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Changes in fish assemblage in the Hungarian section of River Szamos/Someş after a massive cyanide and heavy metal pollution

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Abstract. The main objective of this study was to investigate the regeneration potential of the fish fauna of River Szamos/Someş after a massive cyanide and heavy metal pollution in 2000. The investigation of the fish fauna was started in 2004 in the Hungarian part of the river. Fish samples were taken with electrofishing equipment three times a year, from river sections of the same size. From the spring of 2004 to the autumn of 2009 we carried out 18 samplings; caught and identified 18,751 individuals of 37 fish species. Beside fish sampling, the main water quality parameters of the Hungarian section of the river were measured. The number of fish species increased from the initial 23 to 29; they re-appeared year by year, including some common and typically sensitive species. Our results highlight that the river's fish community has recovered from the shocking effect of the pollution, owing to the significant improvements in water quality. The concentration of more heavy metals reduced significantly, but significant increase were found in concentration of copper [Cu], so it seems copper is the less limiting element for fish of R. Szamos/Someş. From all these results, it can be concluded that the structure and assemblage of the investigated area's fish community had slowly changed.

Key words: water pollution, fish community, reproduction, conformation, ecological guilds.

Introduction

Fish communities are usually greatly affected by water pollution, with pollutants coming from operating and abandoned mines or from tailing ponds and slag heaps (Ardelean & Wilhelm 2007, Wilhelm et al. 2009). The cyanide technology, for instance, is widely used in the gold mining industry and can be very hazardous to the nature. One of the main risks is the use of tailing ponds to convert the residual cyanide. These ponds can overflow after heavy rains and floods, causing serious damages in nature (Liakopoulos et al. 2010).

At the end of January 2000, the dam of a cyanide-laced water reservoir (AURUL Noble Metal Extraction Enterprise, Baia Mare/Nagybánya, Romania) had ruptured. As a consequence, almost 100,000 m^3 of wastewater with high cyanide concentration spilled quickly from one river to the next through Romania, Hungary, Serbia and Bulgaria, killing ten thousands of fishes (not young of the year) and other forms of wildlife and poisoning drinking water supplies (Michnea & Gherheş 2001, Soldán et al. 2001). The contamination consisted of cyanide containing metal-complexes (Kraft et al. 2006), which cause long-term problems in sediments (Macklin et al. 2003, Osán et al. 2007, Taghinia Hejabi et al. 2011) and in the wildlife (Ebrahimpour et al. 2011, Qadir & Malik 2011, Yi et al. 2011). The polluted water crossed the Hungarian border at Csenger on the 1st of February, 2000. The highest concentration of cyanide, which came through the River Szamos/Someş to Hungary, was 32.6 mg × dm^{-3} and was only 15.0 mg × dm^{-3} under the River Tisza-Szamos mouth. Thus, in this reach of the river, according to the highest cyanide concentration, a large-scale devastation of fish fauna occurred (Sályi et al. 2000). Despite of the several reports of severe wildlife mortality in the media, it was difficult to define the rate of damages caused by the spill, and owing to the thick ice, the real destruction of the fish fauna was impossible to reveal (Györe et al. 2001). The pre-pollution fish fauna of the R. Szamos/Someş is well known from the historic and recent scientific papers, consequently our results have an appropriate basis to compare with.

The main aim of this study was to determine the regeneration potential of the fish fauna in the R. Szamos/Someş after the most massive cyanide and heavy metal pollution in Europe via the investigation of qualitative and quantitative changes in the fish assemblages in the polluted area.

