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THE IMPACT OF ANTHROPOGENIC ACTIVITIES ON THE STRUCTURE OF ICHTHYOFAUNA IN THE UPPER COURSE OF THE NERETVA RIVER

Samir Muhamedagić
University of Sarajevo - Faculty of Agriculture and Food Sciences
(s.muhamedagic@ppf.unsa.ba)

ABSTRACT
The Neretva River is one of the most important centers of freshwater fish endemism in Europe, supporting numerous autochthonous and endemic species adapted to cold, fast-flowing habitats. This study examines long-term changes in the ichthyofauna of the upper Neretva River by combining historical records with field data collected between 2011 and 2023, with particular emphasis on native and endemic populations and the impacts of non-native species. Historical data indicate that the upper Neretva was originally dominated by salmonid assemblages, while contemporary results show that headwater sections still retain near-natural, salmonid-dominated communities. In contrast, downstream transitional sections exhibit increasing contributions of allochthonous species and declining abundances of endemic taxa. The most pronounced changes were observed in hydroaccumulations, especially Jablanica Lake, where river impoundment caused a shift from lotic, salmonid-dominated assemblages to lentic communities dominated by non-native, eurythermal species.Overall, dam construction and flow regulation are identified as the main drivers of ichthyofaunal change, promoting biotic homogenization and increasing pressure on endemic species. Conservation efforts should prioritize the protection of remaining free-flowing river sections and the prevention of further species introductions.

Keywords: ichthyofauna; river regulation; endemic species; non-native fishes.

INTRODUCTION

Drainage from Bosnia and Herzegovina occurs toward two major basins, the Sava River (Black Sea basin) and the Adriatic Sea basin. The Adriatic basin largely coincides with the Dinaric karst and is characterized by a complex interaction between surface and subterranean hydrological networks. Within this system, the Neretva River is the largest and most water-rich river discharging into the Adriatic Sea on the Balkan Peninsula and a major contributor of freshwater to the Mediterranean Sea (Skoulikidis et al. 2009, Drešković and Đug 2010, Bijedić et al. 2012). The Neretva River represents one of the most important centers of freshwater fish endemism in Europe. Situated at the boundary between Mediterranean and continental biogeographical regions, the river has functioned as a long-term hydrologically stable and partially isolated system, promoting the diversification and persistence of numerous autochthonous and endemic fish species (Crivelli et al. 1997, Kottelat and Freyhof 2007, Glamuzina et al. 2013, Freyhof et al. 2014, Muhamedagić 2019). Its ichthyofauna is characterized by a high degree of ecological specialization and strong adaptation to hydromorphological conditions, with distinct assemblages along the upper, middle, and lower river courses reflecting gradients in altitude, temperature, flow velocity, and substrate (Crivelli 1995, Kottelat and Freyhof 2007, Rahel 2002). Cold, fast-flowing upper reaches support stenothermic and rheophilic species, whereas downstream sections host more diverse assemblages influenced by eurythermal, migratory, and marine-derived taxa (Crivelli et al., 1997, Rahel, 2007). This pronounced longitudinal zonation highlights both the exceptional biogeographical value of the Neretva River and the vulnerability of its endemic ichthyofauna to environmental change (Dudgeon et al. 2006, Freyhof et al. 2014). Globally, freshwater fish assemblages are increasingly threatened by habitat degradation, overexploitation, river regulation, pollution, species introductions, and illegal fishing (Freyhof and Brooks 2011, Muhamedagić 2019). Additional pressures such as urbanization, deforestation, and waste disposal further accelerate biodiversity loss in freshwater ecosystems (Cowx et al. 2002, Cowx and Gerdeaux 2004). In the Neretva basin, these pressures are intensified by extensive hydromorphological alteration, particularly dam construction and reservoir formation, which have profoundly modified large parts of the upper and middle river courses (Škrijelj 2002, Sofradžija et al. 2003). Such alterations transform lotic systems into (semi-)lentic environments and disrupt hydrological variability, sediment transport, and longitudinal connectivity, with cascading effects on physicochemical conditions and fish communities (Poff et al. 1997, Ward and Stanford 1995, Graf 2006, FAO 2013). These changes favor euryvalent and often non-native species, while displacing native rheophilic and endemic taxa, thereby promoting invasion success and biotic homogenization, particularly in river basins rich in endemic species (Rahel 2002, Gozlan 2008, Villéger et al. 2011, Keller et al. 2011, Vitule et al. 2009).

