Efficiency of restoration measures in a fragmented Danube/tributary network

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ABSTRACT: Within the LIFE-Nature project "Living space of Danube salmon" between 1999-2003 the efficiency of different restoration measures to improve habitat conditions for *Hucho hucho* (L.), one of the most endangered fish species of Europe, was monitored. The monitoring included the investigation of fish migration at 9 fish ladders and the evaluation of the development of fish populations within the whole study area. Successful migration processes were documented within the whole study area, varying between 8 and 33 species and 38 and 2098 individuals passing the fish migration facilities. In total 10 individuals of the "Danube salmon", *Hucho hucho* (L.), were caught at fish ladders, but the most frequent species in traps was *Barbus barbus* (L.). Some individuals of *Barbus barbus* (L.), but also of small-sized species like *Alburnus alburnus* (L.) and *Gobio gobio* (L.), belonging to the Danube population, were found to migrate more than 9 km into the tributaries passing three fish-ladders during one season. Marked individuals of *Barbus barbus* (L.) from different river sections were found to use the same winter habitats in tributaries, documenting the re-connection of formerly fragmented populations. Restoration of regulated river sections led to the creation of spawning places for lithophilous species like *Hucho hucho* (L.) and *Chondrostoma nasus* (L.), and to strongly increased fish densities. The re-opening of the river continuum resulted in a re-increase of river-type specific species within the whole tributary system, for some of them successful reproduction has been re-established in areas where they formerly naturally occurred.

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1 INTRODUCTION

The Danube salmon, the largest salmonid and one of the biggest freshwater fish species in the world, is among the most endangered fish species in Europe. In Austria, as a consequence of river canalisation and hydropower development, only 10 % of its former distribution in Austria (about 4500 km river length) harbours self-sustaining populations (Schmutz et al. 2001).

The European Union (EU) is currently establishing the Natura-2000 network of protected areas. Within these areas, LIFE-Nature projects, aiming to conserve natural habitats and wild fauna and flora of EU-interest, are funded by the EU Commission. The LIFE-Nature project "Living space of Danube salmon" (LIFE99 NAT/A/006054) in particular aims to re-establish the river continuum (fish passes at formerly impassable weirs) and to improve habitat conditions (Leitbild-orientated channel restoration) over a Danube/tributary river network of 78 km length. The re-connection of formerly fragmented sub-populations and increased reproduction should enhance the viability of the populations and the long-term survival of the species. Efficiency of restoration measures were assessed by: (1) evaluation of fish stocks before and after implementation; (2) testing the efficiency of individual fish migration facilities; (3) evaluation of the effects of restructuring measures; (4) following migration pathways to document the re-connection of formerly fragmented sub-populations.

2 STUDY SITE

The river network consists of a free flowing section of the Danube (33 km length), the near-natural tributary, Pielach River (21 km), the canalized tributary Melk River (14 km), and the semi-natural Mank river (8 km), a tributary of the latter. The main characteristics of the rivers are given in Table1.

The river continuum was interrupted by 13 artificial falls as a result of river engineering measures (1-4 m height) and by weirs built for hydroelectric power production (1.2-3.5 m height). In total 11 obstacles have been bypassed within the project. Fish migration facilities were designed as nature-like bypass channels (n=4), rock-ramps (n=6), or pool-and-weir passes (n=1). At the river Mank two weirs (M9,

M11) still exist, the river continuum is not yet fully established there.

Table 1: Main characteristics of rivers Danube, Pielach, Melk and Mank.

Characteristic	Danube	Pielach	Melk	Mank
Streamorder	9	4	5	4
Altitude (maA)	209–196	252–205	233–206	270.5–233
Gradient (‰)	0.4	2.23	1.6	4.6
Meanflow (m^3s^{-1})	~1900	~6.5	~3	~0.5
Flowregime	Moderate-nival	Pluvio-nival	Winter-pluvial	Winter-pluvial
Fishregion	Epi-potamal	Hyporhithral/ Epipotamal	Epi-potamal	Hyporhithral/ Epipotamal