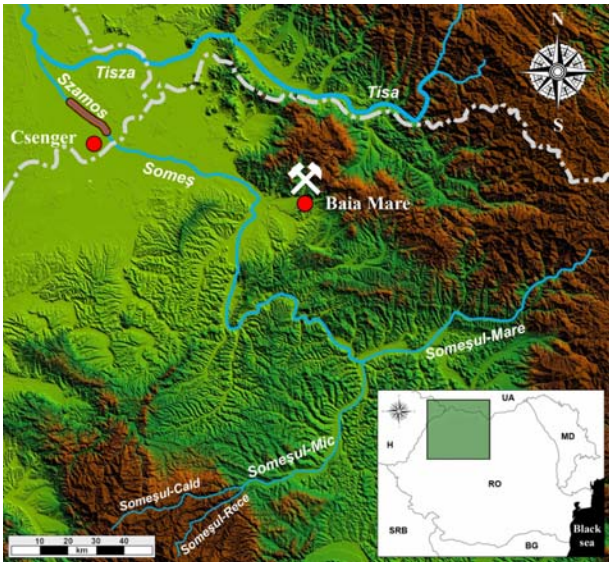

Figure 1. Map of the river Szamos/Someş showing the sites of Csenger and Baia Mare, and the sampling area.

Materials and methods

Study areas

The R. Szamos/Someş is the second largest tributary of the R. Tisza. Out of its 415 km of total length, only 50 km falls inside the current Hungarian border. The river holds up water of the northern part of the Transsylvanian basin (Fig. 1). One of its two main branches is Nagy-Szamos/Someşul-Mare accompanying the Radnai mountains to the south, the other is Kis-Szamos/Someşul-Mic, which originates from the union of Meleg-Szamos/Someşul-Cald, taking its source in the Transsylvanian island range, on the eastern slope of the Bihar mountains (M. Bihorului), and Hideg-Szamos/Someşul-Rece, which springs in the Gyalu mountains (M. Gilău-lui). The total catchment area of R. Szamos/Someş is 15,882 km^2, which is larger than that of the receiving R. Tisza. The mean river slope is 16 m × km^{-1} on the mountain course, 0.64 m × km^{-1} on the Romanian lowland course, while it is about 0.22 m × km^{-1} on the Hungarian lowland course (Lászlóffy 1982).

The Hungarian part of the R. Szamos/Someş, where the river running on plain in the epipotamic region has been studied (Fig. 1). The width of the river changes from 50 to 80 m in the investigated area. The water depth in the current area is typically between 2-3 m; however the deposition of pebbles and sand and therefore the shelf formation is considerable. For this reason the water depth varies, in certain segments it could be very low, only few centimeters for example. The margin is pitched in many places, generally sprinkled stones are typical. The natural base covering consists mainly of pebbles, sand and in the parts with lower currents, clay or mud of organic origin. In the investigated part the aquatic vegetation is not typical, however the roots of the near water trees, and the dead trees fallen into the water provide shelters for the fishes.

Several sub-sampling sites have been marked out in the R. Szamos/Someş between Szamosbecs and Szamosangyalos, taken into consideration the conditions of the investigated section and the protocol of the Hungarian National Biodiversity-monitoring System. The sampling section length was altogether 1,000 m. The sub-sampling sites were chosen by the conditions of the section in such a way that they were entirely characteristic to the habitats of the whole section in respect also to their proportions.

Sampling

Sampling was carried out three times every year between 2004 and 2009, in the spring, summer and autumn. Samples were taken by drifting with a boat in the same direction with the current along a riverbank. The sampling tool was a Hans Grassl EL 64 II/GI electrofishing device (U=600 V; I=14 A; P=7 kW) with hand held anode and direct current, 7 kW output, operated from a generating set. Sampling was performed uniformly in daytimes. The lengths of the sub-sampling sections were measured with GPS (Top coordinate: N47° 51' 11,81", E22° 40' 45,16"; Down coordinate: N47° 52' 54,06", E22° 39' 07,67").

Species identification was carried out in the field; the applied fish nomenclature derives from FishBase database (http://www.fishbase.org), in some cases from Harka & Sallai (2004).

Environmental variables

The R. Szamos/Someş was one of the most polluted eastern tributary of the R. Tisza on account of industry (Császár 1999, Lucas 2001), therefore the water quality of the Hungarian part was studied continuously. Nevertheless, after the cyanide pollution, the River Monitoring System of Upper-Tisza Regional Environmental and Water Directorate built a Water Monitoring Station (MS-2) near the border (Csenger) in 2002 (Fig. 1). The station has been measuring the water quality every hour since

2002. The laborers of Data of Environmental Protection, Nature Conservation and Water Authority, Trans-Tiszanian Region collect environmental data of surface water biweekly.

