

INTRODUCED SPECIES COMMUNITY OVER-DOMINATES ENDEMIC ICHTHYOFAUNA OF HIGH LIKA PLATEAU (CENTRAL CROATIA) OVER A 100 YEAR PERIOD

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108 years after TRGOVČIĆ (1908) authors made a revised list of fish species found in rivers and streams of the Lika region. Throughout the 8 years of investigation a total of 31 species of freshwater fish were recorded, of which only eight are indigenous for this area, for two species the origin is not known, and the remaining 21 species are introduced by anthropogenic activity over the last 100 years. This represents the over-domination of introduced species by the astonishing 300%. All of this increase in numbers causes significant increase in biomass and changes the naturally oligotrophic ecosystem, which might lead to rapid eutrophication and increase of water temperature. Furthermore, induced changes in the system make the habitat more suitable for introduced cyprinid fish, which again causes the increase of biomass production. Endemic fish species are retreating into upper parts of small tributaries and underground cave systems. The present research indicates species *Delminichthys jadovensis*, *D. krbavensis*, *Telestes fontinalis* and *T. croaticus* as real stygophiles, which makes them unique on the European continent.

Key words: ichthyofauna, Lika region, Croatia, fish, distribution, stygophiles

INTRODUCTION

An “introduced”, “non-indigenous”, “alien” or “non-native” species is a species living outside its native distributional range due to either deliberate or accidental human activity (PETTORELLI 2013), and succeed in surviving and subsequently reproducing. The European Union defines “Invasive Alien Species” as species outside their natural distribution area whose introduction and/or spread threaten biological diversity (COMMISSION OF THE EUROPEAN COMMUNITIES 2008). They represent one of the biggest threats to biodiversity in present times, and discussions about their impact on the world economy are increasing (COPP *et al.* 2005). Ecological impacts of invasive alien species (RICCIARDI *et al.* 2013) include predation, competition and hybridization with native species and general alterations of ecosystems (RODRIGUEZ 2006), all of

which lead to invasive alien species being the second largest cause of biodiversity loss (McNEELY *et al.* 2001). Alien species can cause modifications of habitats (GRAROCK *et al.* 2014) because they did not evolve with those habitats (SCHLAEPFER *et al.* 2005) and they effect distribution, abundance and reproduction of many native species (STRAUSS *et al.* 2006). A very high percentage of invasive fish species has been recorded in recent publications on distribution of freshwater fish in Croatian rivers, like Ilova, Česma, Drava and Zrmanja Rivers (MRAKOVČIĆ *et al.* 2006, DUMBOVIĆ *et al.* 2009, JELIĆ *et al.* 2009, 2010, 2012, MROČIĆ-STOŠIĆ *et al.* 2012). Contrary, a sparseness of data on native fish species in the Mediterranean region with very narrow (ŽUTINIĆ *et al.* 2014) or endemic distribution (SMITH & DARWALL 2006) highlights a need to urgently intensify both conservation actions (JONES & OLIVER 2009) and ecological research.

In terms of ichthyology, Lika plateau is one of the most interesting parts of Croatia and Western Balkans, due to high number of endemic species. Despite its attractiveness, the whole area is poorly explored (MRAKOVČIĆ *et al.* 1995). FRANZ STEINDACHNER (1866), Austrian ichthyologist and curator at the Vienna Natural History Museum, was the first who pointed out the potential abundance of endemic species of the region. By examining museum samples from the area he described endemic Croatian minnow, naming it *Paraphoxinus croaticus* (valid name is *Telestes croaticus* Steindachner, 1866). From the list of fish species preserved in the Public Zoological Museum in Zagreb, LANGHOFER (1905) recorded *T. croaticus* and *Anguilla anguilla* (Linnaeus, 1758) for River Lika, and probably *T. fontinalis* (Karaman, 1972) for Krbavsko polje (even though he named it *Paraphoxinus croaticus*). TRGOVČEVIĆ (1905, 1908, 1932) lists eight species for the whole Lika region and claims that "*Paraphoxinus croaticus* Steindachner" is the most abundant species in Lika streams, because "*wherever it lives, and that is in almost every stream... It just thrives, other species are far less represented, and they also live in some streams with no other species found (like Paraphoxinus adpersus in Balatin stream)...*". POLJAK (1924) records *P. croaticus* (*T. croaticus*) in Ljubica stream near Baške Oštarije. Review of more recent studies shows that HABEKOVIĆ *et al.* (1992) recorded *Salmo trutta* Linnaeus, 1758, *T. croaticus*, *Paraphoxinus ghetaldii* Steindachner, 1882 (probably a wrong determination of *Phoxinus lumaireul* (Schinz, 1840)), *Gobio obtusirostris* Valenciennes, 1842 and *Cobitis elongatoides* Băcescu et Mayer, 1969 in several streams of the Zrmanja basin around the town of Gospić (Ričica, Krivak, Suvaja, Banica, Otuča and Opsenica). No native (indigenous) populations of the genus *Squalius* Bonaparte, 1837 exist in the Lika region, except for the introduced *S. cephalus* (Linnaeus, 1758) which originates from the Black Sea drainage basin (BOGUTSKAYA & ZUPANČIĆ 1999, ZUPANČIĆ 2010) and *S. zrmanjiae* Karaman, 1928 from the Zrmanja River. KOTTELAT and FREYHOFF (2007) cite *Padogobius bonelli* (Bonaparte, 1846) and *Pomatoschistus canestrinii* (Ninni, 1883) for the

Ričica River. These species were most likely introduced by reverse hydro-power plant from the Zrmanja River, where they have been recorded before (MRAKOVČIĆ *et al.* 1995). Formerly it was presumed only one species of brown trout in the Lika region, but recent studies show two distinct lineages: Danube lineage (*S. labrax* Pallas, 1814) and Atlantic lineage (*S. trutta* Linnaeus, 1758) (JADAN *et al.* 2007). These two species had also interbred after uncontrolled restocking and it is not possible to distinct them with certainty.

Karstic rivers of Lika region are oligotrophic by origin and characterized by large water oscillations and low yearly mean water temperatures (~9 °C; for more details see BONACCI & ANDRIĆ 2008). Based on available climatic data (Table 1), Lika plateau altitude and terrain slope, we expect these waters to be naturally inhabited by coldwater fish species. Long-lasting human impact on these rivers is increasingly evident in shifts towards water eutrophication and increase of average water temperatures. Main causes for these changes are suspected to be global climate change and large human alternations (see ŽGANEC 2012 for data on rivers from Gorski kotar). However, the impact of accumulated alien biomass on these systems has never been assessed. The aim of this study was to explore negative impacts of non-native species domination over native fish populations in the Lika region. This example is a case study providing valuable insights on how these negative impacts affect Dinaric Arc Karst systems. In addition, a critical review of recent distribution of four endemic fish species is given, with the emphasis on the importance and need for strict protection of river headwaters as their last refuge.