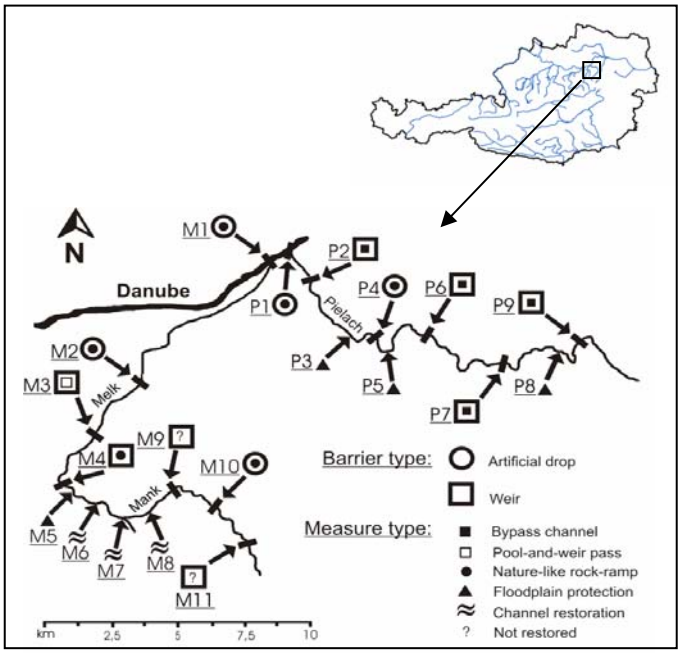

Figure 1: Study area: location of migratory barriers and restoration measures.

3 MATERIALS & METHODS

3.1 *Evaluation of fish stocks*

As a basis for the interpretation of the efficiency of the measures, fish stocks within the study area were estimated. Prior to sampling the fish, a habitat mapping survey was carried out to identify major mesohabitat types and their spatial distribution. In 1999, 22 and 15 mesohabitats (pool, run, riffle) were sampled at the Pielach and Melk rivers, respectively, by electric fishing using the removal method. Populations were estimated by weighting mesohabitat values proportionally to their occurrence in the specific river sections. Due to electric fishing selectivity, small-sized species were excluded from estimations. Juveniles also were probably underestimated. In the river Mank, due to its small channel size and clear water conditions, a combination of visual observation and snorkelling techniques was used to assess fish stocks. Small-sized species and juveniles were probably also underestimated there. Further details are given in Zitek et al. (2001). At the end of the monitoring programme (Nov. 2003) estimations of fish stocks by electric fishing were repeated in rivers Pielach and Melk.

3.2 *Monitoring of fish ladders*

3.2.1 *Fish migration*

Between 2001 and 2003 fish migration was monitored at nine restored continuum interruptions using fish-traps. Additionally a quantitative assessment of immigrating fish from the Danube was conducted upstream P1 in 2001 and 2002 (Mühlbauer et al. 2003). To follow migration paths, all fish caught were marked using individual (Visible Implant Tags) or site-specific (Blank Wire Tags, tattooing, fin-clipping) marking techniques.

3.2.2 *Abiotic survey of the fish ladders*

To aid the evaluation of efficiency of the fish migration facilities, each fish-ladder was surveyed concerning abiotic descriptors as bypassed height, length, slope, discharge, minimum water depths and flow velocities.

3.2.3 *Monitoring of restructured river sections*

Restructured river sections were sampled by electric fishing using the removal method at the river Mank in July 2001, one year after restructuring.

4 RESULTS

4.1 *Situation prior to measure implementation*

In total, the fish fauna of the rivers Pielach, Melk and Mank comprises 19, 25 and 13 species, respectively. Chub *Leuciscus cephalus* (L.) dominates in all three rivers, followed by nase *Chondrostoma nasus* (L.) and barbel *Barbus barbus* (L.). The largest population of Danube salmon *Hucho hucho* (L.) occurs in the Pielach. Total number of individuals in there was 532, about 162 individuals were adults (≥ 70 cm total length). The population was divided into six sub-populations by several migratory obstacles with sizes ranging from 0 to 50 adults. In Melk and Mank, a total of 21 adults of Danube salmon was estimated (9 and 12 individuals, respectively).

