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Seasonal fish diversity, distribution, and their relation to physicochemical parameters: A case study of the Lepenc River basin, Kosovo

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ABSTRACT

This study presents the findings from three seasonal field surveys conducted in the Lepenc River and its tributaries during 2023. The surveys were carried out on May, July, and October, focusing on six sampling sites: Prevallë, Lepenc (Kaçanik), Hani i Elezit, Jezerc, Gerlicë, and Nerodime (Kaçanik). Standardized electrofishing technique was applied, in accordance with the methods used by the European Union Water Framework Directive (EU WFD) monitoring protocols, which have been implemented in many Balkan regions. A total of 790 fish specimens were caught, identified, measured, and subsequently released back into their natural habitats.The species found during this investigation were: *Salmo* sp., *Barbus balcanicus*, *Squalius varedaresnisi*, *Alburnoides thessalicus*, *Alburnus thessalicus*, *Gobio balcanicus*, *Phoxinus* sp., and *Oxynoemacheilus bureschi*. The sampling site in Gerlicë consistently showed no presence of fish, likely due to pollution. The findings provide a comprehensive overview of fish community composition and their seasonal variations, highlighting the influence of physicochemical parameters on aquatic biodiversity. The results emphasize the urgent need for conservation measures to address habitat degradation and pollution, ensuring the preservation and restoration of biodiversity in the Lepenc River Basin.

Keywords: diversity, seasonal variation, electrofishing, water pollution, biodiversity conservation.

INTRODUCTION

Freshwater ecosystems are vital for biodiversity conservation, particularly within river systems. However, these ecosystems face significant challenges due to human activities, including pollution and habitat alteration. Monitoring fish diversity and distribution in the basin can provide insights into the river's ecological health and inform conservation strategies.

Kosovo is no exception to this global problem, and as a result of anthropogenic pressure on many river ecosystems, monitoring and conserving biodiversity in aquatic ecosystems across the country has faced significant challenges in recent years (Gashi et al., 2016; Grapci-Kotori et al., 2010, 2019, 2020; Ibrahimi et al., 2019a; Zogaris et al., 2024).

Lepenc River basin in southern Kosovo, is currently facing a strong pressure from many anthropogenic factors that require serious measures to be taken to conserve and protect aquatic habitats and species inhabiting this basin. Considering that the Lepenc River flows through two countries (Kosovo and R. North Macedonia), it is more than clear that conservation efforts on the river require a joint approach that transcends national borders, focusing on ensuring the interconnectedness of aquatic habitats as well as the shared responsibility of both countries to protect their natural heritage.

Initial studies on freshwater biodiversity, particularly focusing on the aquatic fauna of the Lepenc River basin, that belong to Kosovo, indicate that this region is a critical biodiversity hotspot, home to several range-restricted and endemic species (Bilalli et al., 2018, 2020, 2024; Bytyqi et al., 2019; Gashi et al., 2015; Ibrahimi and Vehapi, 2017; Ibrahimi and Sejdiu, 2018; Ibrahimi et al., 2012, 2014, 2016a, b, 2019b, 2023; Musliu et al., 2020; Valladolid et al., 2021, 2022; Xerxa et al., 2019).

Knowing that monitoring fish diversity in the basin can provide insights into the river's ecological health, the aim of this study was to obtain initial knowledge about seasonal diversity and distribution of fish species in the Lepenc River and its tributaries (from Kosovo part), as well as to identify key environmental factors that affect fish communities. This knowledge is of exceptional importance and supports efforts to conserve and restore aquatic biodiversity in the basin.

MATERIAL AND METHODS

Study area

The Lepenc River is a transboundary river that flows through two countries, Kosovo and the Republic of North Macedonia, before joining the Vardar River in the Aegean Sea basin. It originates on the northern slopes of the Sharr Mountains, specifically at Oshlak, at an altitude of 2,212 meters. Within Kosovo's territory, the Lepenc spans 53 kilometers, encompassing the river's upper and middle parts, with a basin area of 607 square kilometers and an average annual flow of 7.9 cubic meters per second (KEPA, 2022). Upon crossing the border into the Republic of North Macedonia, the river continues for its remaining 15 kilometers, flowing through the lower part of the Lepenc. In this segment, it traverses the low Skopje valley, which forms part of the composite valley of the Vardar River. Along its Macedonian course, it receives several small streams from the Skopska Crna Gora (Karadak) mountain, passes near the ruins of the ancient city of Scupi, and flows through the northern suburbs of Skopje (Bardovci and Novo Selo). It ultimately empties into the Vardar River at Skopje's northern borough of Ǵorče Petrov, at an altitude of 262 meters. The Lepenc River basin spans a total drainage area of 770 km^2, with 695 km^2 in Kosovo and 75 km^2 in North Macedonia. This division underscores its significance as a shared water resource for both countries.

