Ichthyofauna of the River Sava System

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Abstract On the survey of the recent records, the fish and lamprey fauna of the River Sava catchment consists of 74 species, 15 of which being considered alien. The indigenous species diversity, explained using the relation $N = 0.546\,A^{0.232}$, fits well into the range common for large catchments in Europe. Both taxonomic and ecological diversity, as well as the character of fish communities in streams and rivers, are strongly correlated with the stream order. On the relative abundance of species in fish communities, the upper rhithron fish communities cluster distinctly from those belonging to the middle rhithron, within which several subgroups of fish communities were distinguishable. Fish communities of the middle rhithron character in streams and small rivers stand distinctly apart from those belonging to particular sections of large rivers (e.g., the Rivers Sava, Drina, Vrbas, and Bosna), with the transitional type of middle rhithron fish community in larger rivers (e.g., those in the Rivers Una and Sana) that resemble more to the fish communities

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common in middle rhithron streams. Fish communities in the middle section of the River Sava in Croatia and in the bordering area with Bosnia and Herzegovina mainly belong to the lower rhithron, attaining the character of potamon in the most downstream, Serbian section. River Sava's fish communities strongly interact with the ones occurring in the most downstream sections of their largest tributaries, e.g., the Rivers Una, Vrbas, Bosna, Drina, and Kolubara, which makes them very similar in structure in the areas of river mouths. Classification of fish communities based solely on the presence and absence of species revealed similar general pattern of fish community classification, though with the more sharp delimitation between those belonging to the upper and middle rhithron on one and to the lower rhithron and potamon on the other side. That was supported by the determination of fish communities belonging to the upper rhithron with brown trout *Salmo* cf. *trutta*, European bullhead *Cottus gobio*, and minnow *Phoxinus phoxinus* as the most common fish species. Fish communities belonging to the middle rhithron were determined mainly with chub *Squalius cephalus* and spirlin *Alburnoides bipunctatus*, whereas brook barbel *Barbus balcanicus* and stone loach *Barbatula barbatula* occurred in both upper rhithron and middle rhithron. Nase *Chondrostoma nasus* were associated with both middle and lower rhithron fish communities. The most common fish species that determine the lower rhithron fish communities were common bream *Abramis brama*, ide *Idus idus*, and bleak *Alburnus alburnus*, with the northern pike *Esox lucius*, Balon's ruffe *Gymnocephalus baloni*, and racer goby *Neogobius gymnotrachelus* as significant species explaining fish communities of both lower rhithron and potamon. The level of production of fish in the River Sava varies remarkably within the sections with the similar ecological features, as well as between the sections that differ for the type of fish community. The greatest biomass and annual natural production were recorded in the sections homing the potamon and lower rhithron fish communities, especially in the flooding areas of side arms and oxbows which serve as spawning areas and nurseries. A total of 15 alien fish species was recorded in the River Sava catchment, the Prussian carp *Carassius gibelio* and brown bullhead *Ameiurus nebulosus* being assessed the most invasive in the areas with the potamon fish community. A strong impact from both long-term and recent stocking with alien hatchery-reared brown trout strains and rainbow trout in the upper rhithron fish communities was recently recognized. Mudminnow *Umbra krameri* and huchen (or Danube salmon) *Hucho hucho* are considered the two most threatened fish species of the River Sava catchment, where various types of riverbed modifications, especially the damming, were seen the most prominent threatening factors for fish diversity.

Keywords Fish fauna • Lamprey fauna • Diversity • Community structure • The River Sava Basin

1 Introduction

First records about fishes in the River Sava drainage area date far back, in the seventeenth century [1]. In the nineteenth and early twentieth centuries, fish were much more investigated there. Reports of investigations from the River Sava section [2–13] resulted in a list of 54 fish species from 10 families, including particular introduced fish species, e.g., rainbow trout *Oncorhynchus mykiss*, brook trout *Salvelinus fontinalis*, and brown bullhead *Ameiurus nebulosus*. The most recent records of fish from the upper part of the River Sava drainage area were given by Vovk and Budihna [14], Povž [15], Povž and Sket [16], and Šumer et al. [17]. During that period, an introduction of largemouth bass *Micropterus salmoides* and translocation of marble trout *Salmo marmoratus* into the River Sava catchment, as well as a disappearance of sterlet *Acipenser ruthenus*, the only resident sturgeon species in the middle and lower section of the River Sava in Slovenia [18], were reported by Povž [19, 20].

The first investigation of the lower part of the River Sava ichthyofauna downstream of the town of Sisak was given by Plančić [21], where 25 species were then recorded. The most recent records for this part were given by Veljović [22], Suić [23], Zanella et al. [24], Mrakovčić et al. [25], Mikavica et al. [26], Ćaleta [27], and Sofradžija [28].

Mrakovčić et al. [29] stated that 42 native European lamprey and fish species from 13 families occur in the River Sava catchment area, majority of whom (27 species) are from the f. Cyprinidae. Mikavica et al. [26] recorded 29 fish species from seven families in the River Sava section from the confluence with the River Una to the confluence with the River Vrbas, whereas Sofradžija [28] stated 52 fish species for the whole River Sava middle section.

There are a lot of papers related to the fish fauna of tributaries and backwaters of the River Sava, some of the more recent ones being those of Aganović et al. [30], Mehmedagić [31], Mikavica et al. [32], Mikavica and Savić [33], Sofradžija et al. [34], Korjenić [35], Bakrač-Bećiraj and Mujić [36], Skenderović et al. [37], Adrović et al. [38], and Bećiraj and Šahinović [39].

Seven fish species (huchen *Hucho hucho*, mudminnow *Umbra krameri*, Danubian roach *Rutilus pigus*, Kessler's gudgeon *Gobio kessleri*, Danubian gudgeon *Gobio uranoscopus*, striped ruffe *Gymnocephalus schraetser*, zingel *Zingel zingel* and streber *Zingel streber*) that occur in the River Sava catchment are endemics or subendemics of the River Danube catchment. In addition to that, the River Sava catchment holds the specific, Balkan lineage of grayling *Thymallus thymallus*, with the variety of haplotypes, i.e., high level of diversity in the southernmost part of the dispersal area of this widely dispersed species [40]. There is also a notification about the differentiation of the huchen in the River Sava catchment into two distinct stocks: the western one occurring in the upper and middle course in Slovenia and the eastern one that comprises huchen from streams and rivers in eastern Bosnia, Serbia, and northern Montenegro [41, 42]. In contrast to that, the indigenous

diversity assessed in alien hatchery-reared brown trout *Salmo* cf. *trutta* strain was very limited at the mtDNA level in the River Sava drainage area [43, 44].

In contrast to tributaries, where only recreative fishing is allowed, the River Sava itself is both recreative fishery and commercial fishery, except in Slovenia, where only recreative fishery is on board. Both recreative fishing as a modern leisure activity and commercial fishing as an occupation have arisen from the small traditional fishing of the people living near streams and rivers that have provided fish flesh as a food through centuries, using hook-, trap-, and net-based fishing gears. Fishing is legally regulated in all countries in the River Sava catchment, but that legislative frame differs, depending on tradition, fishery settings, state capacity, and opportunities for fishing as an economic category. Each of the states in the River Sava catchment has inland waters' fishery system based on midterm and annual management plans that asses the status of fish stocks and project the rate of fishery utilization, as well as fishery measures, activities (e.g., hatching, rearing, and stocking), and regulations, whose implementation greatly varies from state to state. The gross income from inland water fishery is the greatest in Slovenia, where the River Sava catchment holds many internationally renowned trout and grayling fly-fishing streams (e.g., the Rivers Unec, Sava Bohinjka, and Radovna) with high price of fishing licenses. Certain formerly famous fly-fishing destinations for international fishermen were recently reaffirmed at streams and rivers of the River Sava catchment in Croatia (e.g., the Rivers Kupa, or Kolpa, and Dobra) and Bosnia and Herzegovina (e.g., the Rivers Una, Sana, Klokot, Krušnica, Ribnik, Pliva, Janj), and a new one started to appear in Montenegro (e.g., upper River Lim) and Serbia (the River Gradac). Angling for other fish species is also popular throughout the River Sava watershed. Chub *Squalius cephalus*, nase *Chondrostoma nasus*, common barbel *Barbus barbus*, and Danubian roach are favorite angling species in streams and rivers in highland areas and carp *Cyprinus carpio*, wels *Silurus glanis*, zander *Sander lucioperca*, and northern pike *Esox lucius* in lowland rivers and reservoirs. Other common fish species favored by anglers are clustered in "white fish" comprising breams (*Abramis brama*, *A. sapa*, *A. ballerus*, *Vimba vimba*, *Blicca bjoerkna*) and Prussian carp (*Carassius gibelio*) and introduced bigheads (gray *Hypophthalmichthys molitrix* and white *Hypophthalmichthys nobilis*) and white grass carp (*Ctenopharyngodon idella*). Commercial fishermen use to target economically more valuable fish, like wels, starlet, and zander, though in certain parts of fishing season and on catching "value fish" they also trade with other fish, which is considered second and third grade for their quality and price. Fishery market for the trading with the commercial catches of fish mainly relies on fishermen as individual entrepreneurs in selling, both on shore and at open markets, which slowly changes toward the setting of properly equipped fish markets. Limits and constraints set by fishery legislation in the River Sava catchment vary, e.g., for the minimal landing size and closed season for fishing of huchen in Bosnia and Herzegovina and Serbia, but there is an obvious intent to harmonize national regulations with the international conventions and initiatives, which adds to the harmonization between the states in the River Sava catchment much more and quicker than through their direct negotiations. It seems that despite of variety in

opportunities for the development of fishery, it will share the destiny of the gross development of economies in the states of the River Sava catchment.