MATERIALS AND METHODS

The upper course of the Neretva River was historically defined as the river reach extending from its source to the confluence with the Rama River, about 110 km long. Following the construction of the Jablanica hydropower reservoir in 1955, this upper reach was substantially shortened. It currently extends for approximately 85 km. Considering the geomorphological and hydrological characteristics of the upper Neretva, and to facilitate a clearer interpretation of the present study, the upper course is conditionally divided into four sections: (1) the source region (2) the Župa region, (3) the Neretva canyon and the Konjic valley, and (4) the reservoir section represented by Jablanica lake. In its source section (approximately 45 km), the Neretva exhibits the characteristics of a fast-flowing mountain river, with a steep channel gradient of 15-18 ‰ and strong erosional capacity. Pronounced seasonal fluctuations in physicochemical parameters create highly selective ecological conditions, such that habitats are suitable only for the most resilient and well-adapted, highly specialized fish species. Downstream toward the Župa section, the Neretva gradually transitions into a submontane river type, a change clearly reflected in valley morphology and hydraulic conditions. Within the Župa section (approximately 20 km), the valley is no longer gorge-like but becomes wider and more open. The river exhibits a gentler gradient (around 5‰), a relatively moderate flow velocity, locally develops meanders, and forms sandy bars. The source region and the Župa section are naturally separated by the Treskavac waterfall, approximately 10 m high. This waterfall represents a natural barrier to upstream fish migration and has a pronounced influence on the structure of the ichthyofauna in these sections. The Župa section terminates at a narrow gorge through which the Neretva enters to the canyon (approximately 15 km in length). Within the canyon, the river channel narrows considerably and the Neretva again exhibits a steep gradient of about 16‰. Upon exiting the canyon, the river valley widens into the Konjic valley, with the town of Konjic as its central settlement, where the formation of the Jablanica hydropower reservoir begins.

Table 1. Fish sampling sites

Water body	Central point	Location	Geographical features		
Neretva river	Ulog	Mjedenik	43°19'29.1"	18°25'45.1"	785 m
		Tuhobić	43°22'44.4"	18°21'19.1"	695 m
		Ulog	43°24'59.3"	18°18'48.2"	648 m
		Nedavić	43°27'48.3"	18°19'52.3"	602 m
	Glavatičevo	Ocrkavlje	43°29'01.1"	18°16'25.1"	492 m
		Bijeli Potok	43°29'46.8"	18°06'48.5"	386 m
		Glavatičevo	43°30'11.9"	18°06'24.1"	355 m
		Bukovica	43°32'03.2"	18°04'14.1"	346 m
	Konjic	Džajići	43°36'36.3"	18°01'08.7"	298 m
		Konjic	43°38'47.8"	17°57'53.0"	275 m
Jablanica lake	Čelebići	Donje Selo	43°39'54.2"	17°56'31.1"	263 m
		Čelebići	43°41'33.4"	17°53'43.1"	263 m
		Buturović Polje	43°42'33.7"	17°49'36.6"	263 m

Fish sampling locations are presented in Table 1. The specimens used for morphological analyses were collected as part of the project „Analysis of the state of ichthyofauna in the fishing area in the territories of the municipalities of Kalinovik and Konjic, which territorially share the upper reaches of the Neretva River. Individuals were collected periodically, in 2011, 2012, 2018 and 2023. For catching fish in the Neretva River and its tributaries was used a "Honda" OHV 5.5 electrofishing unit with a power of 3.0 kW. Fishing nets with mesh diameters of 10, 20 and 50 mm were used to catch fish in Jablanica lake. After capture, fish were anesthetized using MS-222 (tricaine methanesulfonate) solution. Anesthetized fish samples were processed in the field and then returned to their native habitat. Morphometric measurements were obtained with an accuracy of 1 mm for body length and 1 g for body weight. Identification and determination of fish was performed according to Vuković (1977) and Kottelat and Freyhof (2007). A smaller number of samples were euthanized using a lethal dose of MS-222 and then fixed in 75% ethanol for laboratory analysis.

RESULTS AND DISSCUSION

Ichthyological investigations conducted during the period 2011-2023 reveal varying degrees of change in the structure of the ichthyofauna of the upper course of the Neretva River, as well as pronounced and often drastic alterations in fish population structure within Jablanica Lake. Notably, the area now occupied by the reservoir formerly belonged to the upper course of the Neretva River prior to dam construction.