Surveys were conducted at six sites in the Lepenc River basin (Table 1). These sites were selected based on their varying altitudes, habitat types, and environmental conditions. Field surveys took place on three occasions: May, July, and October 2023.

L1 Prevallë is situated in the upper course of the Lepenc River. It is important to note that during the autumn survey, the water flow was very low, primarily due to water intake for the hydropower plant's operations, as well as water extraction, waste, and the impacts of tourism. Additionally, upstream of this stretch lies the tourist village of Prevallë, where numerous restaurants operate, further influencing this section of the river.

L2 Lepenc-Kaçanik is located within the urban area of Kaçanik city, where the river is significantly influenced by various anthropogenic

Table 1. Sampling stations in the Lepenc River, Kosovo

No	Coordinates	Location	River	River typology	Type of area
L1	42.21367555 20.92555232	Prevallë	Lepenc	Type – 2	Pristine area
L2	42.22594476 21.2569743	Lepenc-Kaçanik	Lepenc	Type – 5	Urban area
L3	42.141447 21.297305	Hani i Elezit (border with N. Macedonia)	Lepenc	Type – 5	Urban area
L4	42.36338425 21.05288741	Jezerc	Nerodime	Type – 2	Pristine area
L5	42.31149245 21.20416803	Gërlicë	Nerodime	Type – 6	Urban area – downstream
L6	42.236209 21.255655	Nerodime-Kaçanik	Nerodime	Type – 6	Urban area – upstream

activities. This section is affected by discharges of untreated wastewater, solid waste, and the activities of various economic operators in the area. The urban setting and lack of adequate waste management infrastructure contribute to the degradation of water quality and the overall ecological health of this part of the river.

L3 Hani i Elezit is situated in the urban area, near the border with North Macedonia. This section of the river is impacted by discharges of untreated wastewater, solid waste, and the activities of various economic operators. Additionally, this locality is significantly influenced by the operation of the cement factory located in Hani i Elezit. Emissions and runoff from the factory contribute further to the degradation of water quality and the ecological conditions of the river in this area.

L4 Jezerc is located in the pristine area, within the Nerodime River basin. This locality is characterized by its relatively untouched natural environment, with minimal direct human impact compared to urban areas. However, potential threats to this pristine area include illegal logging, agricultural runoff, and occasional waste dumping from nearby settlements.

L5 Gërlicë is located in the downstream section of the Nerodime River. This locality is heavily polluted, with water quality significantly affected by discharges of untreated wastewater, illegal solid waste dumping, and runoff from industrial and agricultural activities in the surrounding area.

L6 Nerodime-Kaçanik is located in the urban area along the Nerodime River. This locality is heavily polluted, with water quality negatively impacted by untreated wastewater discharges, solid waste disposal, and industrial runoff from nearby operations (Fig. 1).

Sampling techniques

Electrofishing

Standardized electrofishing technique was applied, in accordance with the methods used by the European Union Water Framework Directive (EU WFD) monitoring protocols. This approach ensured consistency in data collection while adhering to internationally recognized guidelines for ecological assessments. As a non-lethal and environmentally considerate technique, it facilitated the safe capture, identification, and release of fish, minimizing stress and physical harm to the specimens. This method also allowed for reliable population and diversity assessments, making it

