Arch. Pol. Fish. (2013) 21: 179-188
DOI 10.2478/aopf-2013-0015

RESEARCH ARTICLE

Growth parameters of huchen *Hucho hucho* (L.) in the wild and under culture conditions

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Received – 28 September 2012/Accepted – 14 January 2013. Published online: 30 September 2013; ©Inland Fisheries Institute in Olsztyn, Poland
Citation: Andreji J., Stráňai I. 2013 – Growth parameters of huchen *Hucho hucho* (L.) in the wild and under culture conditions – Arch. Pol. Fish. 21: 179-188.

Abstract. The aim of this study was to determine the age and growth parameters of huchen, *Hucho hucho* (L.), individuals collected in the Dunajec River and from a fish farm in Príbovce. A total of 26 fish ranging in age from 5+ to 24+ were analyzed. Length-weight correlations were calculated with transformed regression equations and the von Bertalanffy growth model. The following equations were calculated for the fish from the Dunajec River – log W = –5.665392 + 3.256319 × log L; log L = 1.739815 + 0.307095 × log W; $L_{(t)} = 1451.4 \times [1 - \exp^{-0.1093 \times (t - 0.1251)}]$, and for the fish from the Príbovce farm – log W = – 7.176307 + 3.773629 × log L; log L = 1.901699 + 0.264997 × log W; $L_{(t)} = 1394.1 \times [1 - \exp^{-0.0997 \times (t - 0.1249)}]$. The values of Fulton's condition coefficient for the fish from the Dunajec River and the Príbovce farm were 1.24 and 1.35, respectively. Back-calculated length-weight growth in subsequent years was higher in the fish from the Dunajec River, but both huchen groups generally exhibited positive allometric growth.

Keywords: huchen, age, growth, Dunajec River, cultivated fish, von Bertalanffy

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Introduction

The huchen, *Hucho hucho* (L.) is Slovakia's largest native salmonid fish species. Its range of occurrence spans the Danube, Váh, Orava, Turiec, Kysuca, and Hron rivers, and it has been introduced into the Poprad, Dunajec, and Hornád rivers (Holčík 1998, Witkowski 2003, Koščo and Holčík 2008, Witkowski et al. 2013). This species is a highly predatory, economically valuable, and a prized trophy fish (Grman 1980). The abundance of the huchen is decreasing primarily because of pollution, stream regulation and fragmentation, and poor fishery management (Holčík 1980a, 1981, 1998, Rothschein 1980, Koščo and Holčík 2008), and its occurrence in streams is sporadic and isolated (Holčík 1981). The decline of it in its area of occurrence has also contributed to decreased catches (Holčík 1980a, Rothschein 1980).

According to Holčík (1998), the huchen is a critically endangered fish species, because its abundance is very low and continually decreasing. However, it is only classified as a vulnerable species on the latest Red List of lampreys and fishes of the Slovak Republic (Koščo and Holčík 2008). While the huchen has been recognized as threatened for the past century, no solution has yet been found to safeguard its future (Holčík 1981). Currently, the huchen is only cultivated at the Martin farm, which produces 1+ and 2+

fish for stocking. Despite the intensity of stocking programs, it is not yet possible to report that this species is safe from extinction in the wild (Holčík 1995).

Fish age and growth data provide plentiful information regarding the characteristics and bionomics of a species, and, combined with other indicators, permit undertaking measures to ensure the rational management of fished stocks and the sustainable exploitation of streams and reservoirs (Holčík 1980b). Unfortunately, there is a dearth of such data regarding the huchen. Therefore, the aim of the present study was to determine age and growth parameters for huchen individuals collected in the Dunajec River and at the salmonid fish farm in Príbovce, and subsequently to compare them.

Material and methods

The material analyzed was collected from the Slovak stretch of Dunajec River by angling in 1986 (n = 1) and in 2000-2008 (n = 13). The individuals collected from the farm in Príbovce from 1988 to 2008 (n = 12) had died during stripping. All of these fish were delivered to our department for trophy mounting. Basic biometric data were recorded for each fish: SL – standard length; TL – total length; W – body weight, to the nearest mm or g. Then two vertebrae were dissected from the spine located between the head and the dorsal fin. These were boiled and then stripped of any remaining tissues with a toothbrush (Holčík and Hensel 1972). The vertebrae were described according to Danko et al. (2011). Clean, dry vertebrae were cut on the medial plane with a fret saw into sections of approximately 0.2-0.3 mm, and then these were fixed in Canadian balm on microscope slides. Completely dry specimens were evaluated with digital picture analysis under an Olympus SZX 16 stereo microscope (Olympus, Japan) coupled with QuickPhoto Micro software (v. 2.3, © Promicra, Ltd., 2009, Czech Republic). Age determinations were estimated from the center to the end of the vertebrae at the fossa under magnifications of 10.0-12.5 X. Length-weight growth was back calculated with corrections for the time of scale setting (Lee 1912) with the Ichtyo software package (v.16/03, © Andrej Makara 1990, Slovakia) and the following log-transformed equation: $W = aL^b$, where W = weight in grams; L = standard length in mm; a and b = constants. A correction value of 30 mm was used according to Peňáz and Příhoda (1981). The von Bertalanffy growth model (Ricker 1975) was fit to the vertebral length-at-age data with a nonlinear least square regression algorithm using the Ichtyo software package (v.16/03, © Andrej Makara, 1990, Slovakia). The von Bertalanffy growth equation is as follows: $L_{(t)} = L_\infty \times [1 - \exp^{-K \times (t - t_0)}]$, where $L_{(t)}$ = standard length in mm at age "t"; L_∞ = asymptotic (maximum) standard length in mm; K = coefficient of increase rate change; t_0 = age at which the fish would have been size zero.