The overall diversity of fish (including lamprey) species in the River Sava catchment, including tributaries, was never surveyed hitherto, although it was well known from the investigations of both academic and applied characters. The main aim of this chapter is to reveal that diversity and its main determinants, with the amount of data that could serve as a starting point for prospect investigations and inferring about the status of fish over the River Sava catchment. In addition, the fishery in the area was reviewed after the available records.

2 Materials and Methods

Data set for analysis of fish community structure was created from the lists of samples taken in each of the countries using various electrofishing and netting gears and consisted of the number of each fish species in the sample caught at each locality representing the absolute abundance, which was transformed in the set of relative abundances for each species at each locality. The only exception is data set obtained from Slovenia that consisted of records denoting the presence and absence of particular fish species at each locality.

Estimation of taxonomic richness of lamprey and fish species in streams and rivers of the River Sava system was estimated following Welcomme [45], after expression:

$$N = fA^b,$$

where N is the number of species and A is the surface of catchment (in square kilometers). Records for surfaces for particular streams' and rivers' catchments were taken from Marković [46].

Overall taxonomic diversity, as well as that of fish community at each of sampling locality, was considered using the Shannon–Weaver Information Index H', with the additional measure that complements the ecological component of diversity esteemed using the Evenness Index (J) [47] for the fish community at each of sampling localities.

Characterization of fish communities was worked out by calculating the Ecological Index E_i that Šorić [48] introduced for fish species in inland waters of the River Danube system in Serbia and adjacent regions. That index uses the rank f (i.e., weight) of each fish species in the sample according to its relative abundance ($f_{(<1\ \%)} = 1$; $f_{(1–3\ \%)} = 2$; $f_{(3–10\ \%)} = 3$; $f_{(10–20\ \%)} = 4$; $f_{(20–40\ \%)} = 7$; $f_{(>40\ \%)} = 9$) and K indicator values for each type of aquatic habitats (1 for upper rhithron, 2 for middle rhithron, 3 for lower rhithron, and 4 for potamon) that is common for particular fish species. It is calculated using the expression:

$$E_i = \sum (K_i f_i) / \sum f_i.$$

Fish communities with the value of E_i lower than 1.5 are upper rhithronic, those with the E_i up to 2.5 are middle rhithronic, those with the E_i up to 3.5 are lower rhithronic, and those over 3.5 belong to the potamon fish community type.

Relationships between fish community structure, stream order, components of diversity, biomass, and annual natural production were checked by Pearson Correlation Coefficient r [49].

Analysis of similarity between fish community samples for their structure was accomplished using cluster analysis of samples on relative abundance of fish species in them, accomplished by Ward's method of clustering on the Chebyshev distance metrics. Ward's method of clustering is a hierarchical (i.e., agglomerative) clustering tool that minimizes the total variance within the cluster [50], whereas the Chebyshev distance metric favors the maximum of distance between two vectors or objects in any of their dimensions, i.e., $D_{\text{Chebyshev}}(x,y) = \max(|x_i - y_i|)$. In addition to that, another method of analysis was applied, in order to investigate the structure of fish communities in the part of the River Sava catchment in Slovenia, where only qualitative data were available. That data set consisting of the presence/absence data for particular fish species in particular streams and rivers was clustered on Euclidean distances [51] between their fish communities using the Ward's clustering method.

To understand correlation between type of fish communities and river zonation, constrained Redundancy Analysis (RDA) [52] with dummy variables (explanatory variables) was used to relate fish species (response variables) with particular locality (samples). RDA is a constrained form of the linear ordination method of principal component analysis (PCA). The output of this analysis is displayed in an ordination diagram with the loadings of response variables represented by arrows and multivariate scores of sampling localities represented by points. RDA was performed for the 74 fish species as response variables studied. To evaluate significance of particular species, the Monte Carlo permutation test ($P > 0.05$) with manual selection was used. The software for this statistical analysis was performed using CANOCO for Windows 4.5 software package [52].

Fish productivity was evaluated from the records of average biomass and annual rate of survival for each age class of fish species in samples taken during an accomplishment of Fishery Management Plans available for streams and rivers in the River Sava catchment.

3 Results

Fish (including lamprey) fauna of the River Sava catchment consists of 74 species belonging to 14 families. Fifteen species are considered alien (Tables 1–8). Their taxonomic diversity assessed for 23 river catchments in the River Sava system is

Table 1 Occurrence of lamprey and fish species in the River Sava from its source downstream to the mouth with the River Danube

Fish species	Sava Dolinka	Sava Bohinjka	Sava Slo (upstream section)	Sava Slo (middle section)	Sava Slo (downstream section)	Sava Medsave	Sava Zagreb	Sava L Dubrovcak	Sava Trebež	Sava Jasenovac	Sava Gradiška	Sava Davor	Sava Slavonski Brod	Sava Babina Greda	Sava Račinovci	Sava Jarak	Sava Mišar	Sava Obrenovac	Sava (R. Kolubara junction)	Sava Makiš
Ukrainian lamprey *Eudontomyzon mariae*	+	+			+															
Sterlet *Acipenser ruthenus*							+											+		+
Brown trout *Salmo trutta*	+	+	+	+	+															
Rainbow trout *Oncorhyncus mykiss*	+	+	+	+	+															
Arctic char *Salvelinus alpinus*		+																		
Brook trout *Salvelinus fontinalis*	+	+	+																	
Huchen *Hucho hucho*	+	+	+	+	+															
European grayling *Thymallus thymallus*	+	+	+	+	+															
Northern pike *Esox lucius*			+	+	+				+	+	+	+	+	+	+		+	+	+	+
Bream *Abramis brama*			+	+	+	+	+		+	+	+		+	+	+	+	+	+		+
Whiteye bream *Abramis sapa*											+		+	+		+		+	+	
White bream *Blicca bjoerkna*				+	+				+	+	+	+	+	+	+	+		+	+	+
Blue bream *Abramis ballerus*									+											
Vimba *Vimba vimba*			+	+	+	+	+	+	+	+	+	+	+	+	+			+		+
Tench *Tinva tinca*			+	+	+										+					
Common carp *Cyprinus carpio*			+	+	+				+	+	+	+	+	+			+			+
Crucian carp *Carassius carassius*				+	+	+														
Giebel carp *Carassius gibelio*			+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+
White grasscarp *Ctenopharyngodon idella*				+	+															
Rudd *Sacrdinius erythrophthalmus*			+	+	+						+									
Asp *Aspius aspius*				+	+	+	+	+	+	+	+	+	+	+	+		+			+

(continued)

Table 1 (continued)

Fish species	Sava Dolinka	Sava Bohinjka	Sava Slo (upstream section)	Sava Slo (middle section)	Sava Slo (downstream section)	Sava Medsave	Sava Zagreb	Sava L Dubrovcak	Sava Trebež	Sava Jasenovac	Sava Gradiška	Sava Davor	Sava Slavonski Brod	Sava Babina Greda	Sava Račinovci	Sava Jarak	Sava Mišar	Sava Obrenovac	Sava (R. Kolubara junction)	Sava Makiš
Danubian roach *Rutilus pigus*			+	+	+	+	+	+	+	+	+	+	+	+	+					
Roach *Rutilus rutilus*			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Bitterling *Rhodeus sericeus*				+	+	+	+	+	+	+	+	+	+	+	+					
Bleak *Alburnus alburnus*			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+
Spirlin *Alburnoides bipunctatus*			+	+	+	+	+			+										
Minnow *Phoxinus phoxinus*	+	+	+	+	+															
Bladgeon *Leuciscus souffia*	+	+	+	+	+															
Dace *Leuciscus leuciscus*				+		+	+	+	+											
Chub *Squalius cephalus*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+				
Nase *Chondrostoma nasus*		+	+	+	+	+	+		+	+	+	+	+	+	+	+			+	
Orfe *Idus idus*					+				+	+	+	+	+	+	+		+			
Common barbel *Barbus barbus*		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+
Brook barbel *Barbus balcanicus*		+	+	+	+	+	+		+											
Gudgeon *Gobio gobio*		+	+	+	+	+	+	+	+											
Danubian gudgeon *Gobio uranocopus*		+	+	+	+		+			+	+									
Whitefin gudgeon *Gobio albipinnatus*				+	+				+	+	+	+	+	+	+					
Kessler's gudgeon *Gobio kessleri*			+	+	+															
Topmouth gudgeon *Pseudorasbora parva*				+	+	+	+	+	+	+	+	+	+	+	+					
Gray bighead *Hypophthalmichthys nobilis*																	+		+	+
Stone loach *Barbatula barbatula*	+		+	+	+	+	+	+												

Weather loach *Misgurnus fossilis*			+	+							+									
Balkan loach *Cobitis elongata*					+	+	+	+	+	+	+	+	+	+	+					
Riffle loach *Cobitis elongatoides*	+		+		+	+	+	+	+	+	+	+	+	+	+					
Golden loach *Sabanejewia aurata*					+							+		+	+					
Wells *Silurus glanis*		+			+	+	+		+	+	+	+	+	+	+	+		+	+	+
Brown bullhead *Ameiurus nebulosus*										+	+	+	+	+	+					+
Burbot *Lota lota*		+		+	+				+	+		+	+	+						
Eurasian perch *Perca fluviatilis*		+		+	+			+	+	+	+	+	+	+	+	+				
Common ruffe *Gymnocephalus cernuus*				+	+				+	+		+	+	+	+					
Striped ruffe *Gymnocephalus schraetseri*					+				+							+		+		
Zander *Sandra lucioperca*				+	+					+		+	+	+		+	+	+	+	+
Zingel *Zingel zingel*														+				+		
Streber *Zingel streber*				+	+								+		+					
Pumpkinseed *Lepomis gibbosus*					+	+		+	+	+	+	+	+	+	+		+			+
Miller's thumb *Cottus gobio*					+											+	+	+	+	+
Monkey goby *Neogobius fluviatilis*			+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+
Round goby *Neogobius melanostomus*													+	+	+	+	+	+	+	+
Racer goby *Neogobius gymnotrachelus*																+	+	+	+	+
Bighead goby *Neogobius kessleri*												+	+		+			+	+	+
Tubenose goby *Proterorhinus marmoratus*																+	+	+	+	+
Fish species number	11	18	29	39	47	22	23	17	30	29	28	28	31	31	29	18	16	19	17	22