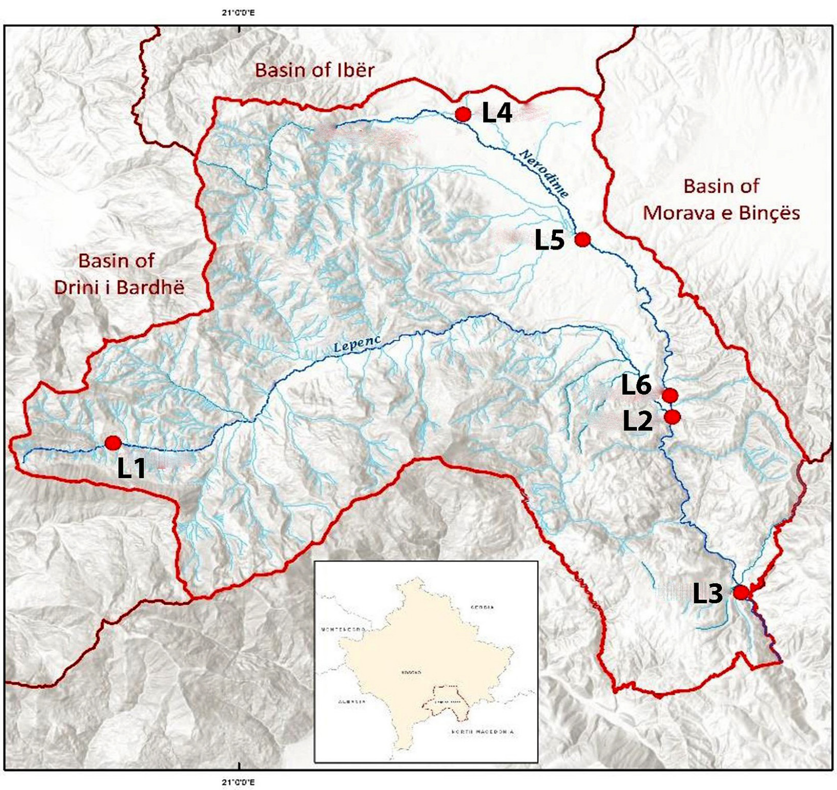

Figure 1. Details for the six selected sampling stations in the Lepenc River

an ideal tool for biodiversity monitoring and conservation studies in freshwater ecosystems. Fish were sampled using an electrofishing device (model SAMUS RICH P2000). Individuals were identified to the species level following the taxonomic nomenclature of Kottelat & Freyhof (2007). The caught fish, after taking the basic biometric analyzes and their quantification, were returned alive to the waters of the river, at the place from where they were caught (Fig. 2).

Physicochemical analysis and calculation of diversity and similarity indices

Physicochemical analysis

Physicochemical parameters of the water were measured directly in the field using portable equipment. Key parameters such as temperature, pH, dissolved oxygen, conductivity, turbidity, and nutrient concentrations (e.g., nitrates and phosphates) were monitored to assess water quality and the overall health of the aquatic ecosystem. These measurements were taken at various sampling sites and depths to capture spatial and temporal variations in water quality. The tools used included digital meters for pH, dissolved oxygen, and conductivity, and specialized kits for nutrient analysis.

Calculation of diversity and similarity indices

Biodiversity was assessed using diversity indices, which quantify species richness, evenness, and overall community diversity. To calculate these indices, species composition data collected during electrofishing and other sampling methods were processed using ComEcoPac software.

RESULTS

During this study, a total of 790 fish specimens were captured and identified eight fish species recorded in the basin (Table 2), belonging to three families: Salmonidae, Cyprinidae, and Nemacheilidae. Notably, *Squalius vardarensis*, *Alburnus thessalicus*, and *Gobio balcanicus* were recorded in all three sampling months (May, July, and October), indicating their adaptability and stable presence in the ecosystem. In contrast, other species were observed in different months, suggesting potential seasonal or habitat-specific preferences. Sampling site L2 stood out as the most diverse, hosting six species, while other sites like L1 and L4 showed lower diversity. Sites like L1 and L4 are situated in the upper reaches of the river, representing source areas with limited habitat heterogeneity and lower productivity, which naturally supports fewer species. In contrast, L2, located in the lowland courses of the river, is characterized by greater habitat diversity, more stable environmental conditions, and higher nutrient availability, which collectively promote higher species richness.

Physico-chimical analysis

During this research, conducted over three seasons (spring, summer, and autumn), physicochemical parameters of water quality were measured across six localities (L1–L6) (Table 3). The findings revealed significant spatial and seasonal variability:

- Water temperature ranged from 7.4 °C (L1 in spring) to 20.4 °C (L6 in summer).
- Turbidity levels varied between 1.84 NTU (L1 in autumn) and 107 NTU (L2 in spring).