Fish growth was estimated with the methods developed by Szczerbowski (1977) and Holčík et al. (1988). The condition factor (CF) was calculated as: $CF = W / SL^3 \times 100$, where W = weight in grams; SL = standard length in cm; specific growth rate (length – SLGR, weight – SWGR) were calculated as: $SLGR = [(SL_2 / SL_1)^{1/t} - 1] \times 100$; $SWGR = [(W_2 / W_1)^{1/t} - 1] \times 100$ according to Holčík and Hensel (1972), where SL_1 = final standard length in mm; SL_2 = initial standard length in mm; W_1 = final weight in grams; W_2 = initial weight in grams; t – time in years. All estimated statistics were calculated with Statgraphic Centurio XV (© StatPoint Technologies, Inc., USA).

Results

A total of 26 specimens of huchen from the Dunajec River (n = 14) and the Príbovce farm (n = 12) were examined for age determinations and growth parameter estimations. Their basic biometric data are presented in Table 1. The fish from the Dunajec River were in age classes from 5+ to 6+ and 8+ to 12+ (Table 2). Transformation equations were applied to convert between TL and SL: $TL = 14.3844 + 1.07733 \times SL$ ($P < 0.001$; $r = 0.9989$; $r^2 = 99.38\%$).

Table 1
Base biometric data of the analyzed individuals of Danube salmon (*Hucho hucho*)

		TL (mm)		SL (mm)		W (g)	
	n	mean ± S.D.	range	mean ± S.D.	range	mean ± S.D.	range
Dunajec	14	1005 ± 159	780 - 1230	920 ± 147	700 - 1127	10502 ± 5166	3700 - 18200
Príbovce	12	1047 ± 268	650 - 1400	957 ± 249	595 - 1280	15999 ± 13737	2050 - 41000

Table 2
Back-calculated growth of Danube salmon (*Hucho hucho*) in the Dunajec River

Age category	n	SL/W	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+
V.	2	mm	175	371	546	645	699							
		g	44	503	1769	3044	3955							
VI.	3	mm	172	306	445	537	660	744						
		g	41	268	909	1676	3281	4846						
VIII.	2	mm	186	343	473	551	630	715	796	842				
		g	53	389	1109	1823	2819	4257	6038	7250				
IX.	1	mm	172	297	439	493	617	689	742	769	876			
		g	41	244	870	1269	2634	3774	4804	5396	8248			
X.	1	mm	216	284	362	421	519	666	714	861	910	959		
		g	86	211	464	759	1500	3379	4238	7797	9337	11075		
XI.	2	mm	140	258	359	454	556	656	735	790	851	917	982	
		g	21	154	452	970	1877	3216	4658	5891	7506	9573	11964	
XII.	3	mm	144	259	341	454	567	643	722	809	892	961	1015	1069
		g	23	156	382	970	2001	3013	4395	6365	8749	11151	13324	15773
Mean		mm	167	302	423	513	613	688	742	814	880	946	1002	1069
		g	37	257	771	1444	2579	3756	4804	6494	8371	10594	12776	15773

The back-calculated mean lengths are presented in Table 2. According to the values obtained, huchen growth is slow in the first year, average in the 2nd to 6th years, and then slow again from the 7th year. The length-weight relationship (LWR) was calculated with transformed regression equations: $\log W = -5.665392 + 3.256319 \times \log L$ and $\log L = 1.739815 + 0.307095 \times \log W$ ($r = 0.989$; $P < 0.05$). The parameters that describe length growth were identified using: $L\infty = 1451.4$ mm SL, $K = 0.1093\ \text{year}^{-1}$, $t_0 = 0.1251$ year. Using these parameters, the von Bertalanffy growth model (VBGM) was calculated as follows: $L_{(t)} = 1451.4 \times [1 - \exp^{-0.1093 \times (t - 0.1251)}]$. The estimated condition factor value was 1.24.