Table 2 Occurrence of lamprey and fish species in the tributaries at the Slovenian section of the River Sava catchment listed in order by their position from the upper section downstream, eastward, as well as by stream order (with numbers, in rising order from headwater section downstream) where applicable and locality of sampling

Fish species	Sora	Ljubljanica	Mirna	Krka	Kolpa	Savinja	Sotla
Ukrainian lamprey *Eudontomyzon mariae*		+	+	+	+		+
Brown trout *Salmo trutta*	+	+	+	+	+	+	+
Rainbow trout *Oncorhyncus mykiss*	+	+	+	+	+	+	+
Brook trout *Salvelinus fontinalis*	+	+		+	+	+	
Huchen *Hucho hucho*	+	+	+	+	+	+	
European grayling *Thymallus thymallus*	+	+	+	+	+	+	
Northern pike *Esox lucius*		+	+	+	+	+	+
Bream *Abramis brama*		+		+		+	+
White bream *Blicca bjoerkna*		+		+			+
Vimba *Vimba vimba*		+		+	+	+	+
Tench *Tinca tinca*		+		+	+	+	+
Common carp *Cyprinus carpio*		+	+	+	+	+	+
Crucian carp *Carassius carassius*		+		+	+	+	+
Giebel carp *Carassius gibelio*				+		+	+
White grasscarp *Ctenopharyngodon idella*					+	+	
Rudd *Sacrdinius erythrophthalmus*		+		+		+	+
Asp *Aspius aspius*			+	+		+	
Danubian roach *Rutilus pigus*	+	+	+	+	+	+	+
Roach *Rutilus rutilus*		+	+	+	+	+	+
Bitterling *Rhodeus sericeus*		+		+	+	+	+
Bleak *Alburnus alburnus*		+	+	+	+	+	+
Spirlin *Alburnoides bipunctatus*	+	+	+	+	+	+	+
Minnow *Phoxinus phoxinus*	+	+	+	+	+	+	
Bladgeon *Leuciscus souffia*	+	+	+		+	+	+
Dace *Leuciscus leuciscus*			+				
Chub *Squalius cephalus*	+	+	+	+	+	+	+
Nase *Chondrostoma nasus*	+	+	+	+	+	+	+
Orfe *Idus idus*				+			+
Common barbel *Barbus barbus*	+	+	+	+	+	+	+
Brook barbel *Barbus balcanicus*	+	+	+	+	+	+	+
Gudgeon *Gobio gobio*	+	+	+	+	+	+	+

(continued)

Table 2 (continued)

Fish species	Sora	Ljubljanica	Mirna	Krka	Kolpa	Savinja	Sotla
Danubian gudgeon *Gobio uranocopus*	+			+	+	+	+
Whitefin gudgeon *Gobio albipinnatus*			+	+		+	
Kessler's gudgeon *Gobio kessleri*				+	+		+
Topmouth gudgeon *Pseudorasbora parva*				+		+	+
Stone loach *Barbatula barbatula*	+	+	+	+	+	+	+
Weather loach *Misgurnus fossilis*		+		+		+	+
Balkan loach *Cobitis elongata*			+	+	+	+	+
Riffle loach *Cobitis elongatoides*	+	+	+	+	+	+	+
Golden loach *Sabanejewia aurata*	+	+	+	+	+	+	
Wells *Silurus glanis*		+		+	+		
Brown bullhead *Ameiurus nebulosus*							+
Burbot *Lota lota*		+	+	+			+
Eurasian perch *Perca fluviatilis*		+	+	+	+	+	+
Common ruffe *Gymnocephalus cernuus*				+	+	+	
Balon's ruffe *Gymnocephalus baloni*	+						
Striped ruffe *Gymnocephalus schraetseri*					+		
Zander *Sandra lucioperca*		+		+		+	+
Streber *Zingel streber*			+	+	+	+	+
Pumpkinseed *Lepomis gibbosus*		+		+	+	+	+
Monkey goby *Neogobius fluviatilis*	+	+	+	+	+	+	
Fish species number	20	36	29	45	37	41	37

Table 3 Occurrence of lamprey and fish species in the River Una catchment, listed in order by their position from the upper section downstream by stream order (with numbers, in rising order from headwater section downstream) where applicable, by tributaries and by locality of sampling

Fish species	Una 1 Unac	Una 2 Martinbrod	Una 3 Bihać	Una 4 B Krupa	Una 5 B Krupa	Una 6 Otoka	Krušnica	Klokot	Mlječanica	Sana 1 Ključ	Sana 2 Sanica	Sana 3 Sanski Most	Pakra Banova Jaruga
Brown trout *Salmo trutta*	+	+	+	+	+	+	+	+		+	+	+	
Rainbow trout *Oncorhyncus mykiss*							+	+					
European grayling *Thymallus thymallus*		+					+	+			+		
Northern pike *Esox lucius*					+	+	+	+				+	
Bream *Abramis brama*													+
Vimba *Vimba vimba*												+	
Giebel carp *Carassius gibelio*													+
Danubian roach *Rutilus pigus*			+	+	+	+	+	+					
Roach *Rutilus rutilus*	+		+		+	+		+					+
Bleak *Alburnus alburnus*						+		+				+	+
Spirlin *Alburnoides bipunctatus*	+		+	+	+	+				+	+	+	
Minnow *Phoxinus phoxinus*	+		+	+			+	+	+	+	+		
Chub *Squalius cephalus*	+		+	+	+	+	+	+	+			+	+
Nase *Chondrostoma nasus*												+	

Common barbel *Barbus barbus*	+		+	+									
Brook barbel *Barbus balcanicus*	+		+	+	+	+			+	+	+	+	
Gudgeon *Gobio gobio*					+	+	+		+			+	+
Stone loach *Barbatula barbatula*			+	+		+			+	+			
Riffle loach *Cobitis elongatoides*									+				
Spined loach *Cobitis taenia*			+	+	+	+				+			
Burbot *Lota lota*									+				
Eurasian perch *Perca fluviatilis*												+	+
Common ruffe *Gymnocephalus cernuus*													+
European bullhead *Cottus gobio*	+	+	+	+				+	+		+	+	
Fish species number	8	3	11	10	9	11	8	10	8	7	6	11	8

Table 4 Occurrence of lamprey and fish species in the River Vrbas catchment and Pakra reservoir, listed in order by position of localities from the upper section downstream (with numbers, in rising order from headwater section downstream) with the name of the locality of sampling

Fish species	Vrbas 1 Jelić	Vrbas 2 Bugojno	Vrbas 3 Jajce	Vrbas 4 Jajce	Vrbas 5 HE Jajce	Pakra reservoir
Brown trout *Salmo trutta*	+	+	+	+	+	
European grayling *Thymallus thymallus*				+	+	
Northern pike *Esox Lucius*						+
Common carp *Cyprinus carpio*						+
White grasscarp *Ctenopharyngodon idella*						+
Roach *Rutilus rutilus*						+
Bleak *Alburnus alburnus*						+
Spirlin *Alburnoides bipunctatus*		+	+	+	+	
Minnow *Phoxinus phoxinus*					+	
Chub *Squalius cephalus*			+	+	+	+
Nase *Chondrostoma nasus*		+	+		+	
Common barbel *Barbus barbus*				+	+	
Brook barbel *Barbus balcanicus*		+	+	+	+	
Brown bullhead *Ameiurus nebulosus*						+
Eurasian perch *Perca fluviatilis*						+
Zander *Sandra lucioperca*						+
Pumpkinseed *Lepomis gibbosus*						+
European bullhead *Cottus gobio*		+				
Fish species number	1	5	5	6	8	10

explained with the expression $N = 0.546\,A^{0.232}$ ($r = 0.59$; $F_{(1,21)} = 11.092$; $p < 0.05$). Increase in stream order is significantly correlated with the increase in number of fish species ($r^2 = 0.717$; $p < 0.001$) (Fig. 1), being for the River Sava even stronger ($r^2 = 0.884$; $p < 0.001$). Increase in stream order is also significantly correlated with the values of Shannon–Weaver Index H' ($r^2 = 0.664$; $p < 0.001$) representing the taxonomic diversity (Fig. 2) and Ecological Index E_i ($r^2 = 0.786$; $p < 0.001$) that

Table 5 Occurrence of lamprey and fish species in the River Bosna and its tributaries, listed in order of localities by their position from the upper section downstream and by stream order (with numbers, in rising order from headwater section downstream) where applicable

Fish species	Bosna 1 izvor	Bosna 2 Zenica	Bosna 3 Zavidovići	Bosna 4 Maglaj	Krivaja 4 ušće	Krivaja 3 Maoča	Krivaja 2 Solun	Krivaja 1 Olovo	Lašva 5 ušće	Lašva 4 Donja Rovnja	Lašva 3 Mali Mošunj	Lašva 2 crkva	Lašva 1 izvor
Brown trout *Salmo trutta*	+						+			+	+	+	+
European grayling *Thymallus thymallus*											+		
Vimba *Vimba vimba*				+									
Giebel carp *Carassius gibelio*		+											
Bleak *Alburnus alburnus*		+		+									
Spirlin *Alburnoides bipunctatus*		+	+	+	+	+	+	+					
Minnow *Phoxinus phoxinus*	+												
Chub *Squalius cephalus*		+	+	+	+	+	+		+				
Nase *Chondrostoma nasus*					+	+							
Common barbel *Barbus barbus*				+									