Statistical analysis

Similarities between relative abundances (percentage scores calculated from individual numbers) of fish families in different sampling years were plotted using square-root transformed datasets and PCA ordination. PCA was calculated using CANOCO 4.5 program-package (ter Braak & Šmilauer 2002) (Fig. 2). The changes of guilds were illustrated with Microsoft Excel software (Fig. 3). Water quality datas was plotted with 2D Box Plots of STATISTICA 12.0 software (StatSoft 2007) (Fig. 4). Kruskal-Wallis test was used to determine the existence of any significant differences among time variable (years), and the Dunn's multiple comparison test was used to determine among which years the differences occurred. Different superscript letters indicate significant differences among the years (Fig. 4).

Results

Between 2004 and 2009, 18,751 individuals of 37 fish species were recorded during the monitoring (Table 1). Although the number of species increased from the initial 23 to 29, the number of individuals decreased because of the high initial number of bleak *Alburnus alburnus* (Linnaeus 1758).

Fish families and sampling years were plotted using square-root transformed datasets based on relative abundance scores by a PCA ordination (Fig. 2). Eigenvalues were 0.79 and 0.12, while cumulative species variances 78.5 and 90.5 for the first and second axis, respectively.

Regarding the ecological guilds of fish species, two processes can be observed. The first is that the number of disturbance-tolerant species – which was very high after pollution – decreased, while the number of specialist species increased. Secondly, the dominances of eurytopic and rheophilic species showed similar trends (Fig. 3).

The changes of concentration of dissolved metals and cyanide are represented by 2D Box Plot – Box Whiskers (Fig. 4). With Kruskal-Wallis test the following changes were detected: high significant reductions in concentrations of iron [Fe] ($p < 0.0001$), manganese [Mn] ($p < 0.0001$) and cyanide [CN] ($p < 0.0001$), normal significant reductions in concentrations of lead [Pb] ($p = 0.0038$), zinc [Zn] ($p = 0.0161$), cadmium [Cd] ($p = 0.0029$) and normal significant accretions in concentrations of copper [Cu] ($p = 0.0003$). In case of nickel [Ni] significant variability change was not found ($p = 0.0564$), but it was reduced too (Fig. 4).

Discussion

For data evaluation, first information on the past (Kriesch 1868, Herman 1887, Vutskits 1918, Vásárhelyi 1960, 1961) and recent (Harka 1995, Kovács 1995, Bănărescu et al. 1999) history of the fish fauna of R. Szamos/Someş before the pollution of 2000 was collected. Based on these literary data, 63 species were recorded from the full length of the R. Szamos/Someş, but there were some species found only in the backwaters of the river (Table 2). After the pollution, the fish fauna of the R. Szamos/Someş was described in details only by Györe et al. (2001). In the May of 2000, there was a disastrous situation in the number of species and individuals, since only 63 individuals of 12 species were recorded (Györe et al. 2001) (Table 1).

Between 2004 and 2009, 18,751 individuals of 37 fish species were recorded during the monitoring process of the investigated area. The Caucasian dwarf goby *Knipowitschia caucasica* (Berg 1916) was a new fish species, which was detected in 2009. It was the first record of the species in both the R. Szamos/Someş and the Carpathain basin (Halasi-Kovács et al. 2011).

The results of the survey carried out between 2004 and 2009, showed that the structure of the fish community of the R. Szamos/Someş suffered significant changes due to the cyanide and heavy metal pollution. The initial dwindling population, the rearrangement of species and individual numbers (the pushing forward of invasive species, the high number of fries), all these unusual incidents and oscillations presently have calmed down or even stopped. During the course of the research, with each sampling the number of fish species showed gradual increase. The results of the survey also prove that after the pollution some tolerant species (mainly *Cyprinidae*) were present in a larger extent, but recently the relative abundance of sensitive species (e.g. *Petromyzontidae*, *Acipenseridae*, *Percidae*) has been progressively increased by years, as confirmed by PCA ordination (Fig. 2).

On the basis of composition of fish communities, the examined Hungarian section of the R. Szamos/Someş can be ranked into the category of "hilly section of mid-sized and large rivers with high sloped and gravelled bottom" (Halasi-Kovács & Tóthmérész 2011), therefore the observed proc-

Table 1. Registered species in the River Szamos/Someş after pollution.

