdella octoculata **(Linnaeus, 1758)**								+
Arthropoda								
Malacostraca								
Amphipoda								
Gammarus balcanicus **Schäferna, 1923**	+							
Decapoda								
Astacus astacus **(Linnaeus, 1758)**	+							
Insecta								
Diptera								
Chironomidae								
Orthocladius thienemanni **Kieffer & Thienemann, 1906**	+		+			+		
Tanypus punctipennis **Meigen, 1818**	+					+	+	+
Cladotanytarsus mancus **(Walker 1856)**	+	+	+		+			
Chironomus plumosus **Linnaeus, 1758**		+	+		+		+	+
Tipulidae								
Tipula maxima **Poda, 1761**							+	+
Ephemeroptera								
Caenidae								
Caenis macrura **Stephens, 1835**							+	+
Baetidae								
Baetis rhodani **(Pictet, 1843)**							+	+
Cloeon dipterum **(Linnaeus, 1761)**						+		
Heptageniidae								
Ecdyonurus venosus **(Fabricius, 1775)**							+	+
Trichoptera								
Micropterna sequax **McLachlan, 1875**							+	+
Rhyacophila fasciata **Hagen, 1859**							+	+
Coleoptera								
Platambus maculatus **(Linnaeus, 1758)**							+	+
Odonata								
Lestes virens **(Charpentier, 1825)**			+					
Hemiptera								
Corixa panzeri **Fieber, 1848**							+	+
Total number of taxa:	6	3	4	/	2	4	11	12

Concerning Temnica river near the photovoltaic plant (T7) and right after the photovoltaic plant (T8), the results showed that the aquatic invertebrate community is characterised by moderate diversity (11 and 12 taxa) presented with aquatic mollusks (Mollusca), annelids (Annelida) and aquatic insects (Insecta) such as mayflies (Ephemeroptera), caddisflies (Trichoptera), dragonflies (Odonata), aquatic bugs (Hemiptera), beetles (Coleoptera) and true flies (Diptera) (Table 2, Figure 4). It should be pointed out that the macroinvertebrate community structure on the two sampling sites on Temnica river is almost the same (Table 2, Figure 4) and indicative to increased level of ecosystem stress. Namely, on the both sampling sites only limited number of EPT taxa (5) and tolerant Chironomini (Chironomidae) were registered, accompanied by the absence of sensitive stonefly (Plecoptera). According to Slavevska-Stamenković et al. (2011) stoneflies, as the most sensitive group, immediately disappear under disturbance, while mayflies and caddis flies vanish in conditions of higher pollution stress. Additionaly, the populations of all detected taxa were noted in low density, meaning that water quality alteration is not caused only by organic loading,since the organic pollution is known to initiate presence of tolerant taxa, but not demolish species populations. Its obvious that Temnica river in the studied river sector suffers habitat degradation and puts up with different pollutants not only organic, probably introduced through the soil and sediment that entered the river during the construction of the PV Oslomej 3 on the defforestated mining area, and/or during operation phase of the plant through the outlets from the rain water collecting ducts without precipitator. It is not excluded that previous acid mine drainage from the coal mine Oslomej contributed for the low macroinvertebrate diversity and density in river Temnica. Many studies have documented the negative effects of acid mine drainage on species richness and abundance of benthic macroinvertebrates (e.g. He et al., 2015; Steyn et al., 2019). According He et al. (2015), the reduction in diversity and abundance of macroinvertebrates by acid mine drainage (AMD) is well established and commonly used as ecological indicators.

Although local fishermen provided us with information that river Temnica is the place from where the noble crayfish (*Astacus astacus*) dispersed into Oslomej reservoir, no specimens were noted during the conducted fieldwork in July 2024. Therefore, more comprehensive investigations on longer river stretch are necessary as soon as possible to confirm wether this species became extinct in the river. If so, urgent measures for its reintroduction accompanied by erosion control works and cleaning of the river bed and river shore are obligatory.

The macroinvertebrate valorisation was completed in accordance with the EU Habitats Directive (Directive 92/43/EEC) and Bern Convention for the Protection of European Wildlife and Natural Habitats (1979). The National Lists of strictly protected (I) and protected (II) wild species in the Republic of Macedonia (Official Gazette of the Republic of Macedonia, No. 139/2011) were also checked for possible presence of some of the species registered within the project area. Identification of species of conservation importance was made according to the criteria of the Global and European Red Lists of IUCN. Finally, the distribution range of all taxa identified during this project was investigated in order to identify protentional endemic species (Table 3).

Table 3. Aquatic macroinvertebrate species of conservation importance registered within the Project area.

Species	IUCN European Red List	IUCN Global Red List	Mediterranean Red List of dragonflies and damselflies	National Lists of Strictly Protected and Protected Wild Species	Bern Convention	Habitats Directive	Endemism
Astacus astacus (Linnaeus, 1758)	/	VU	/	II	III	V	/
Lestes virens (Charpentier, 1825)	LC	LC	LC	/	/	/	/

Out of all aquatic invertebrate taxa noted in Oslomej reservoir and Temnica river during this research, as well as during other studies related to the project area, two species collected from Oslomej reservoir were shown to be important for conservation (Table 3). The damselfly *Lestes virens* is is known to have stable populations across Europe as well as all around the globe, thus the European Red List of Dragonflies (Kalkman et al., 2010) and the Global IUCN Red List of Threatened Species lists them as Least Concern (LC). On the other hand, the IUCN Red List of Threatened Species classifies the noble crayfish *Astacus astacus* as a vulnerable species (VU) with a decreasing population trend (Edsman et al., 2010). It is further included in the Bern Convention (Appendix III) and listed in the EU Habitat Directive 92/43/EEC (Appendix V), and presents protected wild species in the country (Official Gazette of the Republic of Macedonia, No. 139/2011).
However, its status Vulnerable (VU) on the IUCN Red List of Threatened species (Edsman *et al.,* 2010), triggers the PBF – criteria ii elevating the biological value of the Oslomej reservoir which qualifies as Priority biodiversity feature. Considering the significance of Oslomej reservoir for its visual landscape values and recreation and tourism and additionally as home for the noble crayfish, it is essential to undertake long-term monitoring on its population size, mortality, sex ratio and presence of juvenile specimens, as well as way of introduction of the noble crayfish in Oslomej reservoir as soon as possible. It is obligatory to undertake particular erosion control activities and measures in the watershed, not only to reduce the amount of sediment entering the reservoir but also to prevent chemical and mechanical pollution that affects water quality nessecary for ensuring successful functioning of the reservoir and support aquatic life over long term.
The proposed further investigation will resolve whether Temnica river also qualifies as Priority biodiversity feature.

CONCLUSION

In conclusion, the findings highlight the urgent need for erosion control and long-term ecological monitoring in the Oslomej reservoir and Temnica river watershed. Past mining activities and ongoing construction have significantly degraded the aquatic environment, leading to sedimentation, chemical pollution, and reduced biodiversity. Despite these pressures, the presence of aquatic vegetation and the noble crayfish *Astacus astacus* in Oslomej reservoir offer a glimpse of ecological resilience and underscore the reservoir's potential as a Priority Biodiversity Feature. To protect and enhance this value, it is essential to implement targeted restoration measures, control sediment and pollutant inputs, and conduct further studies to support aquatic life and preserve ecosystem functions over time.

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