(continued)

Table 5 (continued)

Fish species	Bosna 1 izvor	Bosna 2 Zenica	Bosna 3 Zavidovići	Bosna 4 Maglaj	Krivaja 4 ušće	Krivaja 3 Maoča	Krivaja 2 Solun	Krivaja 1 Olovo	Lašva 5 ušće	Lašva 4 Donja Rovnja	Lašva 3 Mali Mošunj	Lašva 2 crkva	Lašva 1 izvor
Brook barbel *Barbus balcanicus*		+	+	+	+	+	+	+	+	+			
Gudgeon *Gobio gobio*		+	+		+								+
Spined loach *Cobitis taenia*		+			+								
European bull-head *Cottus gobio*	+												+
Fish species number	3	7	4	6	6	4	4	2	2	2	2	1	3

Table 6 Occurrence of lamprey and fish species in tributaries of the River Bosna, listed in order of localities by their position from the upper section downstream and by stream order (with numbers, in rising order from headwater section downstream) where applicable

Fish species	Željeznica	Zujevina	Fojnica	Zlaća	Krabanja	Oskova	Gostelja	Spreča 1	Modrac reservoir	Spreča 2	Tinja	Brka	Prača	Sniježnica
Brown trout *Salmo trutta*	+	+	+	+	+	+	+						+	
Rainbow trout *Oncorhyncus mykiss*			+				+							
European grayling *Thymallus thymallus*			+										+	
Northern pike *Esox lucius*								+	+					
Bream *Abramis brama*								+	+	+				+
Whiteye bream *Abramis sapa*							+			+				
Vimba *Vimba vimba*										+	+			
Tench *Tinca tinca*							+		+					+
Common carp *Cyprinus carpio*									+					+
Crucian carp *Carassius carassius*									+					
Giebel carp *Carassius gibelio*						+	+		+					+
Rudd *Sacrdinius erythrophthalmus*								+	+					+
Asp *Aspius aspius*									+					
Danubian roach *Rutilus pigus*														
Roach *Rutilus rutilus*						+	+	+	+					+
Bitterling *Rhodeus sericeus*	+						+	+	+			+		+
Sichel *Pelecus cultratus*														

(continued)

Table 6 (continued)

Fish species	Željeznica	Zujevina	Fojnica	Zlaća	Krabanja	Oskova	Gostelja	Spreča 1	Modrac reservoir	Spreča 2	Tinja	Brka	Prača	Sniježnica
Bleak *Alburnus alburnus*			+				+	+	+	+				+
Shemaya *Chalcalburnus chalcoides*														
Spirlin *Alburnoides bipunctatus*	+		+				+	+		+	+	+		
Minnow *Phoxinus phoxinus*	+	+	+	+	+	+	+					+	+	
Chub *Squalius cephalus*	+	+	+			+	+	+	+	+	+	+		
Nase *Chondrostoma nasus*	+							+						+
Common barbel *Barbus barbus*		+								+				
Brook barbel *Barbus balcanicus*	+		+			+	+	+	+	+	+	+		
Gudgeon *Gobio gobio*		+	+			+	+	+	+	+	+	+		
Topmouth gudgeon *Pseudorasbora parva*												+		
Stone loach *Barbatula barbatula*						+	+					+		
Balkan loach *Cobitis elongata*		+							+					
Riffle loach *Cobitis elongatoides*	+		+				+	+	+			+		
Golden loach *Sabanejewia aurata*						+	+					+		
Wells *Silurus glanis*									+	+				
Black bullhead *Ameiurus melas*									+					

Eurasian perch *Perca fluviatilis*							+	+	+	+				
Common ruffe *Gymnocephalus cernuus*							+	+	+					
Balon's ruffe *Gymnocephalus baloni*														+
Zander *Sandra lucioperca*								+	+					
Streber *Zingel streber*			+											
Pumpkinseed *Lepomis gibbosus*							+		+					+
European bullhead *Cottus gobio*	+	+	+			+							+	
Fish species number	9	7	12	2	2	10	19	15	22	11	5	10	4	11

Table 7 Occurrence of and fish species in the River Drina and its tributaries, listed in order of localities by their position from the upper section downstream and by stream order (with numbers, in rising order from headwater section downstream) where applicable

Fish species	Drina 1 Šćepan polje	Drina 2 Goražde	Drina 3 Perućac	Drina 4 Ljubovija	Drina 5 Zvornik	Drina 6 Loznica	Drina 7 Ušće	Ljubovića 1	Ljubovića 2	Drinjača 1	Drinjača 2
Sterlet *Acipenser ruthenus*						+					
Brown trout *Salmo trutta*	+	+						+	+	+	
Huchen *Hucho hucho*	+	+	+	+		+	+				
European grayling *Thymallus thymallus*	+	+		+							
Northern pike *Esox lucius*						+	+				
Bream *Abramis brama*			+		+	+	+				
White bream *Blicca bjoerkna*							+				
Vimba *Vimba vimba*			+	+	+	+	+				
Tench *Tinca tinca*			+								
Common carp *Cyprinus carpio*					+		+				
Crucian carp *Carassius carassius*							+				
Giebel carp *Carassius gibelio*				+	+	+					
Rudd *Sacrdinius erythrophthalmus*						+	+				
Asp *Aspius aspius*				+			+				
Danubian roach *Rutilus pigus*	+	+	+	+		+	+				
Roach *Rutilus rutilus*					+	+					
Bitterling *Rhodeus sericeus*					+	+	+				
Sichel *Pelecus cultratus*							+				
Bleak *Alburnus alburnus*	+	+	+	+	+	+	+				

Shemaya *Chalcalburnus chalcoides*				+		+	+				
Spirlin *Alburnoides bipunctatus*	+	+		+		+			+	+	+
Minnow *Phoxinus phoxinus*	+			+				+	+	+	
Bladgeon *Leuciscus souffia*	+										
Chub *Squalius cephalus*	+	+	+	+	+	+	+		+		+
Nase *Chondrostoma nasus*	+	+	+	+	+	+	+				+
Orfe *Idus idus*							+				
Common barbel *Barbus barbus*	+	+	+	+	+	+	+				
Brook barbel *Barbus balcanicus*	+	+	+	+	+			+	+	+	+
Gudgeon *Gobio gobio*	+	+	+	+		+					+
Danubian gudgeon *Gobio uranocopus*											
Whitefin gudgeon *Gobio albipinnatus*				+	+						
Kessler's gudgeon *Gobio kessleri*											
Topmouth gudgeon *Pseudorasbora parva*					+						
Stone loach *Barbatula barbatula*							+				+
Weather loach *Misgurnus fossilis*							+				
Balkan loach *Cobitis elongata*				+							
Spined loach *Cobitis taenia*			+	+	+	+					
Wells *Silurus glanis*			+			+	+				

(continued)

Table 7 (continued)

Fish species	Drina 1 Šćepan polje	Drina 2 Goražde	Drina 3 Perućac	Drina 4 Ljubovija	Drina 5 Zvornik	Drina 6 Loznica	Drina 7 Ušće	Ljubovića 1	Ljubovića 2	Drinjača 1	Drinjača 2
Burbot *Lota lota*						+	+				
Eurasian perch *Perca fluviatilis*				+		+	+				
Common ruffe *Gymnocephalus cernuus*			+		+						
Striped ruffe *Gymnocephalus schraetseri*			+	+	+	+	+				
Zander *Sandra lucioperca*							+				
Zingel *Zingel zingel*				+			+				
Streber *Zingel streber*			+		+		+				
Pumpkinseed *Lepomis gibbosus*					+	+					
European bullhead *Cottus gobio*	+	+		+							
Fish species number	14	12	16	22	18	23	27	3	5	4	6

Table 8 Occurrence of lamprey and fish species in two localities (Krstonošić oxbow and Vok canal) of the Obedska swamp, in the River Bosut as well as in the River Kolubara and its tributaries, listed in order by their position from the upper section downstream and by stream order (with numbers, in rising order from headwater section downstream) where applicable

Fish species	Krstonošić	Vok	Bosut	Kolubara 1	Kolubara 2	Jablanica	Obnica	Gradac 1	Gradac 2
Ukrainian lamprey *Eudontomyzon mariae*				+					
Brown trout *Salmo trutta*								+	+
European grayling *Thymallus thymallus*								+	
Northern pike *Esox lucius*	+	+	+						
Bream *Abramis brama*	+	+	+		+				
White bream *Blicca bjoerkna*			+						
Blue bream *Abramis ballerus*			+						
Tench *Tinca tinca*	+		+						
Common carp *Cyprinus carpio*	+		+						
Crucian carp *Carassius carassius*	+								
Giebel carp *Carassius gibelio*	+		+						
Rudd *Sacrdinius erythrophthalmus*	+		+						
Asp *Aspius aspius*			+						
Roach *Rutilus rutilus*	+	+	+						
Bleak *Alburnus alburnus*	+	+	+		+				
Spirlin *Alburnoides bipunctatus*						+	+	+	+
Minnow *Phoxinus phoxinus*								+	+
Chub *Squalius cephalus*				+		+		+	+
Nase *Chondrostoma nasus*				+					
Orfe *Idus idus*			+		+				
Common barbel *Barbus barbus*				+					
Brook barbel *Barbus balcanicus*				+		+	+	+	+
Gudgeon *Gobio gobio*						+	+		
White bighead *Hypophthalmichthys molitrix*			+						