Figure 2. Fieldwork activities in the Lepenc River Basin, Kosovo

Table 2. Seasonal fish diversity and distribution in the Lepenc River basin

Fish species	May	July	October	Sampling sites
Family Salmonidae				
Salmo sp.*	+	+		L1, L4
Family Cyprinidae				
Barbus balcanicus Kotlik, Tsigenopoulos, Rab & Berrebi, 2002		+	+	L1, L2, L3, L4, L6
Squalius vardarensis Karaman, 1928	+	+	+	L2, L3, L6
Alburnoides thessalicus Stephanidis 1950		+	+	L2, L3
Alburnus thessalicus Stephanidis, 1950	+	+	+	L2, L3
Gobio balcanicus Dimovski & Grupche, 1977	+	+	+	L3
Phoxinus sp.**	+		+	L2
Family Nemacheilidae				
Oxynoemacheilus bureschi Drensky, 1928		+	+	L2

Note: *According Kottelat & Freyhof (2007), *Salmo macedonicus* is present in the waters of the Vardar River basin, to which Lepenec belongs. However, taking into account the fact that in the past, several watercourses in Kosovo, including Lepenec, were repeatedly stocked with trout of unknown origin, at this moment remains unclear which trout species inhabits in the researched area (Locality L1 and L4). **According to Kottelat & Freyhof (2007), the western Balkan Peninsula is populated by two species *Phoxinus phoxinus* in the Danubian part and *Phoxinus lumaireul* in the Adriatic part of the peninsula. As Bogutskaya et al. (2012), hinting at an even higher level of diversity of *Phoxinus* in the Balkans, in this study we named the channel minnow as *Phoxinus* sp.

- Conductivity values ranged from 62 µS/cm (L1 in summer) to 680 µS/cm (L6 in both summer and autumn).
- pH levels were recorded between 7.3 (L1 and L5 in spring) and 8.1 (L2 in spring).
- Dissolved oxygen concentrations ranged from 2.5 mg/L (L5 in autumn) to 8.7 mg/L (L3 in summer).
- Total suspended solids (TSS) ranged from <0.1 mg/L (L1 in autumn) to 146 mg/L (L5 in spring).
- Biochemical oxygen demand (BOD) was lowest at <0.2 mg/L (L1 in autumn) and highest at 86.5 mg/L (L5 in spring).
- Nitrate levels ranged from <0.5 mg/L (L4 in all seasons) to 14.4 mg/L (L3 in autumn).
- Ammonium concentrations varied between 0.012 mg/L (L1 in spring) and 13.8 mg/L (L6 in summer).
- Total nitrogen ranged from 0.12 mg/L (L1 in spring) to 13.4 mg/L (L6 in summer).
- Phosphate levels ranged from <0.2 mg/L (L1, L4, and L5 in spring) to 3.6 mg/L (L6 in summer).

These results underscore the dynamic nature of water quality parameters across different localities and seasons within the study area.

Calculation of diversity and similarity indices

The calculated diversity and similarity indices highlight notable variations in species richness, diversity, and composition across the Lepenc River sites. The highest species richness (7 species) and diversity (H' = 2.26) were observed at L2, while the lowest values for both metrics (2 species, H' = 0.66) were recorded at L6, indicating significant ecological differences. Simpson's and Hill's indices further support this trend, with L2 and L3 showing greater diversity and evenness compared to L6, which had higher dominance. Among richness indices, Margalef's index peaked at L2 (0.82), while the lowest value was at L1 (0.23). Similarity indices revealed the greatest compositional overlap between L1 and L4 (1), whereas sites like L1 and L2 (Ja=0.14; So and Sb=0.25) and L2 and L4 exhibited low similarity (Ja=0.14; So and Sb=0.25). These findings underscore the dynamic nature of the river's ecosystem, with L2 showing the healthiest diversity and L6 reflecting the most anthropogenic pressure (Table 4).