4.2 *Efficiency of the fish-ladders*

Within the whole study area at rivers Pielach, Melk and Mank 3250 individuals were caught passing fish ladders (554, 2658 and 38 individuals, respectively; Tab. 2, for Tab. 3 & 4 see Appendix). In total the dominant species in traps was barbel. Highest numbers of this species were caught at M1 at the conjunction of Melk and Danube, where also bleak *Alburnus alburnus* (L.), *Abramis brama* (L.), *Blicca bjoerkna* (L.) and *Rutilus rutilus* (L.) were found to

migrate in high numbers. Although some fish ladders were characterised by relatively high slopes (3.8 %, 5.1 %, 7.5%; M1, P4 and M10), adults and juveniles of most species known to occur downstream were able to pass. In total 10 individuals of the Danube salmon were caught at fish ladders.

Table 2: Fish stock (total number per species divided into adults/juveniles) between migration barriers (M_i-M_j), number and range of total length (L_T) in mm of individuals caught in traps.

River section	M7-M9	M9-M10	M10		M10-M11	upstream M11	Total
Length [m]/date of monitoring	*2426*	*2243*	*28.03.-14.06.03*		*2347*	*470*	*5060*
Species	n in stock	n in stock	n in trap	L_T (mm)	n in stock	n in stock	n in stock
Barbatula barbatula (L.)	do.	do.	1	100	do.	do.	do.
Barbus barbus (L.)	30/2	59/0	7	125-555	35/1	13/0	137/3
Chondrostoma nasus (L.)	157/0	74/0	10	380-480	6/0	6/0	243/0
Cobitis taenia (L.)	ra.	-	-	-	-	-	ra.
Cottus gobio (L.)	fr.	fr.	-	-	fr.	fr.	fr.
Gobio gobio (L.)	fr.	fr.	2	125-145	fr.	fr.	fr.
Hucho hucho (L.)	2/9	5/21	2	685-715	5/8	-	12/38
Leuciscus leuciscus (L.)	ra.	-	-	-	-	-	ra.
Leuciscus cephalus (L.)	174/422	154/15	9	115-460	109/52	112/37	549/526
Oncorhynchus mykiss (Wal.)	1/29	-	-	-	0/2	0/1	1/32
Phoxinus phoxinus (L.)	do.	do.	2	75-80	do.	do.	do.
Salmo trutta f.f. (L.)	8/20	13/15	4	90-345	0/4	1/1	22/40
Thymallus thymallus (L.)	3/51	11/51	1	360	0/5	-	14/107
Total number of species	13	10	9	-	11	9	13
Total number of individuals	375/533	316/102	38	-	155/72	132/39	978/746

4.3 *Individual migration pathways*

19 barbels and two individuals of grayling *Thymallus thymallus* (L.) marked at P2, originating from the Danube population, were caught at P4 in 2003 (see Fig. 1). One of these barbels was caught again at P6 passing three fish ladders during one season and migrating more than 7.5 km into the tributary. Nine individuals of barbel and one chub caught at P2 in 2003 were marked as Danube immigrants in 2002 below; five barbels marked as Danube immigrants in 2002 below P2 were caught at P4 in 2003. At P2, one grayling marked in 1999 below, was caught in.

At M3 two individuals of *Gobio gobio* (40% of total marked individuals), one barbel and one bleak, marked at M1 in 2003, were caught within the same season, passing three fish ladders and migrating more than 9.5 km into the tributary.

4.4 *Efficiency of channel restoration*

The Leitbild-orientated restoration of canalised river sections and the re-creation of habitat heterogeneity led to an enormous increase of fish densities (from 620 to 1984 individuals per 100 m) and had a significant influence on population structure (Zitek, unpublished data). Spawning of nase was observed there just one year after restructuring.

4.5 *Monitoring results of the situation after the re-establishment of the river continuum*

At the end of 2003 total stock estimation within the whole project area was repeated. In river Pielach, bleak and juveniles of asp *Aspius aspius* (L.) were found in the impoundment directly above P2 for the first time. Overwintering of barbel and chub (one individual, respectively) marked at P2 was documented in the impoundment above P2. One chub, marked at P4 in 2003, was found overwintering in the impoundment above P4. Two individuals of barbel, immigrants from the Danube (one marked at P2 in 2003, and one marked below P2 in 2003), were found overwintering in a pool below P6 together with one barbel marked at P4.