(continued)

Table 8 (continued)

Fish species	Krstonošić	Vok	Bosut	Kolubara 1	Kolubara 2	Jablanica	Obnica	Gradac 1	Gradac 2
Stone loach *Barbatula barbatula*				+		+	+		+
Spined loach *Cobitis taenia*	+								
Wells *Silurus glanis*	+	+	+						
Brown bullhead *Ameiurus nebulosus*			+						
Burbot *Lota lota*		+							
Eurasian perch *Perca fluviatilis*		+	+						
Common ruffe *Gymnocephalus cernuus*			+						
Zander *Sandra lucioperca*			+						
Volga zander *Sandra volgense*			+						
Pumpkinseed *Lepomis gibbosus*	+	+							
European bullhead *Cottus gobio*								+	+
Fish species number	12	8	19	6	3	5	4	7	7

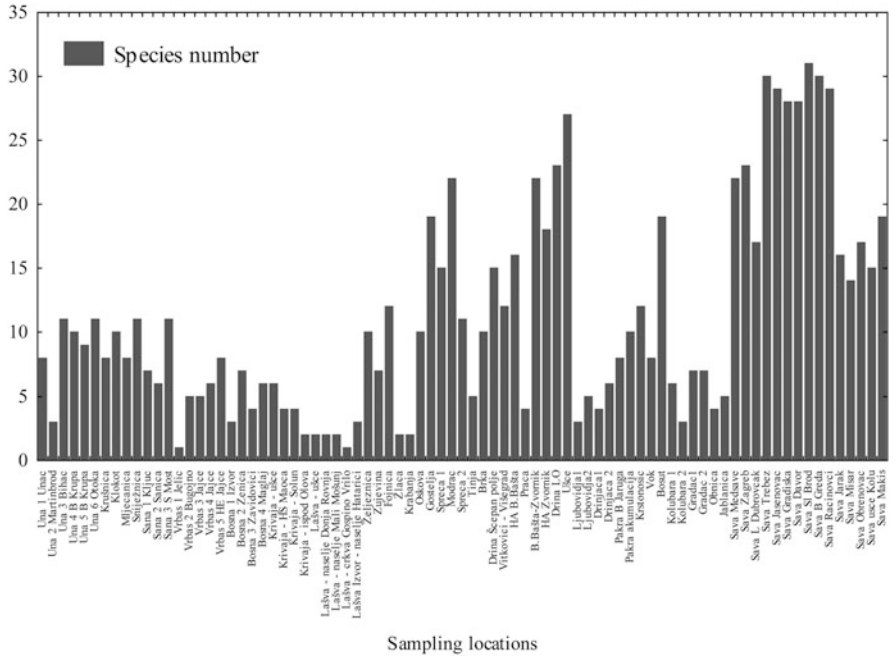

Fig. 1 Number of lamprey and fish species for streams and rivers at localities in the River Sava catchment

assigns the type of fish communities in streams of the River Sava catchment (Fig. 3). In contrast to that, there is no correlation ($r^2 = 0.147$; $p > 0.1$) with the Evenness Index J (Fig. 2). Likewise, considering only the River Sava, the increase in order downstream is not significantly correlated either to the fish biomass ($r^2 = -0.208$; $p > 0.1$) or their annual natural production ($r^2 = 0.308$; $p > 0.1$).

Streams and rivers in the River Sava system with the similar E_i values usually clustered together, but some of them deviated from that general pattern at the first glance (Fig. 4). The most distinct main cluster standing apart from all others was that of upper rhithron streams Ljubovida 1, Krabanja, Zlaća, Vrbas 1 Jelić, and Lašva 2 crkva, holding either exclusively or predominantly brown trout with associated minnow and brook barbel in much smaller abundance. All other upper rhithron fish communities (e.g., Una 2 Martinbrod, Sana 2 Sanica, Vrbas 2 Bugojno, Prača, Lašva 2, 3, and 4, Bosna 1 izvor, Fojnica, Krivaja 1 Olovo and 2 Solun, and Gradac 1 and 2) homed also other fish species of the upper rhithron fish community (e.g., European bullhead and stone loach) in greater abundance but also some of fish species (e.g., grayling, spirlin, and common gudgeon *Gobio gobio*) that belong to the next, middle rhithron type of fish community, which clustered them with the streams of that type that were the greatest cluster comprising the majority of fish communities. River Sava was regularly divided for its fish community character: middle rhithron fish communities from the section Zagreb–Babina Greda clustered

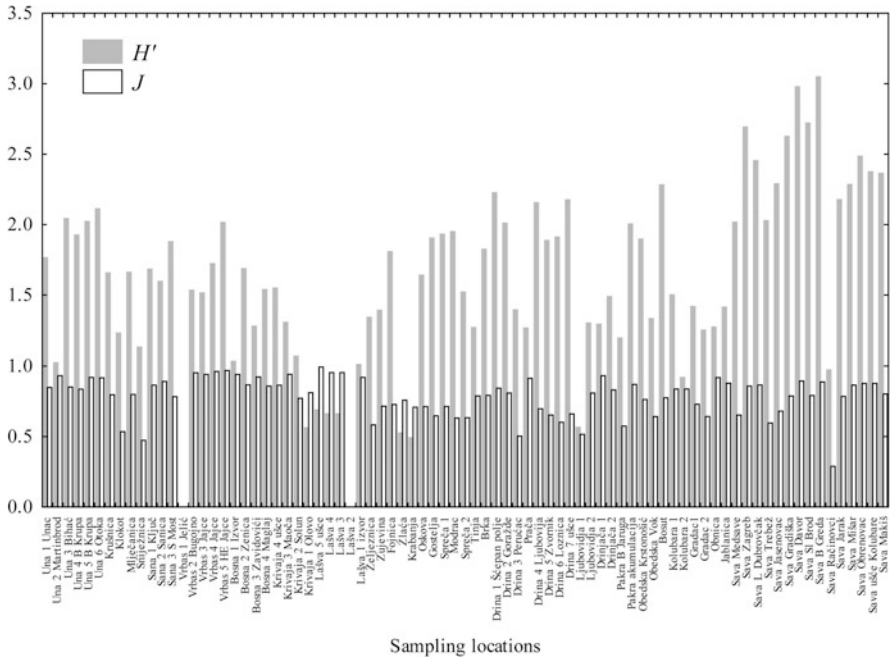

Fig. 2 Shannon Diversity (H') and Evenness (J) Indices for generated from records for structure and abundance of lamprey and fish species in streams and rivers at localities in the River Sava catchment

distinctly, as well as those of the character of potamon from the section Mišar–Obrenovac–Makiš. Only the section in Jarak was more similar to the lowest, lower rhithron sections (6 Loznica and 7 ušće) of the River Drina. Potamon fish communities in lentic habitats (e.g., Modrac, Pakra reservoir, Drina 5 Zvornik, Obedska Vok, and Obedska Krstonošić) clustered irregularly in various clusters with the lotic habitats.

Patterns revealed for the similarity in structure of fish community were even more pronounced using the data set with the only presence and absence of particular fish species in fish communities (Fig. 5). Fish communities in lower and middle sections of the River Sava and of streams Ljubljanica, Kolpa, Mirna, Krka, Sotla, and Savinja were more similar to those in the sections of the River Sava from Jasenovac and Gradiška to Babina Greda. However, fish communities from the Rivers Sava Bohinjka, Sava Dolinka, and Sora clustered with those from the streams that have both upper rhithron fish community, e.g., Klokot and Krušnica in the River Una drainage area, and the fish community that is transitional to the middle rhithron, e.g., the Rivers Una, Sana, and Drina in their most lotic sections at Bihać, Ključ, and Šćepan Polje, respectively.

In RDA with 74 fish species as response variables, first four axes were retained in the analysis, accounting for 80 % of the total variability explained by fish abundance (Table 9). The Monte Carlo permutation test showed that 11 fish species were

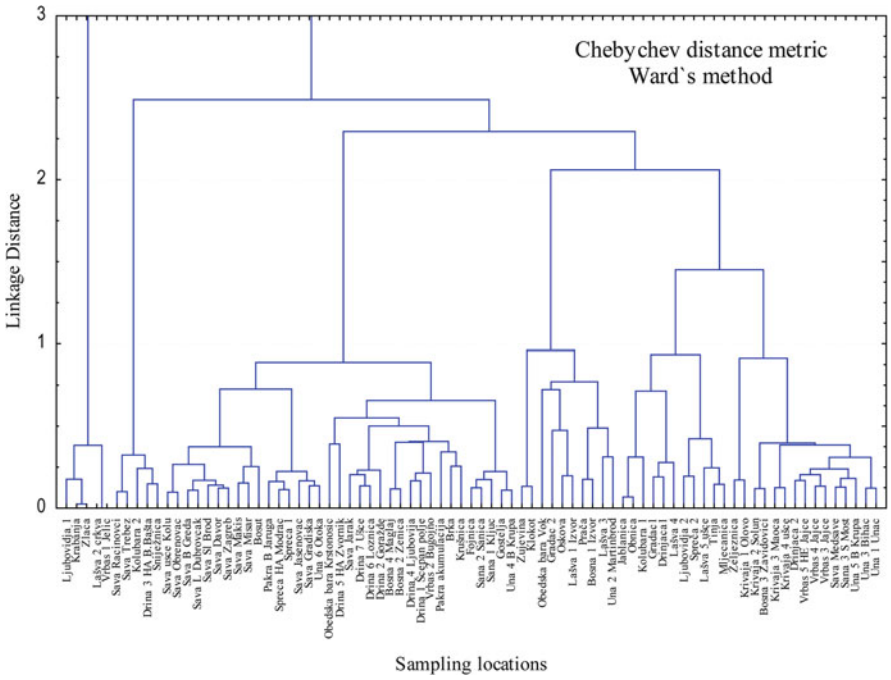

Fig. 3 Relationships between fish communities ascertained using the Ward's clustering of Chebyshev distances between them, as revealed from abundance data recorded in streams and rivers at sampling localities in the River Sava catchment