DISCUSSION

The findings from the Lepenc River Basin, from Kosovo, study reveal complex interactions between fish diversity, seasonal dynamics, habitat characteristics, and the physicochemical parameters of water. The study, which documented 790 fish specimens representing eight

Table 3. Physico-chemical parameters in the Lepenc River (V-May, VII-July, X-October)

Water quality parameters	Unit	L1			L2			L3			L4			L5			L6		
		V	VII	X	V	VII	X	V	VII	X	V	VII	X	V	VII	X	V	VII	X
Water temp.	°C	7.4	12.4	9.6	9.9	19.3	18.3	11.2	18.7	17.8	11.3	16.3	11.6	12.6	18.7	16.2	13.7	20.4	17.8
Smell	yes/no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
Color	yes/no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
Turbidity	NTU	12.2	1.93	1.84	107	5.31	3.82	78	5.42	6.17	19	52.3	5.16	37	10.8	15.6	61	10.6	13.2
Conductivity	μScm^{-1}	90	62	72	180	340	340	220	420	480	120	150	160	406	610	660	460	680	680
TDS	mg/L	45	31	36	90	170	170	110	210	240	60	75	80	203	305	330	230	340	340
pH value	0–14	7.3	7.65	7.49	8.1	7.9	7.96	7.9	7.89	7.96	7.7	7.75	7.9	7.3	7.91	7.8	7.8	7.52	7.86
Red ox	mV	-91	-67.6	-87.3	-91	39.7	-91.7	-80	49.4	-83.2	-68	-51.2	-83.6	-48	-31.4	-33.4	-64	-48.7	-52.2
Diss. O_2	mg/L	8.3	7.6	7.5	7.2	6.9	7.8	7.4	8.7	7.4	7.7	8	7.2	7.1	6.7	2.5	6.8	5.4	5.4
O_2 Sat.	%	78	87	79	71	72	82	72	90	78	75	88	78	69	69	26	64	61	58
Sediment	mL/L	< 0.1	<0.1	<0.1	0.4	0.2	<0.1	0.2	0.1	<0.1	< 0.1	<0.1	<0.1	0.4	0.1	0.2	0.2	<0.01	0.1
Total suspended solids - gravimetry	mg/l	1.8	2.3	<0.1	120	6	3.8	81	25	15	1.2	36	3.2	146	16	23	105	26	20
Chemical oxygen demand-Cr	mg/l	2.5	1.5	1.0	94	35	22	19	20	17	2.0	8.6	2.3	153	42	56	132	56	55
Biochemical demand O O_2	mg/l	1.1	0.6	<0.2	56	17.2	14	8.6	10.7	9.4	1.0	3.8	0.8	86.5	19.6	28.6	60.5	23.6	30.5
Total organic C	mg/l	0.6	<0.5	<0.5	33	7.5	5.9	5.3	6	6	0.6	5.8	0.7	57	13	21	43	16	22
Nitrate	mg/l	0.1	0.5	0.6	2.1	3.5	3.9	10.1	10.5	14.4	< 0.5	< 0.5	< 0.5	1.8	2.7	2.4	1.9	2.3	3.9
Detergents	mg/l	< 0.1	<0.5	<0.5	< 0.1	<0.5	<0.5	< 0.1	0.5	0.7	< 0.1	<0.5	<0.5	< 0.1	0.7	2.7	< 0.1	1.1	2
Phosphate	mg/l	< 0.2	< 0.2	< 0.2	0.6	0.3	0.4	0.7	0.9	0.9	< 0.2	1.4	0.2	1	1.7	1.9	0.7	3.6	3
Total P	mg/l	0.13	0.11	0.09	1.61	2.07	1.68	0.68	0.87	0.77	0.34	0.97	0.128	2.69	1.73	2.18	3.47	2.74	2.51
Ammonium	mg/l	0.012	0.061	0.07	0.3	0.48	0.14	0.47	0.65	0.57	0.06	0.06	0.08	2.05	6.58	8.7	1.2	13.8	13
Nitrite	mg/l	0.011	0.027	0.015	0.17	0.22	0.22	0.25	0.86	0.79	0.09	0.11	0.12	0.51	0.65	1	0.28	1.19	1.34
Sulphate	mg/l	5	4	6	16	18	26	22	23	27	7	20	14	25	30	39	23	31	38
Total nitrogen	mg/l	0.12	0.22	0.23	3.4	2.38	1.78	4.39	3.80	4.50	0.25	0.86	0.28	7.21	7.31	9.46	5.80	13.4	13.00
Chloride	mg/l	6.41	11.63	6.0	8.14	15.20	10.72	11.26	21.43	23.59	4.05	6.5	5.8	22.7	36.38	43.03	20.7	50.0	43.5

species across three families, provides for the first time significant insights into fish diversity and their distribution in this river ecosystem from Kosovo.