MATERIAL AND METHODS

Study area characteristics

Lika is a vast, elliptically shaped basin bordered with arched rows of towering mountain ridges of Mala Kapela and Plješivica mountains whose bottom lies at an average altitude of 500–700 meters a.s.l. Climatic data of the study area is given in Table 1. Lika region can be divided into three smaller parts: 1) Gacka River with Brinje area, 2) Lika-Gračac basin with the Krbava River and Lika part of the Una River basin, and finally 3) Ogulin-Plaški basin (PAVIĆ 1975). All rivers in the Lika region are characterized as karst sinking rivers and together they produce one of the largest and most interesting hydrogeological systems in Europe (Fig. 1). In hydrological terms this area can be divided into three large sub-areas where drainage basin of Gacka and Lika Rivers (3000 km²) and drainage basin of Zrmanja (700 km²) are parts of a larger Adriatic drainage basin, while drainage basin of Una river (1200 km²) is a part of the Black Sea drainage basin (MARKOVIĆ *et al.* 2000).

Lika River rises at the foot of the Velebit Mountain in the southern part of Ličko polje at the altitude of about 600 m a.s.l. With its 78 km of length it is the largest sink river in Lika region and the second largest in Europe. Main tributaries of Lika are Novčica and Otešica from the left and Glamočnica and Jadova from the right. Besides these, Lika accepts a lot

Table 1. Climatic data for larger towns in Lika region indicating cold alpine climate (source: Croatian Meteorological and Hydrological Service 2014).

Month	Gospić		Korenica		Otočac	
	average air temp. (°C)	precipitation (mm)	average air temp. (°C)	precipitation (mm)	average air temp. (°C)	precipitation (mm)
January	0.3	96.7	-0.5	41.3	-0.2	97.6
February	-1.6	84.4	-2.9	97.8	-2.8	77.6
March	5.1	75.4	3.9	86.5	5.3	63.3
April	10.3	91.0	8.9	93.0	10.0	48.2
May	13.5	103.8	11.9	141.3	13.3	93.9
June	18.7	81.4	16.7	77.6	18.9	45.3
July	20.7	43.4	18.6	78.3	20.4	64.3
August	20.9	22.9	18.6	56.0	20.1	19.5
September	15.7	121.3	14.2	134.5	16.1	117.3
October	10.2	165.4	9.2	111.3	9.4	103.9
November	5.6	176.0	4.4	165.7	5.2	159.5
December	1.6	126.4	0.6	90.3	1.0	77.2

of smaller tributaries like Bogdanica, Brušanica, Lopuža, Rizvanuša, Rakovac, Bužimica, Počiteljica, Crno vrelo and Balatin. It has a typical canyon/gorge riverbed formed by water cutting through the underlying limestone and dolomite rocks. Kruščica reservoir was formed in 1971 by a dam built in the lower part of the river canyon, near the village Mlakva in Kosinj. Afterwards, the river continues its flow to Lipovo polje where it is redirected from its sink hole to Gacka River through the Lika-Gacka tunnel.

Ričica, Otuča and Opsenica Rivers are parts of Zrmanja River drainage basin with which they are connected through underground flows. They are rising through various springs, with Krupa and Krnjeza Rivers being the largest (Bonacci 1990). Štikada reservoir (13 650 000 m³) was built on Ričica River in the period from 1978 to 1985 as a part of Velebit reverse hydro-power plant complex. The lake was subsequently connected to Opsenica reservoir (2 700 000 m³) and Otuča River to obtain better water supply.

Krbava and Matica (Korenica), streams of Krbavsko and Koreničko poljes, are parts of the smallest Una River drainage basin. Water from both poljes sinks and flows underground to the Una River spring in the vicinity of Donji Srb village.

Methods used

During the period from 2006 to 2013 a total of 51 locations on four distinct drainages in the Lika region were sampled (Lika and Jadova; Gacka; Ričica, Otuča and Opsenica; Matica and Krbavsko polje). Sites were chosen according to accessibility and absence of mine fields (Table 2, Fig. 1). Standard fishing equipment was used, according to size and depth of a specific water body. Three one-layer nets were used: 1) 50 m × 2.2 m, eye diameter 6 cm; 2) 19 m × 3 m, e. d. 4 cm; 3) 23.5 m × 1.4 m, e. d. 2 cm). Nets were set up in the water overnight and pulled out in the morning. SAMUS 725MP backpack device for