In the river Melk at the end of 2003 several new species were documented for the first time after the re-establishment of the river continuum. *Zingel zingel* (L.) was found between M3 and M4 at km 10; at the beginning of the monitoring this species only was documented for the area below M2. High densities of bleak and intensive reproduction of this species, not documented in the river Melk before, were documented within the whole system up to 12 km distance from the Danube (between M4 and M6). Juveniles of asp were also found between M4 and M6 for the first time and documented successful reproduction of this species there; migration of adults has been documented since the beginning of the monitoring (at M2; see Tab. 4). *Lota lota* (L.) was found between M2-M3 for the first time. *Gymnocephalus cernuus* (L.), documented to migrate in from the Danube in 2003, was found below M2. *Vimba vimba* (L.), also a new species in stock after implementation of the measures, was documented between M2-M3. Some individuals of barbel (marked at M3 in 2003) were found overwintering in pools below M3 (2 individuals) and between M4 and M6 (3 individuals).

5 CONCLUSION

Restoration of river continuum and regulated river sections at rivers Pielach, Melk and Mank had significant influence on the fish community and population structure. Channel restoration resulted in a strong increase of fish densities and the creation of spawning places for lithophilous species. Exchanging processes led to a re-increase of river type specific species and the re-connection of formerly segregated sub-populations.

6 REFERENCES

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7 APPENDIX

Tables 3 & 4: Fish stock (total number per species divided into adults/juveniles) between migration barriers (P_i-P_j; M_i-M_j), number and range of total length (L_T) in mm of individuals caught in traps at rivers Pielach & Melk.

Table 3: River section/study site at river Pielach	P1-P2			P2		P2-P4	P4		P4-P6	P6		P6-P7	P7-P8	P8		upstream P8	Total	
Length [m]/date of monitoring		*1760*		05.03.-23.06.03		*3703*	27.03.-23.06.03		*2884*	06.06.-26.06.03		*4918*	*4420*	03.04.-07.06.02		*864*	*18549*	
Species	1999 in stock	imm. 2001*	imm. 2002*	n in trap	L_T (mm)	1999 in stock	n in trap	L_T (mm)	1999 in stock	n in trap	L_T (mm)	1999 in stock	1999 in stock	n in trap	L_T (mm)	1999 in stock	1999 in stock	n in trap
Abramis brama (L.)	-	22	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alburnus alburnus (L.)	-	234	21	13	135-175	-	-	-	-	-	-	-	-	-	-	-	-	13
Alburnoides bipunctatus (Bloch)	fr.	-	7	-	-	fr.	4	100-115	fr.	4	95-115	fr.	fr.	23	80-120	fr.	fr.	31