Key findings on fish species and seasonal dynamics

Species such as *Squalius vardarensis*, *Alburnus thessalicus*, and *Gobio balcanicus* were consistently present across all sampling months (May, July, and October), suggesting their adaptability and resilience within the ecosystem. These traits likely result from physiological adaptations that enhance survival under varying environmental conditions, as noted by Claireaux et al. (2005) in their study on fishes' cardiac performance and swimming abilities. Seasonal variations also play a pivotal role in shaping fish distributions, as species respond to fluctuations in temperature and habitat conditions (Shen, 2023). Warmer water temperatures during spring and summer stimulate feeding and reproductive activities, which contribute to increased diversity during these seasons. In contrast, the absence of certain species in specific months may indicate seasonal or habitat-specific preferences, consistent with findings by Nahid (2024).

Habitat characteristics and diversity across sites

The variation in species richness and diversity across sampling sites underscores the importance of habitat-specific factors. For instance, site L2 recorded the highest species richness (7 species), abundance (442 individuals),

Table 4. Species richness, species diversity and matrices of similarity between sample

	L1	L2	L3	L4	L6
S	2	6	5	2	2
N	73	442	171	52	52
S_E	2	4	3	2	2
S_D	0	1	1	0	0
S_Sd	0	0	1	0	0
S_R	0	1	0	0	0
S_Sr	0	0	0	0	0
N_E	73	410	157	52	52
H’	0.78	2.26	1.80	1.00	0.66
D	0.64	0.22	0.35	0.50	0.71
N2	1.56	4.46	2.89	2.00	1.40
D_{Ma}	0.23	0.82	0.78	0.25	0.25
D_{Me}	0.23	0.29	0.38	0.28	0.28

Ja	L2	L3	L4	L6
L1	0.14	0.17	1.00	0.33
L2		0.57	0.14	0.33
L3			0.17	0.40
L4				0.33
So	L2	L3	L4	L6
L1	0.25	0.29	1.00	0.50
L2		0.73	0.25	0.50
L3			0.29	0.57
L4				0.50
Sb	L2	L3	L4	L6
L1	0.25	0.33	1.00	0.62
L2		0.67	0.25	0.50
L3			0.33	0.60
L4				0.62

Note: S - number of species (species richness); SE, SD, SSd, SR, SSr - number of eudominant, dominant, subdominant, recedent, subrecedent species (Tischler’s scale); NE - abundance for eudominant; H’ - Shannon-Wiener diversity index; D - Simpson’s index; N2 - Hill’s index (inverted Simpson’s index); DMa - Margalef index; DMe - Menhinick index; Ja - Jaccard’s similarity index; So - Sörensen’s similarity index; Sb - Baroni-Urbani & Buser index; *L5 **-** no fish data recorded (fish absent, likely due to pollution).

and diversity indices (H’ = 2.26), reflecting favorable environmental conditions. In contrast, L6 showed significantly lower species richness (2 species) and diversity (H’ = 0.66), suggesting ecological stress or habitat limitations. Notably, L1 is heavily influenced by upstream hydropower plants, which disrupt ecological conditions (Ibrahimi et al., 2024). The findings also align with studies highlighting the influence of habitat diversity on fish populations. For example, Mueller et al. (2011) and Huang et al. (2019) demonstrated how anthropogenic modifications, such as dam and habitat homogenization, can reduce species richness and community diversity. In the Lepenc River, sites L5 and L6 exhibited higher pollution indicators (elevated nutrients, COD, BOD, and chloride levels), pointing to significant anthropogenic impacts. These conditions likely explain the absence of fish at L5, as poor water quality and oxygen depletion are detrimental to aquatic life (Grapci et al., 2019, 2020; Zogaris et al., 2024). Similarly, site L4 experienced increased pollution during summer, potentially due to reduced flow or heightened external inputs, which further stress fish populations. In contrast, site L1 demonstrated better water quality, with lower turbidity, nutrient concentrations, and organic pollution levels, serving as a benchmark for upstream conditions.