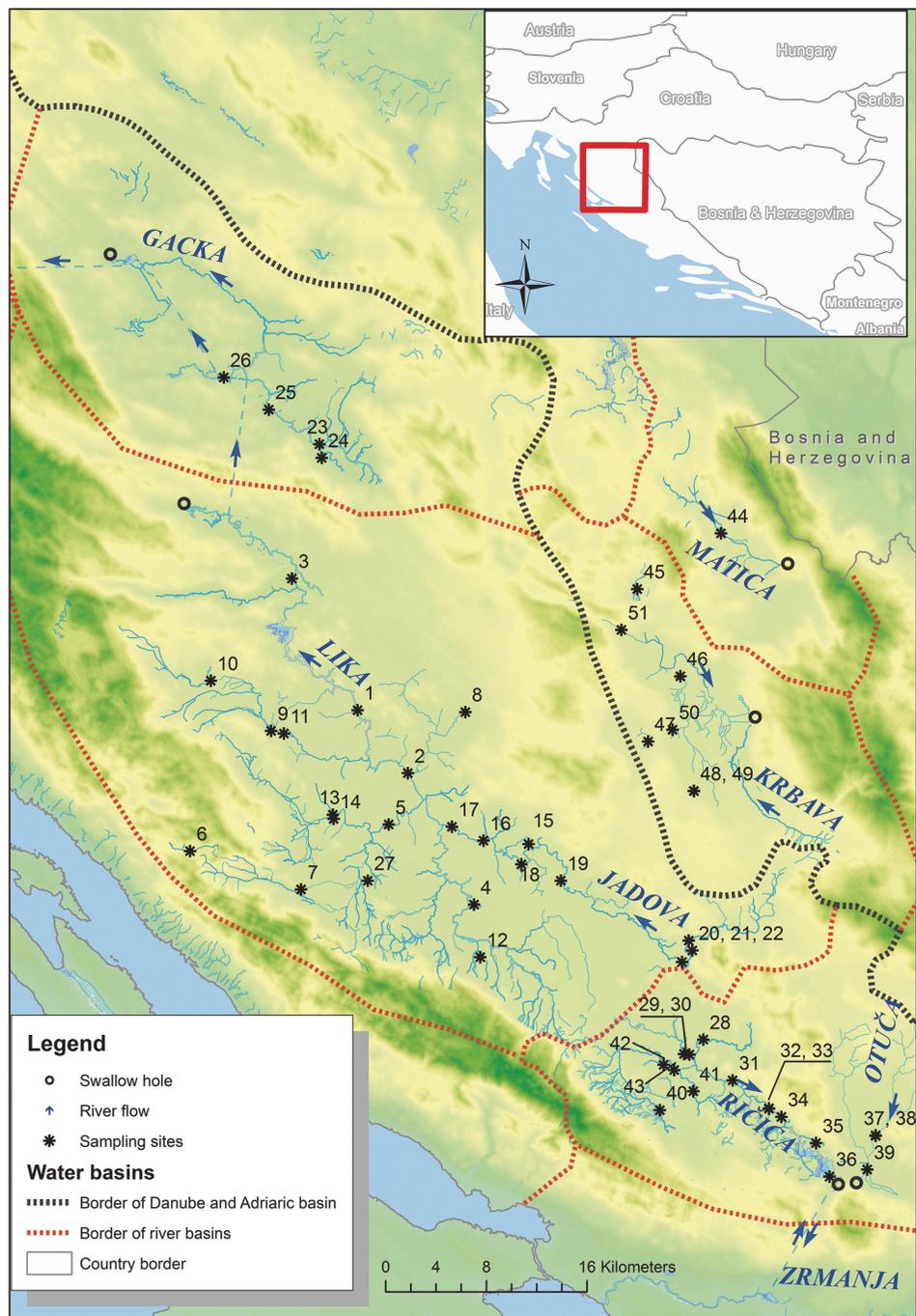


Fig. 1. River systems of high Lika plateau with all 51 sampling sites.

Table 2. List of localities visited (plotted in Fig. 1; X and Y are presented in Gauss-Kruger 5th zone coordinate system) in the high Lika plateau, habitat types, sampling methods and effort (fishing hours). Abbreviations: electrofishing = EF, fishing nets = FN, diving = D.

Code	Locality	X	Y	Habitat	Method	Effort
1	Lika, Malo selo	5527632	4942417	Main river	EF / FN	8
2	Lika, Gospić bridge	5531631	4937431	Main river	EF / FN	8
3	Lika, Kosinj	5522415	4952842	Lake	EF / FN	8
4	Lika, Lički Ribnik	5536899	4927023	Main river	EF / FN	8
5	Novčica in Gospić	5530112	4933366	Main river	EF / FN	8
6	Ljubica, Oštarijsko field	5514320	4931264	Stream	EF	1
7	Brušnica, Suvaja	5523144	4928221	Stream	EF	1
8	Lički Osik, Široka Kula, Balatin stream	5536210	4942267	Stream / spring	EF	1
9	Otešica, Jelići	5520763	4940779	Main river	EF	2
10	Otešica, Pazarišnica	5515969	4944748	Main river	EF	1
11	Otešica, Rastoke	5521775	4940573	Main river	EF	2
12	Počiteljica, Medak	5537394	4922853	Main river	EF	1
13	Bogdanica, Kaniža Gospićka	5525668	4934143	Main river	EF	4
14	Bogdanica, Zablato	5525736	4933808	Main river	EF	4
15	Jadova, Vrebac, Gradina village	5541226	4931818	Main river	EF	4
16	Jadova, Barlete	5537644	4932090	Main river	EF	4
17	Jadova, under the highway	5535134	4933189	Main river	EF	4
18	Jadova, Vrebac location 3	5540653	4930218	Main river	EF	4
19	Jadova, Vrebac location 4	5543799	4928918	Main river	EF	4
20	Jadova/Suvaja, field spring	5554256	4923393	Spring	EF	2
21	Jadova/Suvaja, Suvaja spring, Lazići	5553974	4924170	Spring	EF	1
22	Jadova/Suvaja, pool, Gornja ploča	5553431	4922486	Main river	EF	4
23	Gacka, Čovići bridge	5524602	4963479	Main river	EF	4
24	Gacka, Perušić, Kostelka, Plasina bridge	5524785	4962400	Main river	EF	6
25	Gacka, Perušić, Obilje	5520572	4966213	Main river	EF	6
26	Gacka, Perušić, Otočac, under the highway	5516995	4968768	Main river	EF	6
27	Gacka, Perušić, Sv. Franjo	5528440	4928918	Main river	EF	4

Table 2 (continued)

Code	Locality	X	Y	Habitat	Method	Effort
28	Ričica, Lovinac, Kuzminac spring	5555125	4916330	Spring	EF	6
29	Ričica, upper part, Lovinac bridge	5554017	4915147	Main river	EF	2
30	Ričica, upper part, Veliki Bregovac	5553590	4915193	Main river	EF	2
31	Ričica, middle part	5557456	4913106	Main river	EF	8
32	Ričica, Tomičići	5560346	4910864	Main river	EF	4
33	Ričica, Ličko Cerje	5560349	4910896	Main river	EF	4
34	Ričica, lower part	5561335	4910214	Main river	EF	4
35	Ričica, lower part, Štikada	5564091	4908141	Accumulation	EF	4
36	Ričica, Štikada, Gračac	5565166	4905491	Accumulation	EF	6
37	Otuča, Gračac	5568832	4908755	Main river	EF	4
38	Otuča, Ričica tributary	5568841	4908711	Main river	EF	4
39	Otuča, Žižinka, Gračac	5568167	4906045	Main river	EF	2
40	Opsenica, towards Mali Alan	5551682	4910743	Main river	EF	1
41	Opsenica, upper part	5554328	4912245	Main river	EF	2
42	Opsenica, lower part	5551970	4914346	Main river	EF	2
43	Opsenica, sv. Rok Lake	5552811	4913923	Accumulation	EF	4
44	Matica (Titova Korenica)	5556530	4956423	Main river	EF	4
45	Krbavica	5549881	4952008	Main river	EF	2
46	Krbavsko polje, Laudanov gaj	5553307	4945105	Pond	EF	6
47	Krbavsko polje, Podlapačko polje	5550739	4939938	Spring / Cave	EF	1
48	Krbavsko polje, Suvaja Me-kinjarska	5554375	4936020	Stream	EF	4
49	Krbavsko polje, Suvaja cave	5554383	4936013	Spring / Cave	EF / D	2
50	Krbavsko polje, Vukova cave	5552674	4940873	Spring / Cave	EF	6
51	Krbavsko polje, Zelena cave (Bunić)	5548620	4948772	Spring / Cave	EF / D	2

electrofishing was also used for fish sampling. It produces pulse direct electric current with 650 W maximum power (1000 V, 10–20 A). Methods used and fishing effort for each locality are listed in Table 2 for reference. Larger fish specimens were measured and released at the spot while the rest of the catch was preserved in 4% formaldehyde solution and processed in the laboratory. Fish species were determined using relevant fish identification keys (VUKOVIĆ & IVANOVIĆ 1971, POVŽ & SKET 1990, MAITLAND 2000, KOTTELAT & FREYHOFF 2007). Total (TL) and standard length (SL) were measured by ichthyometer with the nearest millimeter precision. Weight of each fish specimen was measured by a digital scale with the 0.1 gram precision.