statistically significant at the levels $p < 0.05$ and $p < 0.01$ as representatives of particular river zones, i.e., fish communities (Fig. 5). Localities with the upper rhithron fish communities (e.g., the spring section of the Rivers Bosna, Vrbas, Una, Sana, Drinjača, and Lašva, as well as the Rivers Gradac, Ljubovića, Zlaća, Krabanja, Prača, Krušnica, and Žujevina) were explained with characteristic fish species for that type of fish community (e.g., brown trout, minnow, and European bullhead). Spirlin and brook barbel, which according to the E_i values characterize the upper rhithron fish community, determined fish communities at several localities in the streams (e.g., Obnica, Jablanica Brka, Tinja, Oskova and Gostelja, upper Rivers Drina and Kolubara, as well as lower Rivers Una, Lašva, Krivaja, and Drinjača) that were transitional to the middle rhithron type of fish community. Likewise, they were closely associated with chub and common gudgeon (e.g., in the middle course of Rivers Una, Sana, Drina, Bosna, Spreča, and Sava at several localities). Though being considered common members of the middle rhithron fish community, nase appeared slightly transitional toward the lower rhithron fish community (e.g., at particular localities in middle section of the Rivers Sava, Drina, and Spreča). Fish typical for the lower rhithron, e.g., bleak, were interconnected with the typical potamon fish representatives, such as common bream, northern pike, ide, Balon's ruffe, and racer goby. Those species were

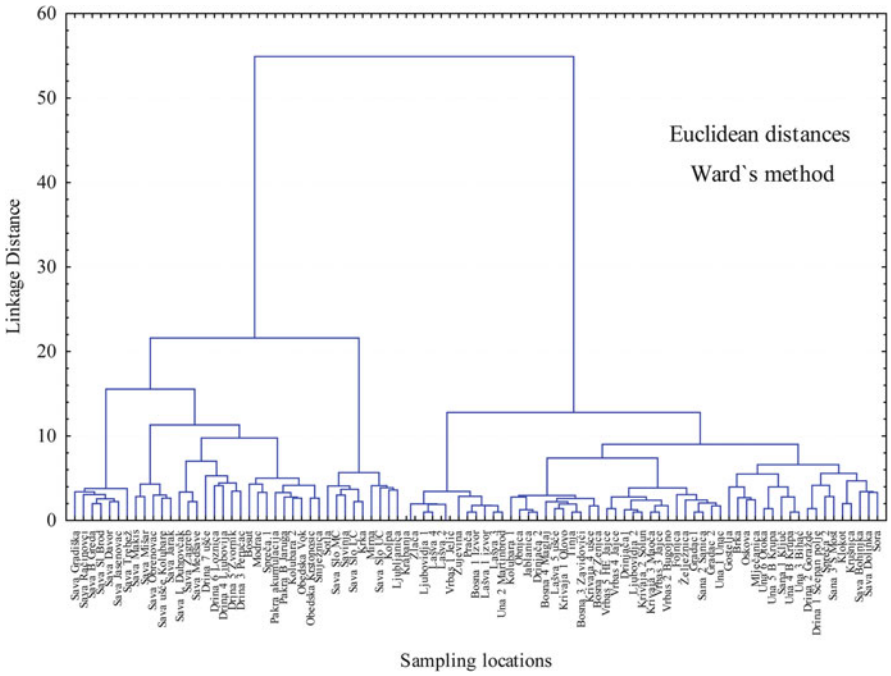

Fig. 4 Relationships between fish communities ascertained using the Ward's clustering of Euclidean distances between them, as revealed from occurrence of particular lamprey and fish species in streams and rivers at particular sampling localities in the River Sava catchment

more closely related to river sections homing the potamon fish community (e.g., Vok and Krstonošić at the Obedska swamp and River Pakra reservoir) than to the lower rhithron fish community (e.g., in the River Sava at localities Obrenovac and join of the River Kolubara, as well as in the River Drina at the Zvornik reservoir).

Survey of Fishery Management Plans available for the Croatian, bordering Croatia/Bosnia and Herzegovina and Serbian sections of the River Sava, revealed in general that there is no clear gradient in the level of productivity that follows the change of the fish community structure (Fig. 6). The greatest biomass record was for the fish community sampled at the locality Mišar (near Šabac, Serbia) characterized as potamon (Table 9). The second greatest one was that at the locality Medsave, the most upstream one in Croatia, whose fish community was characterized as transitional between the middle rhithron and lower rhithron. Annual natural production also did not reveal regular gradient. The greatest absolute natural production followed the greatest biomass record at the locality Mišar in Serbian section. However, the ratio of 16.26 % between them was less than that at the localities Jarak and Makiš, where that ratio was 38.59 % and 22.25 %, respectively. Despite the potamon character (Fig. 3) that fish communities at particular localities in the most downstream sections (e.g., Obrenovac and ušće Kolubare) of the River Sava in Serbia had, their values for biomass and natural production were not that

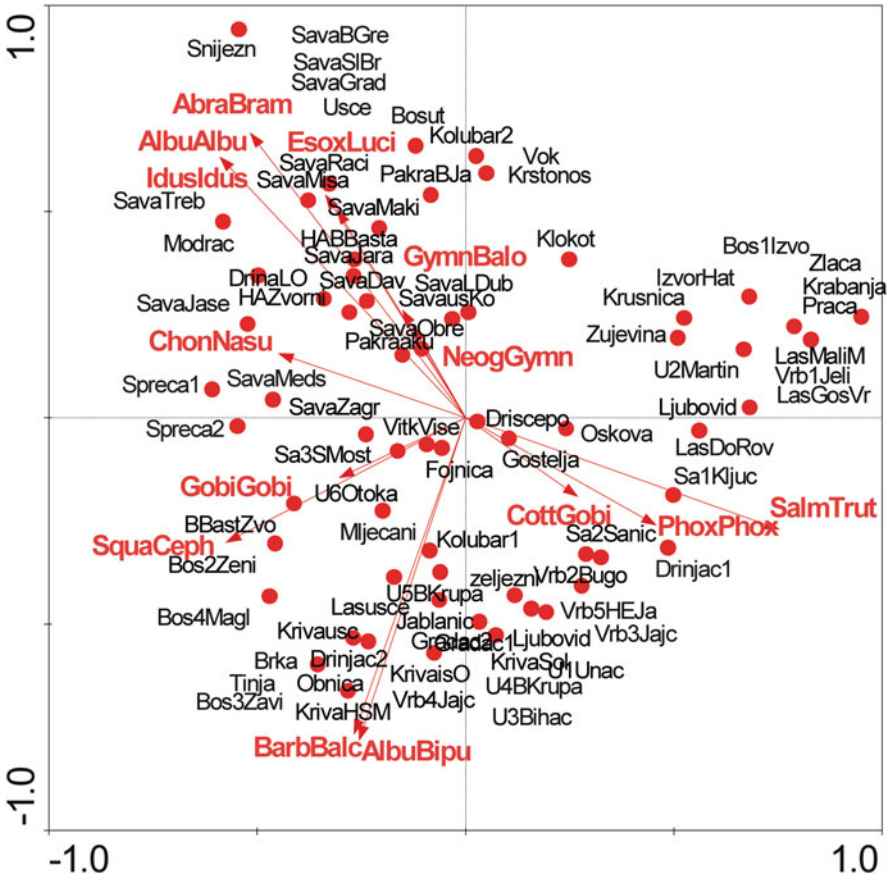

Fig. 5 RDA ordination of fish communities and river sections (explanatory variables: SalmTrut = *Salmo trutta*; PhoxPhox = *Phoxinus phoxinus*; CottGobi = *Cottus gobio*; BarbBalc = *Barbus balcanicus*; AlbuBipu = *Alburnoides bipunctatus*; SquaCeph = *Squalius cephalus*; GobiGobi = *Gobius gobius*; ChonNasu = *Chondrostoma nasus*; IdusIdus = *Idus idus*; AlbuAlbu = *Alburnus alburnus*; AbraBram = *Abramis brama*; EsoxLuci = *Esox lucius*; GymnBalo = *Gymnocephalus baloni*; NeogGymn = *Neogobius gymnotrachelus*)

different from those at particular localities in Croatian and bordering sections with fish communities of lower rhithron type, e.g., at Gradiška and Zagreb (Fig. 6). Both biomass and annual natural production of 13 fish species in the Krstonošić oxbow of the Obedska swamp out of the spawning season in the late summer 2011 were extremely high, in difference to the biomass and annual natural production in the Vok canal that connects River Sava to the Krstonošić oxbow.