No.	Species	Habitat guild	Ecological specialization (§)	2000*	2004	2005	2006	2007	2008	2009
1.	*Eudontomyzon danfordi*	rheo	spec	-	-	-	-	-	-	1
2.	*Acipenser ruthenus*	rheo	spec	1	-	1	1	-	1	1
3.	*Rutilus rutilus*	eury	di-to	-	1	7	1	22	8	4
4.	*Scardinius erythrophthalmus*	stag	spec	1	-	-	-	-	-	-
5.	*Leuciscus leuciscus*	rheo	spec	-	-	-	-	-	1	-
6.	*Squalius cephalus*	rheo	di-to	-	213	300	418	172	230	199
7.	*Leuciscus idus*	rheo	spec	-	1	-	-	-	-	-
8.	*Aspius aspius*	eury	spec	-	-	1	2	32	11	1
9.	*Leucaspius delineatus*	stag	di-to	-	4	-	-	-	-	-
10.	*Alburnus alburnus*	eury	di-to	31	3127	2235	1179	1833	1530	905
11.	*Alburnoides bipunctatus*	rheo	spec	-	103	68	670	316	488	351
12.	*Blicca bjoerkna*	eury	gene	4	6	2	10	6	-	2
13.	*Abramis brama*	eury	gene	4	2	1	6	2	1	-
14.	*Ballerus sapa*	rheo	spec	-	43	33	83	65	52	115
15.	*Vimba vimba*	rheo	spec	-	1	-	5	-	2	3
16.	*Chondrostoma nasus*	rheo	spec	-	11	37	53	66	64	7
17.	*Barbus barbus*	rheo	spec	-	111	148	310	153	144	141
18.	*Gobio gobio* #	rheo	spec	-	1	1	5	1	5	9
19.	*Romanogobio vladykovi*	eury	gene	-	409	22	587	173	104	237
20.	*Romanogobio kessleri*	rheo	spec	-	15	2	30	7	83	13
21.	*Pseudorasbora parva* Δ	stag	di-to	-	2	-	-	-	1	4
22.	*Rhodeus amarus*	stag	spec	8	109	2	13	12	28	8
23.	*Carassius gibelio* Δ	eury	di-to	5	6	8	6	1	8	1
24.	*Cyprinus carpio*	eury	gene	1	2	-	-	-	-	1
25.	*Hypophthalmichthys molitrix* Δ	eury	di-to	-	-	-	-	-	1	-
26.	*Cobitis elongatoides*	eury	gene	2	-	-	-	1	1	2
27.	*Sabanejewia aurata* #	rheo	spec	-	5	16	36	25	33	16
28.	*Barbatula barbatula*	rheo	spec	-	-	-	1	-	-	-
29.	*Ameiurus nebulosus* Δ	stag	di-to	1	-	-	-	-	-	-
30.	*Ameiurus melas* Δ	stag	di-to	-	-	-	1	-	-	-
31.	*Silurus glanis*	eury	gene	-	4	46	51	30	13	37
32.	*Esox lucius*	stag	di-to	1	2	-	-	1	3	-
33.	*Lota lota*	rheo	spec	-	-	1	15	16	13	16
34.	*Lepomis gibbosus* Δ	stag	di-to	4	-	-	-	-	-	-
35.	*Perca fluviatilis*	eury	gene	-	-	-	1	2	5	4
36.	*Gymnocephalus schraetser*	rheo	spec	-	-	1	3	-	1	5
37.	*Sander lucioperca*	eury	spec	-	-	-	10	1	3	2
38.	*Zingel zingel*	rheo	spec	-	8	23	87	29	51	82
39.	*Zingel streber*	rheo	spec	-	-	1	3	-	-	3
40.	*Knipowitschia caucasica* Δ	eury	gene	-	-	-	-	-	-	1
	number of individuals			63	4186	2956	3587	2966	2885	2171
	number of species			12	23	22	27	23	28	29

Legend: * – from Györe et al. 2001; § - Halasi-Kovács & Tóthmérész 2011; # – The scientific name by Harka & Sallai (2004); Δ – invasive; rheo = rheophilic, eury = eurytopic, stag = stagnophilic; spec = specalist, gene = generalist, di-to = disturbance-tolerant

esses regarding the ecological guilds appeared as originally expected. The number of disturbance-tolerant species – that was very high after pollution – decreased as the number of specialist species increased, while the rate of eurytopic and rheophilic species showed similar trend.