Microsoft Excel (Microsoft Office 2010 package) was used for numeric data analysis and tables. ArcGIS 9.3 (ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE 2009) was used for geographical analysis and production of distribution maps.

RESULTS

Altogether 26 species and 8 families of fish with 2084 specimens were recorded (Table 3) during the research. Five more species were listed from analysing fishermen catch: *Anguilla anguilla*, *Cyprinus carpio* Linnaeus, 1758, *Ctenopharyngodon idella* (Valenciennes, 1844), *Hypophthalmichthys nobilis* (Richardson, 1845) and *Silurus glanis* Linnaeus, 1758. When combined, a total of 31 species of freshwater fish was registered in the research area (Table 3). The species were assigned to 10 different families. According to species number Cyprinidae family had the biggest share in overall catch with 18 species (58%). Families Salmonidae, Cobitidae, Gobiidae and Percidae were represented with two species (6.5%). Anguillidae, Blennidae, Centrarchidae, Esocidae i Siluridae were represented with one species (3% of overall family number; Table 3).

In terms of abundance *Salmo* sp. Linnaeus, 1758 was the most dominant species in overall catch with 336 specimens caught (16% of overall catch). Subdominant species were as follows: *Rutilus rutilus* (Linnaeus, 1758) (12%), *Lepomis gibbosus* (Linnaeus, 1758) (11%) and *S. cephalus* (11%). Numerically least represented species (with less than 1% of specimens in overall catch) were *Salaria fluviatilis* (Asso, 1801), *Misgurnus fossilis* (Linnaeus, 1758), *Oncorhynchus mykiss* (Walbaum, 1792), *Scardinius erythrophthalmus* (Linnaeus, 1758), *Phoxinus phoxinus* (Linnaeus, 1758), *T. fontinalis*, *C. jadonaensis* Mustafić and Mrakovčić, 2008 and *Carassius carassius* (Linnaeus, 1758). Among the 31 determined species only eight were autochthonous: *Salmo* sp., *Delminichthys krbavensis* (Zupančić et Bogutskaya, 2002), *D. jadoensis* (Zupančić et Bogutskaya, 2002), *P. phoxinus*, *T. croaticus*, *C. jadonaensis*, *T. fontinalis* and *A. anguilla*, making up 26% of recorded species. Among the 23 allochthonous species (74%) 21 species are invasive, comprising almost 2/3 of overall catch. Complete data on species number and individuals recorded in each of 51 sampled sites are listed in Appendix 1.

Lika and Jadova

Investigation on Lika and Jadova Rivers was conducted on 22 sites. Altogether 984 specimens classified into 14 species and 6 families were recorded. The most abundant family was Cyprinidae with 8 species, followed by family Percidae with two species. All other families (Salmonidae, Centrarchidae, Esocidae and Cobitidae) were represented with just one species per family. The most common species in Lika River was *R. rutilus* (30%), followed by *S. cephalus* (18%), *Alburnus alburnus* (Linnaeus, 1758) (16%), *Perca fluviatilis* Linnaeus, 1758 (15%) and *L. gibbosus* (8%). Other species were represented in smaller percentage. The most abundant species in Jadova were *S. cephalus* (31%), *R. rutilus* (21%), *D. jadovensis* (17%) and *L. gibbosus* (12%). Species with lower abundance were *T. croaticus* (7%) and *Tinca tinca* (Linnaeus, 1758) (7%). Other species were represented with less than 3%. Overall, 10 allochthonous species (*A. alburnus*, *C. carassius*, *R. rutilus*, *T. tinca*, *L. gibbosus*, *S. cephalus*, *S. erythrophthalmus*, *P. fluviatilis* and *E. lucius*) making up 87% of the total catch were recorded, mostly in Lika and lower parts of Jadova. The native species *Salmo* sp. (*S. trutta* / *S. labrax* / *S. fario*ides; still unresolved taxonomic status), was found only in the upper parts of Lika River and its tributaries because of strong human impact in lower parts. Endemic species (*C. jadovaensis*, *D. jadovensis* and *T. croaticus*) were only found in the upper parts of Jadova and a stream called Suvaja (upstream from village Gornja Ploča). *A. anguilla* was not recorded in any of the sampling sites.

Gacka

Gacka River was investigated on 5 sites. A total of 251 fish specimens divided into 9 species and 6 families were recorded. Family Cyprinidae was the most abundant with three species, while Salmonidae contributed with two species. All other families (Percidae, Centrarchidae, Esocidae and Cobitidae) were represented with just one species per family. The most common species was *Salmo* sp. (probably *S. labrax*) (78%) followed by *E. lucius* (9%). Other species were represented with less than 5%. There were eight alien species recorded (*R. rutilus*, *T. tinca*, *L. gibbosus*, *S. cephalus*, *P. fluviatilis*, *E. lucius*, *M. fossilis* and *O. mykiss*) making up 23% of total catch.

Ričica, Otuča and Opsenica

Ričica, Otuča and Opsenica streams were investigated on 16 sites. Overall, 646 fish specimens grouped into 11 species and 5 families were determined. The most abundant family Cyprinidae contributed with 6 species, followed

Table 3. List and number of freshwater fish species recorded for high Lika plateau. Abbreviations: Ričica, Otuča and Opsenica = ROO, Status = ST, Recorded = R, Native = N, Alien = AI, Invasive = In; origin: Asia = A, North America = NA, Adriatic drainage = AD, Black Sea drainage = BSD; *not confirmed; †status questionable.

Species	No.	%	Lika	Jadova	ROO	Gacka	Krbava	Matica	ST	Origin
Family Anguillidae	1	3.13								
<i>Anguilla anguilla</i> (Linnaeus, 1758)	R		X						N	AD
Family Blennidae	1	3.13								
<i>Salaria fluviatilis</i> (Asso, 1801)	2	0.10			X				In	AD
Family Centrarchidae	1	3.13								
<i>Lepomis gibbosus</i> (Linnaeus, 1758)	237	11.37	X	X	X	X			In	NA
Family Cobitidae	2	6.25								
<i>Cobitis jadovaensis</i> Mustafić et Mrakovčić, 2008	10	0.48		X					N	
<i>Misgurnus fossilis</i> (Linnaeus, 1758)	4	0.19	X*		X	X			In [†]	BSD
Family Cyprinidae	18	56.25								
<i>Alburnus alburnus</i> (Linnaeus, 1758)	84	4.03	X						In	BSD
<i>Alburnus arborella</i> (Bonaparte, 1841)	34	1.63			X				In	AD
<i>Carassius carassius</i> (Linnaeus, 1758)	12	0.58					X*		In	BSD
<i>Ctenopharyngodon idella</i> (Valenciennes, 1844)	R		X						AI	A
<i>Cyprinus carpio</i> (Linnaeus, 1758)	R		X						In	BSD
<i>Delminichthys jadovensis</i> (Zupančić et Bogutskaya, 2002)	74	3.55		X					N	
<i>Delminichthys krbavensis</i> (Zupančić et Bogutskaya, 2002)	151	7.25					X		N	
<i>Gobio obtusirostris</i> (Valenciennes, 1842)	108	5.18			X				In	AD
<i>Hypophthalmichthys nobilis</i> (Richardson, 1845)	R		X						AI	A