Tabela 2. Composition of the ichthyofauna in the source region of the Neretva River

Fish species	Body weight (g)		Total length (cm)		Number of individuals
	max	min	max	min	
Brown trout	450.0	9.0	33.0	9.5	240
Eurasian minnow	16.5	3.0	10.5	2.0	85

Stone loach	9.5	8.0	11.0	10.5	15
European bullhead	8.0	4.0	10.5	8.0	20

The ichthyofauna of the source region of the Neretva River exhibits very low species diversity (Table 2) but a high degree of ecological congruence with local habitat conditions. The assemblage consists of three autochthonous species: brown trout (*Salmo trutta*), Eurasian minnow (*Phoxinus phoxinus*), European bullhead (*Cottus gobio*), and one allochthonous species, stone loach (*Barbatula barbatula*). Brown trout dominated the assemblage (66.7%), consistent with its ecological adaptations to cold, fast-flowing, and well-oxygenated waters. Eurasian minnow accounted for 23.6% of total abundance, occupying low-velocity microhabitats and contributing to trophic stability as an important prey species. Stone loach (4.2%) and European bullhead (5.6%) occurred at low abundances, reflecting limited benthic microhabitat availability but confirming high substrate quality and elevated dissolved oxygen concentrations.

Tabela 3. Composition of the ichthyofauna of the Neretva River in the parish region

Fish species	Body weight (g)		Total length (cm)		Number of individuals
	max	min	max	min	
Brown trout	795.0	11.5	44.0	8.0	240
Softmouth trout	1,096.0	45.5	37.0	14.5	40
Marble trout	810.0	13.0	37.5	7.5	3
Grayling	618.5	4.0	39.0	9.5	90
Chub	876.5	67.5	41.0	18.5	20
Eurasian minnow	4.5	2.5	9.0	7.5	50
Gudgeon	23.0	18.5	12.0	9.0	2
European bullhead	20.0	5.0	11.5	6.5	50

The Neretva River in the parish region exhibited a markedly more complex and diverse ichthyofaunal structure than the upstream, strictly mountainous reaches. A total of eight fish species were recorded (Table 3), with autochthonous and endemic taxa remaining dominant in terms of ecological importance, although allochthonous species constituted a substantial component of the assemblage. Brown trout accounted for the largest proportion of the assemblage (46.9%), confirming that this river section retains a predominantly salmonid character. The endemic softmouth trout (*Salmo obtusirostris*) represented 8.3% of the assemblage and occurred in relatively low numbers, indicating that the parish region forms an important part of the species distribution range while also highlighting its sensitivity to habitat alteration and interspecific competition. Marble trout (*Salmo marmoratus*) was recorded only sporadically (0.6%), underscoring both the conservation value of this river section and the fragmented nature of its population. Of particular importance was the relatively high contribution of grayling (*Thymallus thymallus*), an allochthonous species in the Neretva basin, which comprised 18.8% of total abundance. Chub - *Squalius cephalus* (4.2%) and Gudgeon - *Gobio gobio* (0.4%), also allochthonous, occurred at low abundances and reflect the submontane character of this river section and a gradual transition toward assemblages typical of downstream reaches.Among non-salmonid native species, Eurasian minnow and European bullhead each accounted for 10.4% of the assemblage, indicating high water quality, elevated dissolved oxygen concentrations, and well-preserved benthic microhabitats.

Tabela 4. Composition of the ichthyofauna of the Neretva River in the region of Konjic valley

Fish species	Body weight (g)		Total length (cm)		Number of individuals
	max	min	max	min	
Brown trout	1,380.0	73.0	45.0	18.5	130
Softmouth trout	306.0	153.0	30.0	24.0	10
Grayling	490.0	158.0	37.0	25.0	70
Sunbleak	27.0	14.0	16.5	13.5	50
Schneider	17.0	4.0	11.5	7.5	20
Neretva spined loach	13.5	9.0	15.0	11.5	4
European bullhead	34.0	10.0	13.5	9.0	30

Ichthyological surveys confirmed the presence of seven fish species (Table 4) in the main channel of the Neretva River within the Konjic valley. Brown trout accounted for the largest proportion of the assemblage (41.4%), confirming the dominant salmonid character of this river section. Softmouth trout represented 3.2% of total abundance, indicating the presence but relatively low contribution of the endemic salmonid component within the community structure. A substantial proportion of the assemblage consisted of allochthonous species, including grayling (22.3%), sunbleak (*Leucaspius delineatus*) - 15.9%, and schneider (*Alburnoides bipunctatus*) - 6.4%, reflecting pronounced anthropogenic influence through the introduction and maintenance of non-native populations. Among native accompanying species, European bullhead contributed 9.6% of total abundance, while the endemic Neretva spined loach (*Cobitis narentana*) accounted for only 1.3%, suggesting high sensitivity and limited habitat availability for this species.