The fish productivity recorded in the main tributaries of the River Sava was less (Table 9). For the Rivers Bosna, Vrbas, and Drina, biomass varied at particular localities in similar ranges, with the proportion of huchen of 1–2 % in that biomass at particular localities. Its tributary Krivaja was also very rich in fish, whereas the

Table 9 RDA output results on four axes, with their eigenvalues (λ), response–explanatory correlations (R.E. corr), cumulative percentage variance of response data (CPVRD), cumulative percentage variance of response–explanatory relation (CPVR-ER), sum of all eigenvalues ($\sum\lambda_i$), and sum of all canonical eigenvalues ($\sum\lambda_{ci}$)

Axes	1	2	3	4	Total variance
λ_i	0.223	0.146	0.051	0.036	1.000
R.E. corr	0.887	0.892	0.785	0.773	
CPVRD	22.3	36.9	42.0	45.6	
CPVR-ER	39.3	64.9	73.9	80.3	
$\sum\lambda_i$					1.000
$\sum\lambda_{ci}$					0.568

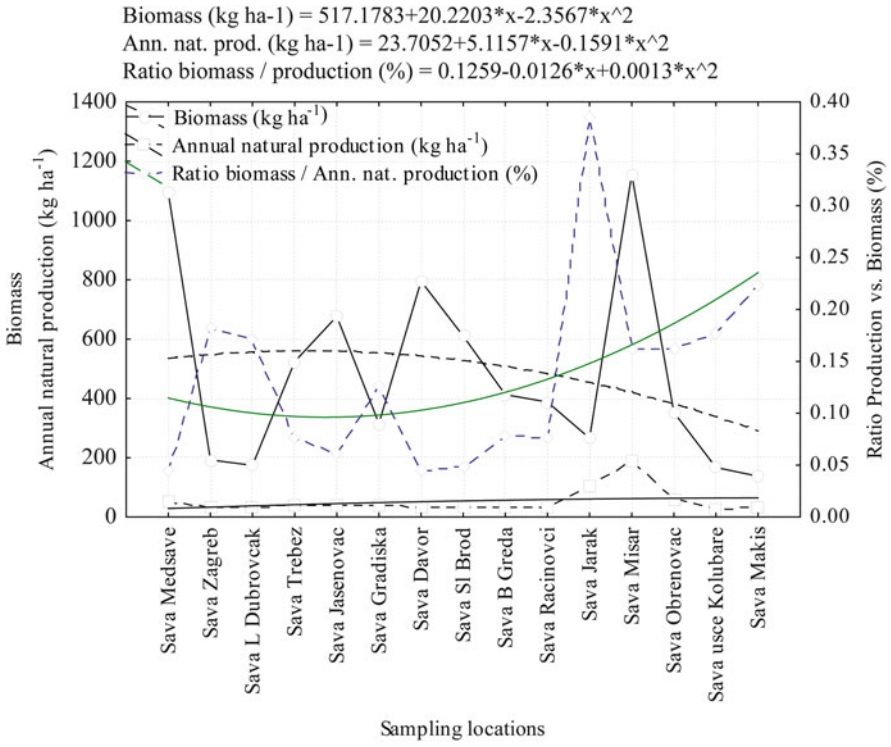

Fig. 6 Biomass, annual natural production, and ratio between them, as revealed from the records for samples from the River Sava in Croatian and Serbian sections at particular localities

most productive fishery was that of the River Spreča in the vicinity of the city of Doboj in northeastern Bosnia, majority of which (72.7 %) consisted of chub, nase, and common bream [53]. The most productive section of the River Drina was the Drina 3 Perućac section. In other sections, both biomass and annual natural production were less. The very big values for biomass and annual natural

production were recorded for the lower section of the River Jadar, a tributary of the River Drinjača in the eastern Bosnia and Herzegovina in the River Drina drainage area. Although both biomass and annual natural production in the brown trout streams (e.g., River Rača, River Rogačica, Gornja Trešnjica stream, all three being tributaries of the Drina River in the Drina 4 section) were commonly much less in comparison to those in streams given above, there are streams (e.g., Gradac stream, a tributary of the River Kolubara) where great biomass and annual natural production of brown trout add mostly to their great overall productivity.

4 Discussion

Survey of the lamprey and fish fauna in the catchment of the River Sava was accomplished using the valid nomenclature that provides continuity with the previous records containing species listed for various parts of the River Sava catchment. The variety in capability of contemporary researchers to identify particular de novo promoted fish species (e.g., *Alburnus sarmaticus*, *Carassius auratus*, and *Cottus metae*) closely related to the common and widespread ones (Danube bleak *Chalcalburnus chalcoides*, Prussian carp, and European bullhead, respectively) in various regions of the catchment and to report them is to be considered another important reason. Neglecting any of those reasons might result in either lacking of valid records or excessive heterogeneity in occurrence of fish and lamprey species in reports published so far, which decreases the opportunity to make competent comparisons and reliable inferences about differences and changes that explain faunistic and community structure in the River Sava catchment.

4.1 Overall Taxonomic Diversity

In comparison to other European catchments, that of the River Sava seems similar in taxonomic diversity of lamprey and fish species to that of Europe in general ($b = 0.236$ for seven catchments), being slightly less than taxonomic diversity of Greece ($b = 0.240$ for 12 catchments), but slightly greater than that of Portugal ($b = 0.190$ for 12 catchments) [45]. It seems that the size of its catchment is large enough to comprise the diversity of lamprey and fish fauna representative in European scale, holding species common to the River Danube drainage area that belong to two great zoogeographic subregions (Mid-European and Ponto-Caspian) of the Palearctic [54].

4.2 Fish Community Structure

Very complex data set revealed several patterns of fish community structure for different kinds of inland waters in the River Sava drainage areas. The most distinct cluster of headwaters of stream orders 1 and 2 comprising the source section of streams Ljubovića, Zlaća, and Krabanja, as well as of the upper section of the River Lašva and source section of the River Vrbas, featured the purest upper rhithron fish community (Fig. 3) consisting exclusively of brown trout *Salmo trutta* (Fig. 4). Other upper rhithron fish communities in headwaters of other streams and rivers comprising other fish species common for that type of fish community (e.g., minnow, brook barbel, European bullhead, and stone loach) were characterized as more or less transitional toward the next, the middle rhithronic type of fish community occurring downstream. That type of fish community was associated with particular fish species (e.g., spirlin, chub, nase, and/or common barbel) featuring it. The position of those streams and rivers in the series of clusters was either determined by occurrence and abundance of particular species characteristic to the downstream middle rhithronic fish community of the same river system (e.g., two most upstream sections of the River Sana in the areas of Ključ and Sanica, stream Željeznica that joins the River Krivaja) or by similarity in that kind of association across the same kind of distant waters belonging to different river systems (e.g., the spring sections of streams Gradac in the River Kolubara drainage, Drinjača in the River Drina system, and Lašva in the River Bosna system; headwater sections of Rivers Una and Bosna, stream Lašva in the River Bosna system; and downstream section of the stream Gradac in the River Kolubara system). The second prominent pattern of fish community determination features also transitional middle rhithron fish communities of distant large rivers, e.g., downstream section of the River Drinjača, River Vrbas at Jajce, River Sana at Sanski Most, River Una at Bosanska Krupa, and River Sava at Medsave (Fig. 3).

Although fish community in the section of the River Sava at Medsave resembles to other middle rhithron fish communities, in the rest of its course, it shows two main community types: the ones being lower rhithron, situated more upstream from Zagreb to Babina Greda, and those situated more downstream from Mišar (near Šabac) to Obrenovac and Makiš, which have the character of potamon (Fig. 3). It is evident that fish in the River Sava and in the most downstream sections of its main tributaries impact each other's fish communities. The lower rhithron fish community of the River Sava at Jarak resembles more to those of the closely situated most downstream sections of the River Drina (at Drina 6 Loznica and Drina 7 ušće at the junction to the River Sava). Likewise, the lower rhithron fish community of the River Sava at the sections at Jasenovac and Gradiška resembles more to that in the most downstream section of the nearby situated River Una at Otoka. Fish communities in certain upstream, i.e., middle sections of the River Sava (e.g., at Račinovci and Trebež), reveal almost the potamon character, making them more similar to the fish community of the lowermost section of the River Kolubara in the most downstream section of the River Sava, as well as to fish communities of the Perućac reservoir (Drina 3 Perućac) of the River Drina and Sniježnica reservoir.

Another prominent feature is the distinctness of middle rhithron fish communities in the large rivers that flow to the River Sava, e.g., the River Drina, which resembles to particular sections of the River Bosna, as well as of the River Vrbas for the structure of its fish communities along its course (Fig. 4). That distinctness clearly delimits them from smaller rivers and streams that hold also fish communities whose structure assigns them middle rhithron character, e.g., upper River Kolubara with the streams Obnica and Jablanica, lower section of the River Drinjača, as well as Rivers Lašva and Krivaja in their middle and lower sections. That difference in middle rhithron fish community structure between large and smaller rivers results in grouping together almost all (five of seven) sections of River Drina, with only the first, the most upstream section at Šćepan Polje, and third, the reservoir Perućac section standing aside from the rest of them. The series of sections reveals the gradual change of the structure of fish communities along the River Drina, retaining sufficiently similar abundance of the most common fish species in the neighboring, successive sections to maintain the resemblance and retain the character of middle rhithron fish community. That succession along the river course features also Rivers Bosna and Vrbas, though in much shorter sections (Fig. 3). For their fish community structure in general, all those large tributaries (Rivers Vrbas, Bosna, and Drina) are more similar to the section of River Sava corresponding them for the fish community structure and geographic position than to their lower-order smaller tributaries. In addition to those two types, there is a group of middle rhithron fish communities in large Rivers Una and Sana, which clearly stand apart from those in both large and small rivers, resembling more to those in the group of streams and smaller rivers than to large rivers (Fig. 4). That supports in general the significant correlation between the increase in stream and gradual increase in the number of fish species (Fig. 1), which adds to the complexity of fish communities and their diversity.

Break in succession of fish community structure of the River Drina (Fig. 4) is probably caused by damming and pollution, respectively. Fish communities of the River Drina in sections 1 Šćepan Polje and 4 Ljubovija were more similar to each other than to the adjacent sections of 2 Goražde, 3 Perućac, and 5 Zvornik, due to the change in the fish community structure from middle to the lower rhithron and even to the potamon that occurs in reservoirs constructed there. The "tailwater" effect of dams on the restoration of middle rhithron fish community in sections downstream of reservoirs is evident in the Drina 4 Ljubovija section downstream of the Perućac reservoir. Similar effect is also evident in the section Spreča 2 downstream of the Modrac reservoir. That effect in general adds to the fishery value by increasing the variety of fish species for angling.