It can be said that the river is regenerated today and has managed to get over the conse-

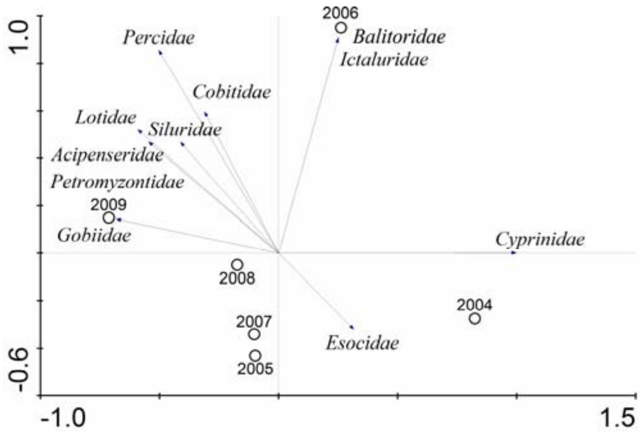

Figure 2. PCA ordination of fish families and years of sampling based on fish relative abundance.

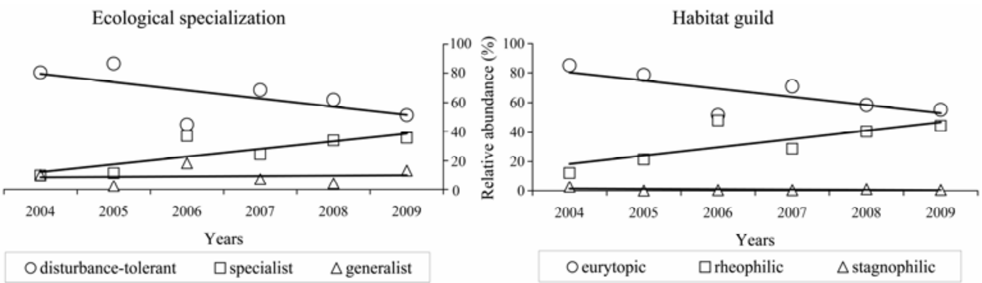

Figure 3. Changes in relative abundance of species groups on the basis of ecological speciali-zation and flow preference.

quences of the pollution. However, it has to be noted that the improving water quality as compared to the late 1990s also played a significant role in the regeneration of the fish fauna. Though the R. Tisza and the backwaters of R. Szamos/Someş undoubtedly played a vital role in the recolonisation of the fishes (Telcean & Cupşa 2009), the revitalisation of the favourable processes would be unimaginable without the improvement in the water quality of the upper reaches. This improvement is indicated by water quality data, within which the concentration of more heavy metals were reduced significantly. Furthermore, the proportions of certain ecological guilds conform to the characteristic value of the water type, and the population sizes of the invasive and disturbance-tolerant species decreased. Concentration of copper [Cu] increased significantly, so it seems that copper is a less limiting element for fish of R. Szamos/Someş (Matasin et al. 2011a, 2011b).

However, the recent fish community structure differs not only from the postpolluted state, but from before the disturbance, too. It is indicated by the increasing dominance of the specialist and rheophilic species. The non-ferrous metal extraction has been practised in the hills around Baia Mare/Nagybánya for centuries, but more gold mines closed on this area since the pollution. Therefore, aside from the decreasing human impacts that remarkably contribute to the observed continous alteration, it can be explained by changes of the environmental attributes of the river as well.