Table 3 (continued)

Species	No.	%	Lika	Jadova	ROO	Gacka	Krbava	Matica	ST	Origin
<i>Phoxinus lumaireul</i> Schinz, 1840	28	1.34			X		X*		In	AD
<i>Phoxinus phoxinus</i> (Linnaeus, 1758)	7	0.34			X			X	N	
<i>Rutilus rutilus</i> (Linnaeus, 1758)	260	12.48	X	X		X			In	BSD
<i>Scardinius erythrophthalmus</i> (Linnaeus, 1758)	7	0.34	X	X					In	BSD
<i>Squalius cephalus</i> (Linnaeus, 1758)	234	11.23	X	X		X			In	BSD
<i>Squalius zrmanjæ</i> (Karaman, 1928)	55	2.64			X				In	AD
<i>Telestes croaticus</i> (Steindachner, 1866)	101	4.85	X	X					N	
<i>Telestes fontinalis</i> (Karaman, 1972)	9	0.43				X			N	
<i>Tinca tinca</i> (Linnaeus, 1758)	59	2.83	X	X		X	X		In ¹	BSD
Family Esocidae	1	3.13								
<i>Esox lucius</i> (Linnaeus, 1758)	46	2.21	X			X			In ¹	BSD
Family Gobiidae	2	6.25								
<i>Padogobius bonelli</i> (Bonaparte, 1846)	76	3.65			X				In	AD
<i>Pomatoschistus canestrinii</i> (Ninni, 1883)	24	1.15			X				In	AD
Family Percidae	2	6.25								
<i>Gymnocephalus cernuus</i> (Linnaeus, 1758)	27	1.30	X						In	BSD
<i>Perca fluviatilis</i> (Linnaeus, 1758)	93	4.46	X		X	X			In	BSD
Family Salmonidae	3	9.38								
<i>Salmo</i> sp.	336	16.12	X	X	X	X	X	X	N	
<i>Oncorhynchus mykiss</i> (Walbaum, 1792)	6	0.29				X			In	NA
Family Siluridae	1	3.13								
<i>Silurus glanis</i> (Linnaeus, 1758)	R		X						In	BSD
Total	2084	100								

by Gobiidae with 2 species. The other three families recorded (Salmonidae, Centrarchidae and Blennidae) were each represented with just one species. The most common species were *L. gibbosus* (22%), *G. obtusirostris* (17%), *Salmo* sp. (17%), *P. bonelli* (12%), *T. croaticus* (11%), and *S. zrmanjæ* (9%). All of the remaining species were represented with less than 5%. However, the presented data arose from intentional effort to map remaining distribution of *T. croaticus* in Ričica. Therefore, potentially favourable habitats for this species were more frequently sampled, and very large number of *P. lumaireul* and *S. zrmanjæ* were not collected even when seen stunned in the water, which could lead to misleading or even biased interpretation of data. Eight alien species (*L. gibbosus*, *S. zrmanjæ*, *Alburnus arborella* (Bonaparte, 1841), *P. lumaireul*, *G. obtusirostris*, *P. bonelli*, *P. canestrinii* and *S. fluviatilis*) comprised 72% of total catch. Most of them reached Ričica through reverse hydro-power plant "Veletit" from the Zrmanja River. The only native species recorded was *T. croaticus*, while the origin of *Salmo* sp. is unknown. Alien species were mostly located in reservoirs Štikada on Ričica and Sv. Rok on Opsenica.

Matica and Kravsko polje streams

The research of Matica River and streams in Kravsko polje was conducted on 8 sites. A total of 203 fish specimens were caught, classified into 7 species and 2 families: Cyprinidae with 6 species, and Salmonidae with one taxa, *Salmo* sp. (probably *S. labrax*). The most frequent species in Kravsko polje was *D. krbavensis* (74%), followed by *Salmo* sp. (10%), whilst other species were represented with less than 5%. Of all species recorded, 4 were allochthonous (*C. carassius*, *M. fossilis*, *T. tinca* and *P. phoxinus* which is allochthonous only for Kravsko polje streams) with 8% of total catch. Altogether, 4 native species comprising 92% of total fish catch were noted: *D. krbavensis* and *T. fontinalis* in Kravsko polje, and *P. phoxinus* and *Salmo* sp. (*S. labrax*) in Matica. *D. krbavensis* and *T. fontinalis* occurred in the polje only during high water levels when it becomes a large floodplain (usually from December to April). As the water retreats into underground fish also retreat back into springs, sinks and estavelas. Also, a number of small ponds, springs and cave systems (i.e. Suvaja Mekinjarska, Pećine, Vukova pećina, Hrnjakova pećina and sinkholes in Podlapačko polje) exist throughout the year in polje where the fish can be found during dry season. Present distribution of endemic *Telestes* and *Delminichthys* species is presented in Figure 2 and 3. They can be considered extinct form all other localities mentioned in the literature.

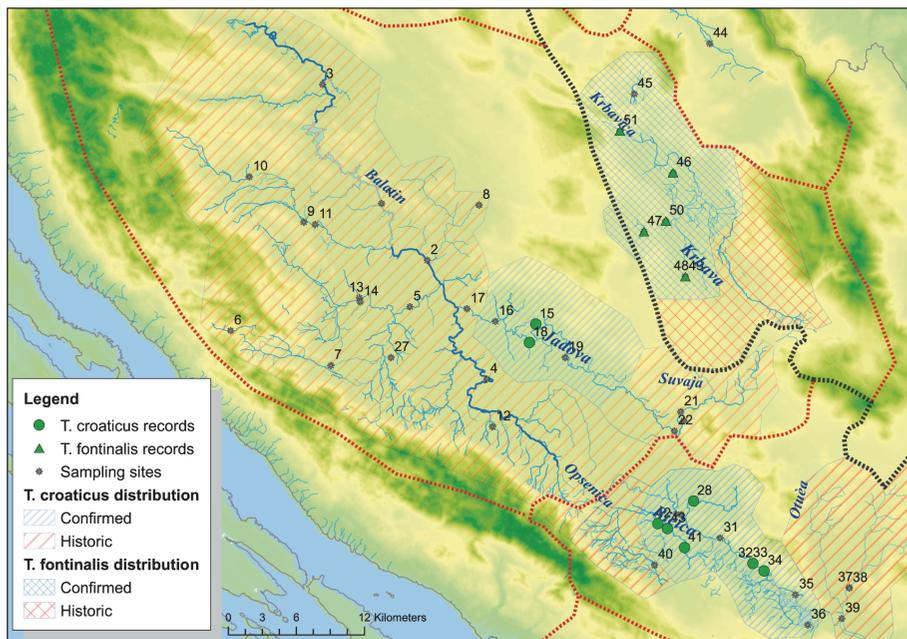


Fig. 2. Distribution of endangered *Telestes fontinalis* and *T. croaticus*.