Seasonal and anthropogenic impacts on physicochemical parameters

The physicochemical data reveal the dynamic interplay of seasonal and anthropogenic factors influencing water quality. Seasonal fluctuations in temperature, dissolved oxygen, turbidity, and nutrient concentrations significantly affect fish distribution, growth, and reproduction. Warmer water temperatures during summer, such as the 19.3 °C recorded at L2_Kacanik in July, promote higher metabolic rates and reproductive activity in fish (Shen, 2023). However, elevated turbidity and nutrient concentrations, particularly at L6 and L4, pose challenges to fish health and survival.

Implications for conservation and management

The calculated indices reveal significant differences in ecological conditions across the Lepenc River sites. Site L2, characterized by high species richness and diversity, serves as a model of ecological integrity. The species recorded at this site, based on their biological sensitivity and habitat preferences, are generally tolerant to a broader range of pollution conditions (Van Treeck et al., 2020). In contrast, sites such as L5 and L6 exhibit notable ecological stress, highlighting the need for targeted conservation measures. The challenges at these sites, primarily driven by discharges of untreated wastewater, illegal solid waste dumping, and runoff from industrial and agricultural activities in the surrounding area, underscore the urgency of addressing these site-specific stressors to restore and maintain the river's ecological balance (Ibrahimi et al., 2024).

To safeguard fish biodiversity and improve water quality in the Lepenc River, continuous monitoring and proactive management strategies are imperative. Priority actions should include:

- Pollution control – identifying and reducing pollution sources, particularly at sites with elevated nutrient and turbidity levels. It is essential to implement pollution control at all sampling sites, as each one is affected in different ways by anthropogenic activities. Specifically, sites like L2 (Lepenc-Kaçanik), L3 (Hani i Elezit), L5 (Gërlicë-Nerodime), and L6 (Nerodime-Kaçanik) are heavily influenced by untreated wastewater discharges, industrial waste, and agricultural runoff. These activities lead to increased nutrient levels and turbidity, which directly impact the river's ecological health. At the other sites, such as L1 (Prevallë) and L4 (Jezerc, Nerodime), while generally in better condition, there is still a need for monitoring and addressing potential localized pollution sources, such as waste disposal and runoff from surrounding areas. Addressing pollution at each of these sites is crucial to restoring and maintaining the river's ecological balance.
- Mitigating hydropower-plants impacts – implementing measures to minimize ecological disruptions caused by hydropower-plants, such as maintaining environmental flow regimes and improving fish passage structures.
- Habitat restoration – enhancing degraded habitats through reforestation of riparian zones, removal of barriers, and restoration of natural flow patterns. Habitat restoration efforts should be focused on several key sites within the study area. At L2 (Lepenc-Kaçanik), L3 (Hani i Elezit), L5 (Gërlicë-Nerodime), and L6 (Nerodime-Kaçanik), the degradation caused by pollution and human activities calls for the reforestation of riparian zones, removal of barriers, and restoration of natural flow patterns to improve water quality and ecological function. Even at L1 (Prevallë) and L4 (Jezerc, Nerodime), which have relatively better water quality, ongoing habitat restoration efforts are essential to prevent further degradation and enhance biodiversity. By addressing habitat degradation and promoting natural processes, these efforts can help restore and maintain the ecological balance of the Lepenc River system.

These integrated approaches will help preserve the river's aquatic life, ensure ecosystem resilience, and support long-term sustainability of the Lepenc River basin. This is particularly important in light of recent studies in Kosovo documenting degradation of freshwater habitats (Bilalli et al., 2022; Buçinca et al., 2024; Etemi et al., 2020; Ibrahimi et al., 2007, 2019c, 2021, 2025; Musliu et al., 2018; Schabetsberger et al., 2021).

CONCLUSIONS

The study of the Lepenc River Basin highlights significant anthropogenic pressure across its entire course, impacting fish populations. Reduced water flow in the upper reaches threatens the survival of barbel (*Barbus*) and trout (*Salmo*), while pollution in the middle reaches significantly reduces the presence of *Phoxinus* sp. To protect fish diversity and maintain ecological balance, targeted conservation efforts, pollution control, and habitat restoration are critical.

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