It is essential that in the future the environment, especially the water bodies, must be protected from pollutants, since accumulation of toxicants and heavy metals will threaten the fish and other aquatic organisms' populations. As the quality of water affects both lower and higher taxa of organisms (Viman et al. 2010, Amundsen et al. 2011, Copat et al. 2012) and they also influence each others, the anthropogenic damage may sweep over the system through many reactions. It can be concluded that if the catchment areas of a watercourse are in connection to each other and

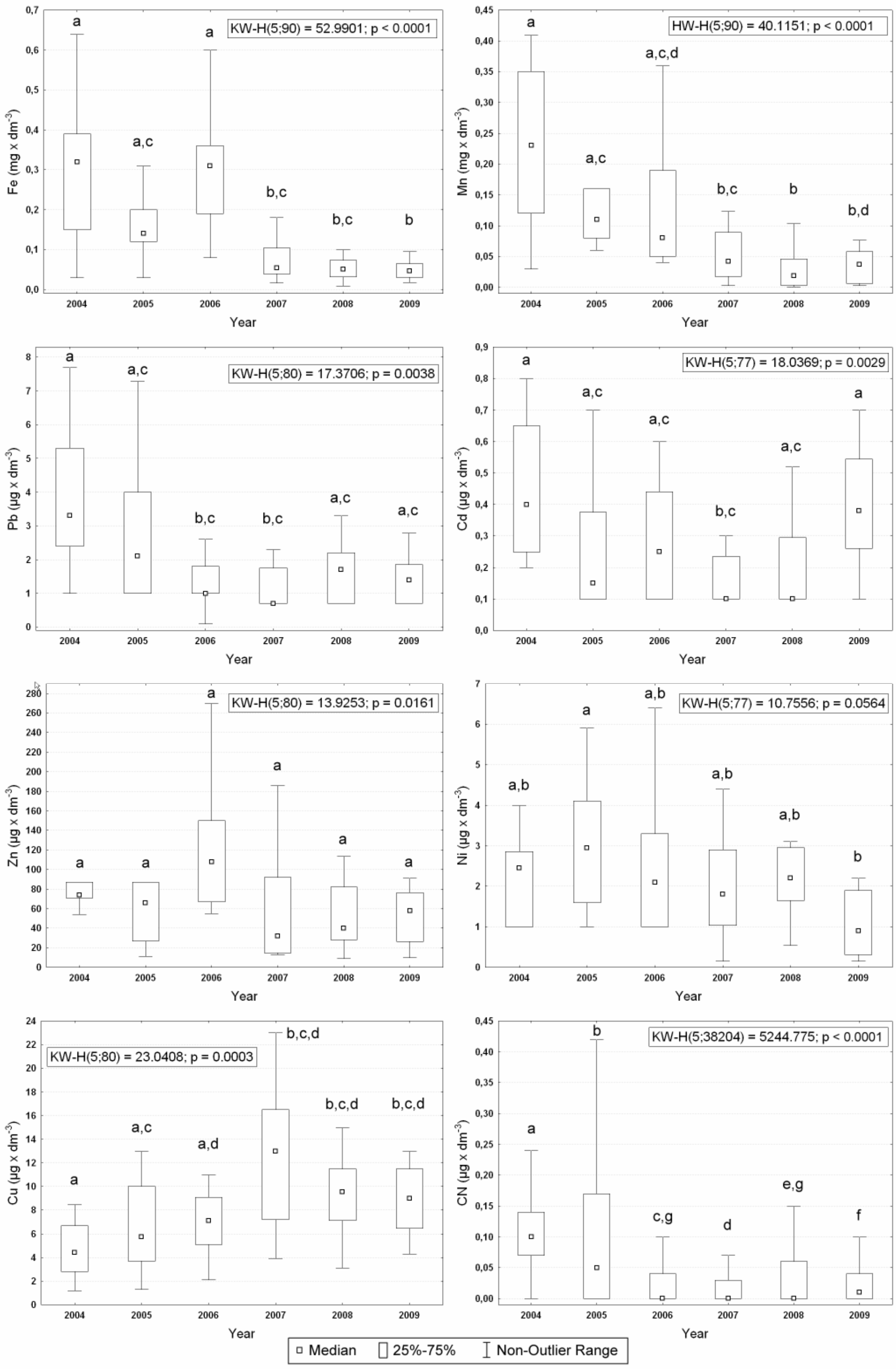

Figure 4. Water quality data results of Kruskal-Wallis test plotted by 2D-Box Plot. *Different superscript letters* indicate significant differences between years.