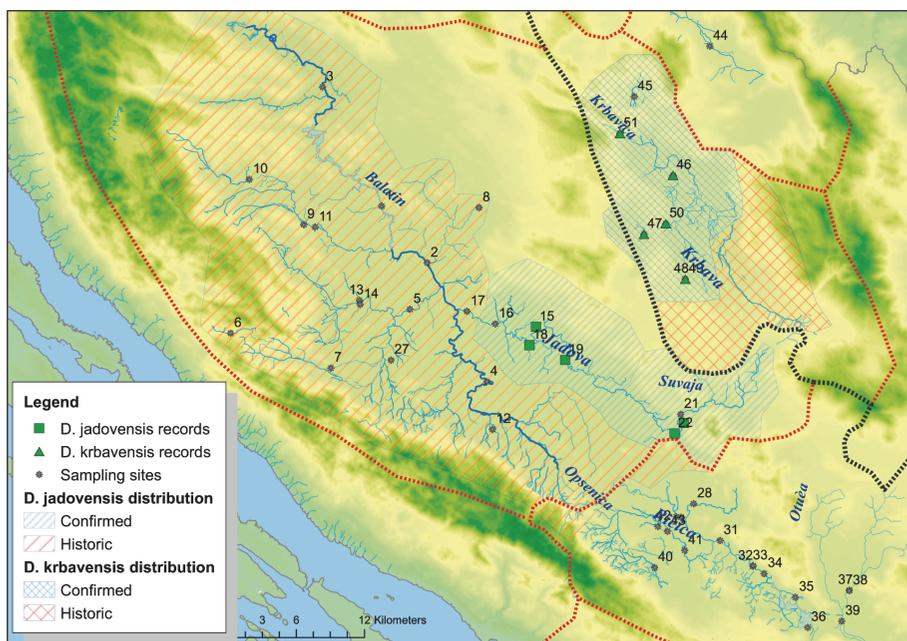


Fig. 3. Distribution of endangered *Delminichthys krbavensis* and *D. jadovensis*.

Table 4. Year of introduction for alien fish species in the Lika River. ŠRU "Lika" Gospić (2014) is a citation of a local fishing organization data on fish introduction and stocking from 1900–2014.

Species	Year of introduction	Reference
<i>Alburnus alburnus</i>	Unknown	ŠRU "LIKA" Gospić (2014)
<i>Esox lucius</i>	1967	K. P. (1968)
<i>Gymnocephalus cernuus</i>	1937	ŠRU "LIKA" Gospić (2014)
<i>Lepomis gibbosus</i>	1935–1936	Pl. (1946); K. P. (1968)
<i>Squalius cephalus</i>	1935–1936	K. P. (1968)
<i>Perca fluviatilis</i>	1937	ŠRU "LIKA" Gospić (2014)
<i>Rutilus rutilus</i>	1935–1936	K. P. (1968)
<i>Tinca tinca</i>	1972	ŠRU "LIKA" Gospić (2014)
<i>Scardinius erythrophthalmus</i>	1937	ŠRU "LIKA" Gospić (2014)
<i>Cyprinus carpio</i>	1933; 1935–1936	Pl. (1946); K. P. (1968)
<i>Carassius carassius</i>	1935–1936	Pl. (1946); K. P. (1968)

Introduced species

Since the middle of the 20th century a significant number of alien fish species (Table 4) was introduced to Lika region, of which some became potentially invasive. Moreover, alien species stocking was done by anglers to increase the number of fish species in streams.

Alien species can be principally divided into two groups: generally allochthonous and locally allochthonous. In Croatia, generally allochthonous species are not naturally occurring in Croatian waters, whilst locally allochthonous species are native for Croatia, but are introduced into habitats in which they do not occur naturally. Besides the introduced European species, generally allochthonous fish species in Croatia originate from Asia and North America. Generally allochthonous species in Lika are represented with four species: *C. idella*, *H. nobilis*, *O. mykiss* and *L. gibbosus*. Other alien species are locally allochthonous, either from the Black Sea drainage or from other parts of the Adriatic drainage. *A. alburnus*, *C. carassius*, *C. carpio*, *E. lucius*, *G. obtusirostris*, *G. cernuus*, *M. fossilis*, *P. fluviatilis*, *R. rutilus*, *S. erythrophthalmus*, *S. glanis*, *S. cephalus* and *T. tinca* originate from the Black Sea drainage, while *A. arborella*, *P. bonelli*, *P. canestrinii*, *S. fluviatilis*, *P. lumaireul* and *S. zrmanjae* originate from the Adriatic drainage (Zrmanja River). Invasive species are alien species that are harming and destroying native populations while reproducing and spreading into invaded area. They do so through predation, resource exploitation, interbreeding with native species or occupation of ecological

niche (EUROPEAN ENVIRONMENT AGENCY 2012). All of the species listed above can be considered invasive except for *C. idella* and *H. nobilis*.

DISCUSSION

Native species

Species native to Lika region were as follows: *T. croaticus*, *T. fontinalis*, *D. krbavensis*, *D. jadovensis*, and *C. jadonaensis* (MUSTAFIĆ *et al.* 2008). One taxa of brown trout (classified as *Salmo* sp.), *A. anguilla* and *P. phoxinus* are presumably native species, but further research is needed for confirmation of their status. The origin of brown trout in the Lika region is fairly unsolved, since no clear conclusions about its biogeographical or phylogenetic status exist. A plausible claim for the existence of trouts in the region could be the undocumented anthropogenic introduction of trouts from Danube, Atlantic and/or Adriatic lineages in the past (as indicated for Gacka in JADAN *et al.* 2007). It is possible that trouts are not native to high Lika plateau, due to their geographic isolation, and that all three *Salmo* sp. taxa have been introduced. One confirmation to the "introduction of trouts" theory is no records of *Cottus gobio* Linnaeus, 1758 in any of the river systems of Lika plateau, although they are found together with trouts in all surrounding regions (Dobra and Mrežnica in Gorski kotar; Una River to the North; and Zrmanja and Krka Rivers to the east and south; JELIĆ 2011). Cold climate (indicated by meteorological data in Table 1), slope and high altitude should promote life of cold adapted fish species and inhibit introduction of warm adapted species. Salmonids would find a favourable habitat for their dispersal no matter if appearing here naturally through drainage shifts (TAKÁCS *et al.* 2014) or through historical human introduction.