The ichthyofauna of Jablanica lake (Table 5) represents a typical example of a strongly anthropogenically altered fish assemblage resulting from the impoundment of the Neretva River and the formation of a large reservoir. A total of nine fish species were recorded, of which only brown trout (Salmo trutta) and Neretva chub are autochthonous, while all remaining species are allochthonous.

Tabela 5. Composition of the ichthyofauna of the Jablanica lake

Fish species	Body weight (g)		Total length (cm)		Number of individuals
	max	min	max	min	
Brown trout	3,800.0	70.0	65.0	18.6	6
Common carp	3,100.0	1.5	52.0	4.5	20
Prussian carp	790.0	76.0	35.0	17.0	150
Tench	1,450.0	267.0	44.0	28.0	110
Chub	815.0	390.0	41.0	31.0	40
Neretva chub	682.0	150.0	38.0	26.0	25
Sunbleak	32.5	3.0	17.0	3.0	210
Pike-perch	2,300.0	48.6	56.0	19.0	60
Pumpkinseed	30.0	6.0	15.0	7.0	45

Brown trout occurred at very low abundance, likely restricted to colder and deeper reservoir zones and tributary inflows, indicating that Jablanica Lake does not constitute suitable habitat for this stenothermic cold-water species and that its persistence depends on continual immigration from tributaries. Neretva chub (*Squalius squalizze*) was present in moderate numbers but showed limited ecological success under altered hydromorphological conditions and strong competition from non-native cyprinids. The assemblage was numerically dominated by allochthonous cyprinid species: sunbleak - 31.5%, Prussian carp (*Carassius gibelio*) - 22.5%, tench (*Tinca tinca*) - 16.5%, and common carp (*Cyprinus carpio*) - 3.0%, which together accounted for 70.5% of total abundance, reflecting successful adaptation to lentic, mesotrophic to eutrophic conditions and pronounced water-level fluctuations. Pike-perch (*Sander lucioperca*), an allochthonous predatory species, comprised 9.0% of the assemblage and exerted a disproportionate ecological impact through intense predation on small-bodied species and juvenile stages of native fishes, further increasing pressure on already vulnerable populations of brown trout and Neretva chub. The presence of pumpkinseed (*Lepomis gibbosus*), an invasive non-native species, further confirms the high degree of biological alteration and represents an additional risk to eggs and juveniles of other species. Overall, the ichthyofaunal structure of Jablanica Lake reflects an ecologically imbalanced reservoir system, dominated by non-native, eurythermal species adapted to lentic conditions, with autochthonous species reduced to a marginal share of approximately 4.7% of total abundance, clearly illustrating a shift from a natural riverine assemblage toward a typical reservoir fish community.

The source region of the Neretva River retains the main characteristics of a near-natural headwater fish assemblage, primarily shaped by extreme hydromorphological conditions. Historical investigations indicate a pronounced dominance of salmonids, with brown trout (*Salmo trutta*) as the key structural species, reflecting cold, fast-flowing, and well-oxygenated habitats (Kosorić et al. 1983, Vuković et al. 1987). Contemporary surveys conducted between 2011 and 2023 confirm that this general structure has largely persisted, with low species richness but high ecological congruence between fish assemblages and habitat conditions.The continued dominance of brown trout and the presence of accompanying benthic species such as Eurasian minnow (*Phoxinus phoxinus*) and European bullhead (*Cottus gobio*) indicate preserved substrate quality and high dissolved oxygen concentrations. The absence or very limited presence of allochthonous species suggests that harsh environmental conditions and natural geomorphological barriers still act as effective ecological filters, limiting biological invasions (Rahel, 2002). However, the naturally low diversity and narrow ecological niches of endemic species imply high sensitivity to future hydrological or thermal alterations, emphasizing the conservation value of this region as a refugial zone (Crivelli 1995, Freyhof and Brooks 2011).