Aspius aspius (L.)	-	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barbatula barbatula (L.)	fr.	4	-	-	-	fr.	-	-	fr.	-	-	fr.	fr.	-		fr.	fr.	-
Barbus barbus (L.)	129/52	20000*	11000*	153	165-630	530/54	87	140-660	315/39	8	165-545	707/78	620/65	4	525-570	116/9	2418/298	252
Blicca bjoerkna (L.)	-	5	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carassius gibelio (Bloch)	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chondrostoma nasus (L.)	190/97	2800*	2800*	17	130-230	362/154	15	190-540	241/108	5	140-215	478/234	428/187	4	100-510	165/27	1864/806	41
Cobitis taenia (L.)	-	-	-	-	-	-	-	-	-	-	-	ra.	-	-	-	-	ra.	-
Cottus gobio (L.)	do.	7	-	1	100	do.	1	75	do.	-	-	do.	do.	-	-	do.	do.	2
Cyprinus carpio (L.)	3/0	6	6	1	235	28/0	1	560	19/0	-	-	42/0	34/0	-	-	12/0	139/0	2
Esox lucius (L.)	-	1	3	-	-	-	-	-	-	-	-	-	-	1	650	-	-	1
Gobio albipinnatus (Lukasch)	-	408	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gobio gobio (L.)	fr.	-	-	3	120-135	fr.	6	120-145	fr.	7	90-140	fr.	?	5	110-140	fr.	fr.	21
Gymnocephalus schrätzer (L.)	-	10	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hucho hucho (L.)	0/46	6	9	1	230	47/78	5	610-850	24/57	-	-	35/87	50/90	1	640	6/12	162/370	7
Leuciscus cephalus (L.)	402/135	1200*	468*	44	135-465	1235/191	26	145-460	710/107	14	155-285	1391/159	1397/206	9	100-455	200/20	5336/818	93
Leuciscus leuciscus (L.)	fr.	54	10	2	160-210	-	-	-	ra.	-	-	ra.	-	-	-	-	fr./ra.	2
Leuciscus idus (L.)	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lota lota (L.)	66/0	9	3	-	-	-	-	-	-	-	-	-	-	-	-	-	66	-
Oncorhynchus mykiss (Walbaum)	34/22	14	35	5	160-220	9/39	3	430-460	9/41	-	-	13/59	11/49	2	210-400	2/4	78/214	10
Perca fluviatilis (L.)	13	19	4	-		-	1	125	-	1	130	-	-	-	-	-	-	2
Phoxinus phoxinus (L.)	do.	2	-	-		do.	-	-	do.	-	-	do.	do.	-	-	do.	do.	0
Rutilus rutilus (L.)	-	2	4	1	130-190	-	-	-	-	-	-	-	-	-	-	-	-	1
Salmo trutta f.f. (L.)	16/52	34	39	5	330-510	13/31	7	165-375	10/34	5	230-375	21/48	16/40	-	-	2/3	78/208	17
Salvelinus fontinalis (Mitchill)	32/0	1	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-
Scardinius erythrophthalmus (L.)	-	-	2	1	250	-	-	-	-	-	-	-	-	-	-	-	-	1
Sander lucioperca (L.)	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thymallus thymallus (L.)	23/39	18	19	7	175-415	43/313	33	105-235	30/255	16	185-375	56/445	50/379	2	190-230	8/45	210/1477	58
Tinca tinca (L.)	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vimba vimba (L.)	-	19	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zingel zingel (L.)	79/3	47	104	-	-	-	-	-	-	-	-	-	-	-	-	-	79/3	-
Total number of species	18	29	28	14	-	13	12	-	14	8	-	15	12	13	-	13	17	17
Total number of individuals	988/447	24931	14584	254	-	2223/905	189	-	1324/673	60	-	2681/1173	2554/1069	51	-	503/130	10273/4397	554