P. phoxinus is native in the Matica River, while populations found in Krbavsko polje (Krbavica) and Ričica River are probably introduced. FRANIĆ (1900b) stated that in Balatin stream two species of fish ("pijor" and "čikov") appear during long periods of floods. As this tributary of Lika River is very similar to Jadova River, we presume that these are *D. jadovensis* and *C. jadonaensis* (often called "pijor" and "čikov" among local people). We assume *Paraphoxinus adspersus* in Balatin mentioned by TRGOVČEVIĆ (1905, 1908, 1932) is probably also referring to *D. jadovensis* because the author emphasizes it as a separate species and clearly separates it from *T. croaticus*. Balatin stream was sampled four times on several locations during the research but no specimens of *Delminichthys*, *Telestes* or *Cobitis* were found. Varieties of larger springs in the surrounding area were sampled (Jezerina and Studenac in Široka kula, a spring in Prvan Selo, etc.) by means of electrofishing and diving (visual obser-

vation) as potential habitats for *Delminichthys* and *Telestes* genus species, but the efforts also yielded no recent records. *Phoxinus phetaldii*, a species listed for Ričica by HABEKović *et al.* (1992), could probably be a mistakenly identified *P. lumaireul* introduced to Ričica from the Zrmanja River. *P. phetaldii* is native to southern Herzegovina and Dalmatia, while *P. lumaireul* is a species very common in the investigated area. Another possibility is that this population belongs to an unidentified *Delminichthys* sp., because Ričica is the only habitat in Lika region solely populated by *Telestes* sp. In both Krbavsko polje and Jadova River we found one species of *Telestes* and *Delminichthys* living in sympatry, and often in syntopy.

A. anguilla should be considered as native species as it was historically recorded in the Lika River (Kosinj stream in LANGHOFER 1904, TRGOVČEVIĆ 1908, not found during this study). Even though eels are native in the Adriatic drainage basin and Lika region is hydrologically partly connected to the Adriatic Sea via underground flows, it was never confirmed that eels can migrate through those waterways to complete their life cycle.

Questionable species

Several problems and uncertainties arise when designating reference status to species with none or very little documented records, for example whether species common to the Black Sea drainage area, like *E. lucius*, *M. fossilis* and *T. tinca* (Table 3), should really be indicated as non-native at these Adriatic drainage sub-areas. Changes of the topographic and hydrographic conditions could cause these sub-areas to be shifted to another drainage (TAKÁCS *et al.* 2014), leaving the possibility that Gacka, Lika and Jadova Rivers used to be in a direct contact with the Black Sea, and thus effectively explaining the appearance of the species. Furthermore, it should be taken into consideration that the samples collected with the latest research methods are fairly difficult to compare with those of the researches done many decades before.

FRANIĆ (1900a) claimed that Gacka receives water from Lika River swallow hole because their water levels are precisely correlated, which is in accordance with the findings of several recent hydro-geological investigations (BONACCI & ANDRIĆ 2008, LUKAČ REBERSKI *et al.* 2013). He also stated that large amounts of fish "pijor" (local name for minnow) appear in one well in Kompolje (NW of Otočac) when there is high water input in the Lika River swallow hole, and that this "pijor" is only present in Lika and not in the Gacka River. BRUSINA (1892) also indicated presence of an unknown minnow in Konjsko polje (Kompolje) that appeared with high waters from the underground. No species of minnow was ever recorded in Gacka and these findings have to

correspond either to *D. jadovensis* arriving from Lika River, or to a new undescribed species.

Invasive species

A very concerning fact is that 23 out of 31 species are introduced (alien species) into this region as a direct result of intense and irresponsible stocking. The share of alien species in overall catch went from 0 (before human introduction) to 29 in less than 100 years of human intervention, with signs of further increase. This is even more evident in the overall fish biomass share, because in most cases introduced species tend to have either higher reproduction (KELLER *et al.* 2011) and resource uptake rates (ALEXANDER *et al.* 2014), faster growth rate (ALBINS 2013) or much larger body size compared to those in native species (VILA-GISPERT *et al.* 2005). The share of allochthonous species in total recorded species was 66%, while the share of invasive specimens in total catch was 67%. *L. gibbosus* and *S. cephalus* cumulatively make up 22% of the total catch in the Lika region, representing a large new biomass input into these mostly oligotrophic ecosystems, leading to rapid eutrophication of the habitat, and thus making it unsuitable for native species. Furthermore, the newly established environmental settings create new habitats to introduced species, consequently increasing their biomass and speeding up the eutrophication. As a result, eutrophication causes the continued increase of average water temperature thereby favouring alien fish species (WHITEHEAD *et al.* 2012). Long human presence in these areas has also directly contributed to these negative effects through input of large amounts of organic waste into the systems and riverine alternations that slow down or disrupt the water flow. In addition to already constructed reservoirs for power stations, local community built a large number of smaller dams for the construction of water mills. Data from 1946 show the presence of small accumulation lakes every 3–4 km along the Lika River flow, causing the river to resemble a series of small lakes during dry months (PL. 1946). According to the same source the water in these lakes would rise up to 25 °C during summer and local people started noticing a gradual disappearance of trouts. Habitat changes and scarcity of food forced local people to introduce warm-water alien fish species from other regions (PL. 1946, K. P. 1968). Introduced species undoubtedly influence populations of native species because many cannot be found in areas where they once thrived (RYDÉN *et al.* 2003), like *T. croaticus* in the Ljubica stream or *D. jadovensis* in the Balatin stream. Local people still report that in their youth these species were so abundant that river would become black when they would come out to breed and that they would catch hundreds of kilograms of them with simple wooden baskets (native type of fishing). Native species only remain in

areas mostly inaccessible to introduced species, like the upper parts of Jadova, Ričica, and underground cave systems throughout the region, especially in Krbavsko polje. Several parts of Jadova and Krbava flow dry up during dry period (June to September), thus isolating the (most) upper parts populated with native ichthyofauna from the lower parts mostly populated by introduced species. Long evolution processes in Dinaric karst have made endemic species resistant to seasonal dry periods and adapted them for retreats into deep underground aquifers (GUNN 2004, BONACCI *et al.* 2009).

The effect of endemic fish species retreating into higher parts of headwaters when pressured by introduced species or pollution is also visible in other similar cases we investigated in Croatia and Bosnia and Herzegovina. Similar effect was observed in Čikola River (Dalmatia, Croatia) where two endemic species, *Telestes turskyi* (Heckel, 1843) and *Phoxinellus dalmaticus* Zupančić et Bogutskaya, 2000, have retreated in the uppermost parts of the river. The same case was observed with *Telestes polylepis* Steindachner, 1866, species endemic to Dobra and Zagorska Mrežnica Rivers (Gorski Kotar, Croatia), but now only found in one of the cave springs of Zagorska Mrežnica. *Telestes methiensis* (Steindachner, 1901) and *Delminichthys ghetaldii* (Steindachner, 1882) populations in Herzegovina (South-Eastern Bosnia and Herzegovina) also exhibit the same faith. Often, limiting factors for the dispersal of introduced species are natural barriers or parts of river that dry out during summer. This presents a very specific phenomenon of Dinaric Karst rivers, where middle parts completely dry out (or the water sinks into underground but continues to flow) but the headwaters and springs (including the spring caves) retain water permanently. These small reservoirs are sole sources for the survival of endemic species populations, and thus their adaptation to water oscillations and retreatment into underground. Therefore, these headwaters are also main priority for conservation action planning.