In the parish region, the ichthyofauna exhibits a transitional structure between the mountain headwaters and downstream river sections. Increased channel width, reduced gradient, and higher habitat heterogeneity support a more diverse assemblage compared with the source region (Škrijelj 2002). Although brown trout remains numerically dominant, the relative contribution of endemic salmonids – softmouth trout (*Salmo obtusirostris*) and marble trout (*Salmo marmoratus*) is reduced, indicating spatial limitation of optimal habitats and increasing interspecific competition. A particularly important feature of this section is the stable presence and relatively high abundance of grayling (*Thymallus thymallus*), which is considered allochthonous in the Neretva basin (Kosorić et al. 1983, Vuković et al. 1987). Its successful establishment suggests effective adaptation to local conditions and potential competitive interactions with native salmonids, especially the endemic softmouth trout. Autochthonous benthic and accompanying species persist in this section, confirming the presence of high-quality microhabitats, however, their low abundances indicate increasing fragmentation and growing sensitivity to anthropogenic pressures. Similar transitional patterns have been reported from other Mediterranean and Dinaric river systems undergoing early stages of ecological alteration (Crivelli 1995, Rahel 2002).

The Konjic valley region shows a further shift in community structure, reflecting intensified anthropogenic influence and hydromorphological modification of the river channel.

While brown trout still represents a significant proportion of total abundance, the increasing share of allochthonous species, including grayling and cyprinids, indicates reduced resistance of the system to biological invasions (Škrijelj 1995). Endemic species - softmouth trout, marble trout and the Neretva spined loach (*Cobitis narentana*) occur at very low abundances, suggesting that suitable habitats are highly localized and insufficient to sustain stable populations. This region illustrates how altered flow regimes, partial river regulation, and habitat simplification facilitate the spread of generalist and non-native species at the expense of specialized endemic taxa. Comparable trends have been documented in other Mediterranean rivers, where endemic fishes persist mainly in isolated refugial habitats while assemblage structure increasingly converges toward homogenized communities dominated by euryvalent species (Crivelli 1995, Rahel 2002, Freyhof and Brooks 2011).

The most profound alterations of ichthyofaunal structure are observed within the Jablanica hydroaccumulation, where the original lotic salmonid community has been almost completely replaced by a lentic, cyprinid-dominated assemblage. Historical studies demonstrated that within a decade of dam construction, cyprinids accounted for up to 96.7% of total abundance, while salmonids declined to only 3.3% (Aganović et al. 1966, Plančić 1953). Subsequent investigations documented further qualitative and quantitative shifts, including the disappearance of several autochthonous species and the dominance of Neretva chub (*Squalius svallize*) and Italian chub (*Squalius squalus*) (Kosorić et al. 1980). Contemporary data confirm that these trends have intensified, with allochthonous cyprinids such as common carp (*Cyprinus carpio*) Prussian carp (*Carassius gibelio*), tench (*Tinca tinca*), and sunbleak (*Leucaspius delineatus*), collectively comprising more than 70% of total abundance. The establishment of pike-perch (*Sander lucioperca*) represents an additional driver of community restructuring, despite moderate numerical abundance, this predatory species exerts strong top-down pressure on small-bodied fishes and juvenile stages of native species. The presence of invasive species such as pumpkinseed (*Lepomis gibbosus*) further indicates a high degree of biological alteration and advanced biotic homogenization, a pattern widely associated with river impoundment and reservoir formation (Rahel 2002, Gozlan 2008, Villéger et al. 2011).

CONCLUSION

The ichthyofauna of the upper Neretva River exhibits a pronounced longitudinal gradient shaped by natural hydromorphological conditions and cumulative anthropogenic pressures. Headwater sections retain near-natural, salmonid-dominated assemblages that function as refugial habitats for autochthonous and endemic species but remain highly sensitive to hydrological alteration. In transitional reaches, increasing contributions of allochthonous species indicate enhanced biotic permeability and early community reorganization, while endemic taxa persist at low abundances and in spatially restricted habitats. The most severe changes occur in hydroaccumulations, where river impoundment has driven a shift from lotic, salmonid-dominated communities to lentic assemblages dominated by non-native, eurythermal species, accompanied by biotic homogenization. Overall, dam construction and flow regulation emerge as the primary drivers of long-term ichthyofaunal change, underscoring the need to protect remaining free-flowing sections, prevent further species introductions, and maintain natural hydrological dynamics to conserve the unique endemic fish fauna of the Neretva River.

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