Table 4: River section/study site at river Melk	M1		M1-M2**	M2		M2-M3	M3		M3-M4**	M4		M4-M7**	Total	
Length [m]/date of monitoring	07.03.-26.06.03		4855**	29.05.-9.07.01		2325	19.04.-22.06.03		1728**	18.05.-09.07.01		2391**	*11299*	
Species	n in trap	L_T (mm)	1999 in stock	n in trap	L_T (mm)	1999 in stock	n in trap	L_T (mm)	1999 in stock	n in trap	L_T (mm)	1999 in stock	1999 in stock	in traps
Abramis ballerus (L.)	*10*	280-335	-	-	-	-	-	-	-	-	-	-	-	10
Abramis brama (L.)	*230*	200-580	-	-	-	-	-	-	-	-	-	-	-	230
Abramis sapa (Pallas)	*1*	165	-	-	-	-	-	-	-	-	-	-	-	1
Alburnus alburnus (L.)	*491*	100-270	-	7	80-180	-	65	105-180	-	-	-	-	-	563
Alburnoides bipunctatus (Bloch)	-	-	fr.	-	-	fr.	-	-	fr.	-	-	fr.	fr.	-
Aspius aspius (L.)	*19*	210-735	8/0	2	575-580	-	1	600	-	-	-	-	8/0	22
Barbatula barbatula (L.)	-	-	fr.	-	-	fr.	-	-	fr.	2	70-90	fr.	fr.	2
Barbus barbus (L.)	*786*	160-675	34/8	66	180-625	0/24	85	65-575	144/38	12	140-550	829/36	1006/106	949
Blicca bjoerkna (L.)	*111*	100-375	-	-	-	-	-	-	-	-	-	-	-	111
Carassius gibelio (Bloch)	*62*	195-460	-	-	-	-	1	380	-	-	-	0/45	0/45	63
Chondrostoma nasus (L.)	*78*	125-485	501/2121	5	175-520	239/967	17	125-530	621/33	-	-	74/10	1435/3131	100
Cobitis taenia (L.)	*1*	105	-	-		-	-	-	-	-	-	-	-	1
Cottus gobio (L.)	-	-	fr.	1	75	fr.	1	100	fr.	2	40-75	fr.	fr.	4
Cyprinus carpio (L.)	*32*	410-840	11/0	3	470-510	-	2	505-630	-	-	-	-	11/0	37
Esox lucius (L.)	*5*	490-615	22/0	-	-	10/0	-	-	3/0	-	-	-	35/0	5
Gobio albipinnatus (Lukasch)	*27*	90-145	-	-	-	-	-	-	-	-	-	-	-	27
Gobio gobio (L.)	*5*	120-135	do.	-	-	do.	117	40-165	do.	21	110-140	do.	do.	143
Gymnocephalus cernuus (L.)	*4*	85-115	-	-	-	-	-	-	-	-	-	-	-	4
Gymnocephalus baloni (Holcik & Hensel)	*2*	75-165	-	-	-	-	-	-	-	-	-	-	-	2
Gymnocephalus schrätzer (L.)	*3*	140-165	-	-	-	-	-	-	-	-	-	-	-	3
Hucho hucho (L.)	-	-	0/88	-	-	0/62	1	250	0/29	-	-	9/61	9/241	1
Leuciscus cephalus (L.)	*23*	170-530	1081/3325	13	50-445	531/1544	34	85-450	107/642	18	75-445	819/285	2539/5796	88
Leuciscus leuciscus (L.)	*23*	145-215	fr.	2	160-215	fr.	2	140-170	fr.	-		fr.	f	27
Leuciscus idus (L.)	*5*	165-475	-	-	-	-	-	-	-	-	-	-	-	5
Lota lota (L.)	-	-	57/0	-	-	22/0	-	-	-	-	-	-	80/0	0
Oncorhynchus mykiss (Walbaum)	*2*	310-365	6/26	7	330-385	0/19	13	205-365	0/8	3	150-330	18/0	23/53	25
Perca fluviatilis (L.)	*21*	80-310	52/0	1	135	22/0	-	-	-	-	-	-	74/0	22
Phoxinus phoxinus (L.)	-	-	do.	-	-	do.	-	-	do.	17	60-100	do.	do.	17
Proterorhinus marmoratus (Pallas)	*2*	60	ra.	-	-	-	-	-	-	-	-	-	ra.	2
Rutilus rutilus (L.)	*109*	85-265	199/110	-	-	94/48	4	100-135	6/3	-	-	-	299/162	113
Sabanejewia balcanica (Karaman)	-	-	ra.	-	-	ra.	-	-	-	-	-	ra.	ra.	-
Salmo trutta f.f. (L.)	*4*	220-345	109/152	7	195-340	74/199	8	220-330	26/64	5	130-290	29/36	238/450	24
Salvelinus fontinalis (Mitchill)	*1*	340	26/0	4	265-305	11/0	-	-	3/0	-	-	-	40/0	5
Sander lucioperca (L.)	*8*	450-750	-	-	-	-	-	-	-	-	-	-	-	8
Scardinius erythrophthalmus (L.)	*6*	195-325	66/66	-	-	29/29	-	-	-	-	-	0/37	95/132	6
Silurus glanis (L.)	*1*	350	-	-	-	-	-	-	-	-	-	-	-	1
Thymallus thymallus (L.)	*8*	115-290	0/48	4	160-380	0/21	-	-	2/25	4	195-210	0/41	2/135	16
Tinca tinca (L.)	*1*	210	-	1	380	-	-	-	-	1	305	-	-	3
Vimba vimba (L.)	*6*	180-350	-	-	-	-	1	335	-	-	-	-	-	7
Zingel zingel (L.)	*11*	215-290	3/0	-	-	-	-	-	-	-	-	-	3/0	11
Total number of species	33	-	24	14	-	20	15	-	16	10	-	16	25	37
Total number of individuals	2098	-	2160/5961	123	-	1027/2919	352	-	905/849	85	-	1769/561	5860/10290	2658

* numbers estimated by mark-recapture analysis; ** impoundments (2500, 1000 & 600 m; total length 4100 m) not considered.