Adaptation to cave life

After the presentation of such an intensive over-domination of alien species the main question arising is how endemic native species manage to survive and do they have a future in this drainage. The largest populations of endemic *D. jadovensis* and *T. croaticus* can be found in upper parts of Jadova and Suvaja. These rivers do not have a permanent water flow, but are actually dry from June to September, during which fish retreat into “grabe” (local denomination for deeper ponds that retain water even during dry season, usually continuing into underground cave systems). Upper parts of Jadova and Suvaja are rich in large springs where *D. jadovensis* and *T. croaticus* retreat. When water comes back into the main streams fish also reappear for breed-

ing. Several *D. jadvensis* were observed during dry period in Suvaja River (tributary of Jadova; location number 20) in a small cave spring during cave diving. *T. fontinalis* and *D. krbavensis* in the Krbavsko polje exhibit the same behaviour, spending even longer time in caves (8–10 months per year). Populations in the cave Suvaja Mekinjarska were never found to come out from the spring into the stream, and it seems there are no other areas where they could come out. Although the water level rises during spring and the stream starts to flow towards Krbava River, neither of the two species was recorded during 3 electrofishing occasions. It seems they are permanently confined to the cave system and spring pond. In January we observed many pregnant females of ~16–18 cm total body length. Males were smaller (up to 14 cm of TL) and very slender bodied. Over the course of several years in the Vukovića cave we observed hundreds of *D. krbavensis* specimens up to 12 cm of total body length coming out of the cave into a small pond for breeding (January–March). For the most part of the year there is no water in the spring pond and fish are hidden underground. Due to spending majority of their lifetime in caves only with short-term surface rise-ups, *D. jadvensis* and *D. krbavensis* could be called “advanced stygophiles”. *T. fontinalis* was also observed during cave diving, but in lower numbers and with smaller individuals (none over 10 cm of TL). This species was more commonly observed in permanent ponds and lakes in the lower parts of Krbavsko polje. Large population was found in ponds in Laudanov gaj, where they preferred vegetation and mud rich habitats. *T. croaticus* from the Ričica River was not found to enter cave systems, but mainly occupying open waters. In Kuzminac spring (village Lovinac, Ričica River) we observed several *T. croaticus* individuals emerging from the underground. *T. fontinalis* and *T. croaticus* could be referred to as “simple stygophiles”, living principally above-ground and occasionally retreating into the caves (during summer or winter). We applied the terms “advanced” and “simple” in this terminology because we did not find any other expert terms to distinguish different types of stygophiles.

Conservation of endemic species

Because of such vast richness of endemic species characterizing Lika region, it is necessary to establish a stricter control of stocking with introduced species and to control the spread of already introduced ones. Any kind of water management should be strictly forbidden. Krbavsko polje still acts as a temporary karst lake and local people have learned to live with its natural water fluctuations. All of the infrastructure is built on the higher ground around the edges of polje, de facto representing the “know-how” of indigenous people about coexisting with nature and its implementation into practice. But

this practical knowledge and experience is being lost and people nowadays are trying to build houses and set up agriculture in areas that flood during 10 year or 100 year maxima. This in return raises the need for hydrological regulations (channels, dams, tunnels, etc.) under the cover of protection of human property and lives. In poljes with this kind of yearly flood regime, we propose setting up historical boundaries of high water level and establishing a strict protection from any form of urbanization. Smaller poljes, like Krbavica and Podlapačko, also have similar water regimes and face the same problem. River systems also face similar problems with hydrological regulations and plans for hydropower usage. All of these changes cause rapid decline of endemic species (MRAKOVČIĆ *et al.* 2006).

As the importance of headwaters, river sources and underground cave systems for survival of endemic fish species has already been stated earlier in discussion, we can distinguish three most important areas for strict habitat conservation: 1) whole Jadova and Suvaja Rivers, 2) South-west part of Krbavsko polje (including Podlapačko polje) covering the drainage of Krbavica River, and 3) upper parts of Ričica River (from Štikada upwards) including the whole Opsenica River. These sites need to be included in Natura 2000 ecological network as important sites for endemic fish species. We also emphasize a need for an invasive species management plan for all three areas to prevent or control their dispersal.

D. jadovensis, *D. krbavensis*, *T. fontinalis* and *C. jadovaensis* are all considered globally Critically Endangered (CR) species (INTERNATIONAL UNION FOR CONSERVATION OF NATURE 2001) because of limited distribution range and observed population declines. *T. croaticus* is considered globally Endangered (EN) species (INTERNATIONAL UNION FOR CONSERVATION OF NATURE 2001). Our data indicate that it disappeared from Rivers Lika, Novčica, Balatin, Otuča and possibly Gacka, with a visible decline of population in Ričica River over the last 8 years. In 2007 and 2008 *T. croaticus* was still a very common species and we found it in several localities in large numbers (one female individual from the mid part of Ričica had 21 cm of total body length). In 2012 and 2013, during a 1500 m transect in a prime habitat (with two electrofishing devices), we caught just 34 individuals and more than 10 kg of *P. phoxinus*, *S. cephalus*, *L. gibbosus* and *G. obtusirostris* (data not included here because the sampling was done to reduce the number of invasive fish and decrease impact on *T. croaticus*). It is our proposition that *T. croaticus* be upgraded to a Critically Endangered species on the condition of observed population decline by at least 80% over a 10-year period, where the reduction and its causes have not ceased and are not reversible – A2ace (estimated in INTERNATIONAL UNION FOR CONSERVATION OF NATURE 2001). The fragmented range of *T. croaticus* and the

existence of two distinct isolated populations, which ought to be treated as separate conservation units, should also be taken into further consideration.

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Appendix 1. Quantitative composition (number of individuals) of ichthyofauna by site and drainage (localities numbers correspond to list in Table 4).

	Lika and Jadova											Gacka																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
<i>C. jadovacensis</i>															10													
<i>D. jadovensis</i>															30					15	28	1*	1					
<i>Salmo</i> sp.								9														3						
<i>T. croaticus</i>															20					10								
Alien species																												
<i>A. alburnus</i>					84																							
<i>C. carassius</i>											8	1	6			*	8	3										
<i>E. lucius</i>					9																							
<i>G. cernuus</i>	27																											
<i>L. gibbosus</i>	8	27			6					1																		4
<i>M. fossilis</i>																												4
<i>O. mykiss</i>																												1
<i>P. fluviatilis</i>	48	3			11					6	12	3																10
<i>R. rutilus</i>	1	79			5					11	60	7																2
<i>S. erythrophthalmus</i>																												
<i>S. cephalus</i>	4	17			12					34	12	16	*															2
<i>T. tinca</i>	1				4																							6