In addition to the riverbed regulation activities for the flood control and water transportation purposes on the River Sava and its tributaries that commenced already in nineteenth century, damming is the next most widespread activity, with the six high dams occurring in the Slovenian section, as well as eight, two, and one high dams in drainage areas of the Rivers Drina, Vrbas, and Bosna, respectively. Only two of those 17 high dams have the operational fish passes. Apart from the obstruction of migration in potamodromous fish, the alteration of habitat in reservoirs resulted in the strong shift of their fish communities. That shift

was usually from middle rhithron community featuring the nearby lotic river sections toward the potamon (e.g., in the Pakra, Zvornik, and Modrac reservoirs). Less frequently, that shift was toward the lower rhithron (e.g., in the Perućac reservoir) (Fig. 3), which was in addition to damming strongly aided by stocking activities that followed it, allegedly aiming to increase the fishery value of reservoirs. That forced the disappearance of native fish species in the altered lentic environment, resulting in even lower diversity than in adjacent lotic river sections (Fig. 2).

4.3 Productivity of Fishery

The lack of correlation between downstream increase in order of the River Sava at the localities Trebež, Jasenovac, Davor, Slavonski Brod, Babina Greda, and Račinovci and fish biomass and increase in order and annual natural production comes from the occurrence of strong and irregular fluctuation in biomass, annual natural production, and ratio between those two parameters. That suggests the harvesting of yield in a very strong intensity there. It is also likely that the productivity level is related to the availability and/or size of the floodplain zone area necessary for the spawning of majority of fish species. The most productive sites in the River Sava valley (the area of Posavina) that serve as spawning grounds are those of Lonjsko Polje in Croatia, Bardača in Bosnia and Herzegovina, and Obedska swamp (here represented with two localities, Krstonošić and Vok) in Serbia, which remained connected to the main riverbed after its regulation as backwaters affected by seasonal flooding. High values for annual natural production in relation to those of biomass at localities Jarak and Makiš are likely a consequence of sufficient spawning areas in the floodplain zone occurring there, with the dikes set sufficiently far apart from the main riverbed and several large wetlands, where high biomass and annual natural production add to that of the main riverbed.

There is also a prominent variability in biomass and natural production in tributaries of different order. Explanation of that variability still lacks, due to scarcity of data about the productivity at other trophic levels in them. In addition to that, it is difficult to judge about the similarity between rivers of different sizes for the relative fish biomass and annual natural production without the data about the fishing pressure, i.e., fishing rate occurring there, which usually do not exist. For example, the extremely high values for the biomass of fish occur for the River Gradac (in the headwater section of the River Kolubara in Serbia), whose greatest part consisted of brown trout and where the catch-and-release fishing regime was enforced in the first decade of the twenty-first century. Those values greatly overcome the values for the biomass of brown trout in streams of similar size holding the upper rhithron fish community, where the fishing control is scarce and brown trout was used to be landed on catching and taken out by poaching. However, the annual natural production in the River Gradac was only slightly greater in comparison to those streams, implying the similar level of productivity for fish in them. That implies the questioning of justification of the unconditional catch and

release as a measure of fishery management. On the other hand, there might be some other reasons that influence the productivity of trout streams. The vast majority of trout streams are typical stone creeks, with the low level of productivity in them in comparison to the stone creeks that hold fish farms rearing rainbow trout. Those farms add the nutrients into the feeding stream and increase their productivity to some higher level. A relative new circumstance is occurrence of tailwaters and their effect on fishery, especially that on the fly-fishing for trout and grayling but also on the coarse fishing to other fish species (e.g., nase, chub, Danubian rudd, and common barbel) that are traditionally target of recreational anglers in the area of the Balkans. It is not still clear if tailwaters, in addition to the restoration of native fish communities, also raise the productivity level. Considering the relative scarcity of records about the productivity of fish communities in Fishery Management Plans and a common lack of fishery statistics, that effect will be hard to infer. It seems that the most productive type of stream is chalk streams, which are much more rare than stone creeks in the River Sava catchment, especially those that feed fish farms with water and receive additional nutrients from them (e.g., the River Ribnik, a tributary of the River Sana in the River Una drainage area in Western Bosnia). Their very rich and diverse fish communities are especially convenient for the setting of the highest grade of fishery. However, the management with those fisheries whose ecosystem is strongly pushed to its mere limits should be accomplished very carefully from both environmental and conservational point of view. For the more reliable inferences about the productivity of fish communities and its various implications for the fishery, however, more complete and accurate data are necessary.

4.4 Alien and Invasive Fish Species

Nonnative fish species in the River Sava catchment and their status were recently and partially assessed in the study of Simonović et al. [55], where for waters of the most downstream, Serbian section, the Prussian carp was assigned the most invasive alien fish species, followed by brown bullhead. That assessment revealed the very high risk they pose to the recipient ecosystems they enter into, due to their environmental versatility, adaptability, and reproductive traits. Those traits are favored by both features of environment (i.e., habitat) and structure of lower rhithron and potamon fish communities common for the lower section of the River Sava and tributaries that join it, with the oxbows, side arms, and marshes connected with them.

There are certain records about the introduction of alien trout species (e.g., rainbow trout, brook trout, Arctic charr *Salvelinus alpinus*) and of hatchery-reared brown trout of the Atlantic strain into the appropriate environment of mountain streams throughout the River Sava catchment [19, 20, 43, 56, 57]. Nevertheless, the reports about their impact on the native trout species and strains in the recipient ecosystems are still scarce and arbitrary. The main vectors for their entrance into the waters were aquaculturists and fishery managers, as revealed clearly in Slovenia by Marić et al. [56]. There are reliable records about the introgression of the stocked

brown trout of Atlantic and marble trout *Salmo marmoratus* strains into the gene pool of the native brown trout of Danubian lineage [20, 43, 57, 58]. In addition, there are also yet unconfirmed hints about the naturalization of the feral rainbow trout in the streams of Slovenia. That must be thoroughly investigated, since that poses additionally high risk and shed different light on the currently low invasive potential of this alien fish species widely spread in aquaculture.

4.5 Conservation of Indigenous Diversity

Considering the great size of the River Sava drainage area in the northwestern Balkans and great habitat and ecological diversity of aquatic ecosystems in it, it is to expect that more diversity, especially that on the level of genetics similar to the diversity found for grayling [40], is to be assessed using the molecular techniques. Preliminary results on the genotyping of huchen stocks [41, 42] from Slovenia, Serbia and Montenegro in the River Sava drainage area revealed monomorphism at the mtDNA level. That was confirmed by Weiss et al. [59] and supported by both the low level and large geographic scale of variability in two microsatellites occurring in stocks from Serbia, Bosnia and Herzegovina, and Montenegro. The low variability level was explained by relatively late immigration of taimen from Siberia during the last Quaternary glaciation [60–62] and specific life-history characteristics such as long life span, small population size, and low metabolism level [63]. The discovery of the three unique alleles at the HLJZ003 microsatellite locus in huchen from the territory of Serbia (in the River Drina and upper section of the River Ibar) warns for caution in the application of fishery measures and activities for the sake of the conservation of native stocks in the River Sava catchment.

The recent advance in genotyping contributed to the assessment of alien strains and lineages of particular native salmonid species in streams of the River Sava catchment. The introduction of the hatchery-reared, i.e., domesticated brown trout of Atlantic mtDNA (At) lineage (sensu [64, 65]) into the River Sava catchment started in Slovenia far back in 1920 [66], where almost all streams in the River Sava drainage area were widely stocked [56]. However, the first record of brown trout of At lineage in Serbia was in the River Gradac, the River Kolubara headwater [44], where it established so far, showing invasive character [57]. Likewise, the Da25 mtDNA haplotype of grayling native to streams and rivers in the River Sava catchment in Slovenia was found as introduced into the River Drina in frequency of 40 % [40]. Advance in knowledge about the indigenous character of brown trout and grayling stocks throughout the River Sava catchment area will lead to the more effective conservation measures in the fishery management with them.

In addition to fish species listed and explained in the chapter dealing with the threatened species in the River Sava catchment [67], there are two especially important threatened fish species. The first one is the mudminnow *Umbra krameri*, of the IUCN status V (vulnerable) A2c, whose historical occurrence in the River Sava catchment was recorded for the River Lonja at Lupoglav in Croatia, in 1899 and 1908, as well as for the floodplain area in Surčin, upstream of Belgrade in 1950s

[68]. IUCN [69] stated that the main threatening factors causing the decrease of mudminnow are river regulation for water transport that reduces the oxbows and drainage of wetlands to arable land. The contemporary findings in the Zasavica swamp area in Serbia, downstream of the junction of the River Drina with the River Sava [70], and in the Gromiželj wetland in Bosnia and Herzegovina, upstream of the junction with the River Drina [71], lead to declaring protected areas for both of those recent habitats of mudminnow. The other important fish species is huchen, which inhabits the southernmost part of its dispersal area in the River Sava catchment. Its southernmost place of occurrence is the Lake Plav and its tributary Ljuča in the northeastern Montenegro, with the River Lim, which outflows from the Lake Plav and joins the River Drina, where huchen attains the greatest age and size. Giving already the recent discoveries for particular features important for the conservation of this endemics and having in mind the prospect intentions to dam large mountain rivers and to construct myriad of hydropower plants, it is necessary to warn about the importance of this already threatened fish species and to undertake activities for its conservation in situ, from the proper and efficient methods of sampling and data assessment to the implementation of knowledge in the management practices of all activities within the integrative management with the River Sava catchment.

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