Table 2. Recorded species in the River Szamos/Someş before pollution.

No.	Species	H	R1	R2	No.	Species	H	R1	R2
1.	*Eudontomyzon danfordi*	+	+		33.	*Pseudorasbora parva*		+	+
2.	*Acipenser ruthenus*	+	+	+	34.	*Rhodeus amarus*	+	+	+
3.	*Acipenser gueldenstaedtii*	+			35.	*Carassius carassius*	+	+	+
4.	*Acipenser stellatus*	+			36.	*Carassius gibelio*		+	+
5.	*Anguilla anguilla*	+	+	+	37.	*Cyprinus carpio*	+	+	+
6.	*Rutilus rutilus*	+	+	+	38.	*Hypophthalmichthys molitrix*		+	+
7.	*Rutilus virgo*	+			39.	*Hypophthalmichthys nobilis*		+	+
8.	*Ctenopharyngodon idella*		+	+	40.	*Misgurnus fossilis*	+	+	+
9.	*Scardinius erythrophthalmus*	+	+	+	41.	*Cobitis elongatoides*	+	+	+
10.	*Leuciscus leuciscus*		+		42.	*Sabanejewia aurata* #		+	+
11.	*Squalius cephalus*	+	+	+	43.	*Barbatula barbatula*		+	
12.	*Leuciscus idus*	+	+	+	44.	*Ameiurus sp.*		+	+
13.	*Phoxinus phoxinus*	+	+		45.	*Silurus glanis*	+	+	+
14.	*Aspius aspius*	+	+	+	46.	*Esox lucius*	+	+	+
15.	*Leucaspius delineatus*		+	+	47.	*Umbra krameri*		+	+
16.	*Alburnus alburnus*	+	+	+	48.	*Thymallus thymallus*	+	+	
17.	*Alburnoides bipunctatus*	+	+		49.	*Hucho hucho*		+	
18.	*Telestes souffia*	+			50.	*Salvelinus fontinalis*		+	
19.	*Blicca bjoerkna*		+	+	51.	*Salmo trutta*	+	+	
20.	*Abramis brama*	+	+	+	52.	*Oncorhynchus mykiss*	+	+	
21.	*Ballerus ballerus*	+	+	+	53.	*Lota lota*	+	+	+
22.	*Ballerus sapa*		+	+	54.	*Cottus gobio*		+	
23.	*Vimba vimba*		+	+	55.	*Lepomis gibbosus*		+	+
24.	*Pelecus cultratus*	+	+	+	56.	*Perca fluviatilis*	+	+	+
25.	*Chondrostoma nasus*	+	+	+	57.	*Gymnocephalus cernua*		+	+
26.	*Tinca tinca*	+	+	+	58.	*Gymnocephalus baloni*		+	+
27.	*Barbus barbus*	+	+	+	59.	*Gymnocephalus schraetser*		+	+
28.	*Barbus peloponnesius petenyi* #	+	+		60.	*Sander lucioperca*	+	+	+
29.	*Gobio gobio* #	+	+	+	61.	*Sander volgense*		+	+
30.	*Romanogobio vladykovi*		+	+	62.	*Zingel zingel*	+	+	+
31.	*Romanogobio uranoscopus*		+		63.	*Zingel streber*	+	+	+
32.	*Romanogobio kessleri*		+	+					

Legend: H – Historic data: Kriesch 1868, Herman 1887, Vutskits 1918, Vásárhelyi 1960, 1961; R1 – Recent data 1: Whole river length by Bănărescu et al. (1999); R2 – Recent data 2: Hungarian river section by Harka (1995), Kovács (1995); # – The scientific name according to Harka & Sallai (2004)

the negative effects are absent, the regeneration can take place. The permeability between the different ranked watercourses in the catchment area is crucial (Nilsson et al. 2005). Furthermore, the research also concludes that the character of fish fauna will never be exactly the same as the original ones. Furtunately for R. Szamos/Someş the process of regeneration took place during an increase of water quality of the river's upper region, which as a consequence a more natural fauna than the one originally found in late 1990s has emerged.

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