The absolute annual length increments ranged from 54 to 167 mm, with a tendency to decrease as age increased (Fig. 1). A similar trend was noted for the specific length growth rate (SLGR) values of which varied from 5.7% to 511.8% (Fig. 2). The opposite was observed for weight parameters: absolute annual weight increments increased as age increased ($P < 0.05$), and values ranged from 37 to 2,997 g (Fig. 3). The specific weight growth rate (SWGR) exhibited the same tendency as that of the SLGR with estimated values of 18.7-361.1% (Fig. 4), and the SWGR decreased as age increased ($P < 0.05$).

Although the fish from the farm in Príbovce were older, the individuals examined represented only the

Table 3
Back-calculated growth of Danube salmon (*Hucho hucho*) from the farm in Príbovce

Age category	n	SL/W	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	13+	14+	15+
V.	2	mm	181	308	430	560	608										
		g	22	164	577	1564	2134										
VI.	1	mm	173	294	445	634	710	755									
		g	19	138	657	2499	3831	4831									
VIII.	2	mm	171	315	431	543	600	708	772	832							
		g	18	178	582	1393	2030	3790	5254	6969							
IX.	2	mm	176	279	372	504	590	682	763	829	880						
		g	20	113	334	1051	1905	3291	5027	6894	8611						
XV.	1	mm	150	250	380	430	490	550	630	730	780	860	920	960	1020	1080	1160
		g	11	75	362	577	945	1462	2440	4254	5462	7896	10184	11959	15033	18651	24424
XVI.	1	mm	156	247	327	390	470	562	671	722	808	876	951	1008	1048	1099	1151
		g	13	71	205	399	808	1586	3095	4081	6240	8465	11541	14376	16650	19920	23717
XX.	2	mm	125	240	315	367	432	507	610	668	763	830	877	929	982	1020	1057
		g	5	64	178	318	588	1075	2160	3043	5027	6906	8501	10565	13026	15033	17196
XXIV.	1	mm	120	211	287	384	474	523	593	648	711	759	822	870	926	961	1009
		g	5	39	126	377	834	1209	1942	2714	3851	4928	6658	8248	10437	12006	14430
Mean		mm	159	274	378	482	550	618	687	751	798	831	889	939	991	1036	1087
		g	14	105	355	888	1462	2269	3383	4735	5954	6937	8949	11001	13482	15942	19112

5-6, 8-9, 15-16, 20, and 24 age classes (Table 3). In comparison to the fish from the Dunajec River, the values obtained were lower and the growth estimated for the first six years was classified as slow, and from the seventh year as very slow. The transformation equation for the conversion between TL and SL was

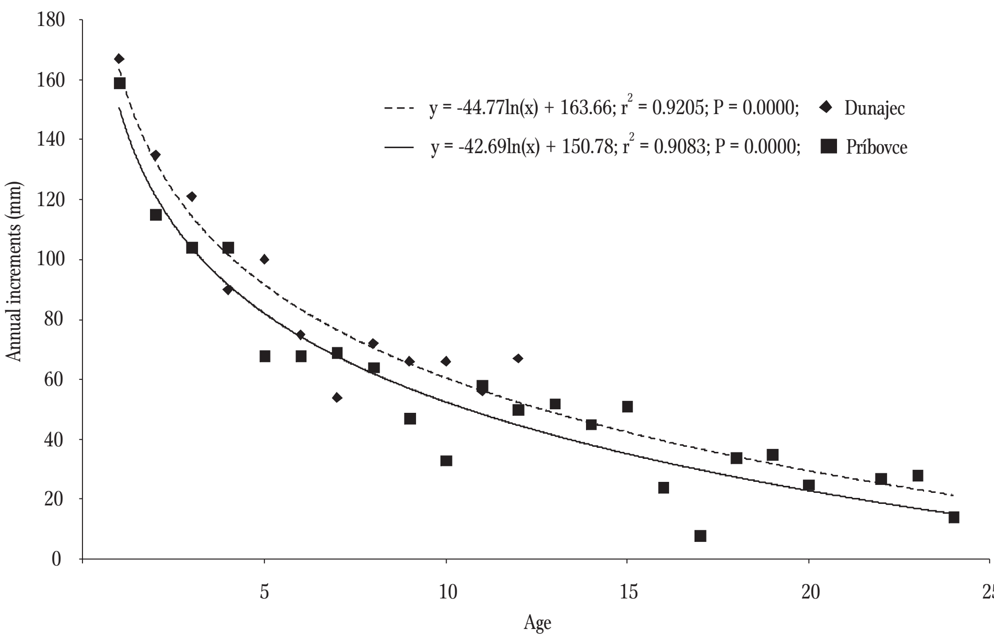

Figure 1. Annual length increments of Danube salmon (*Hucho hucho*) from the farm in Príbovce and Dunajec River.

Table 3. Continue

Age category	n	SL/W	16+	17+	18+	19+	20+	21+	22+	23+	24+
V.	2	mm									
		g									
VI.	1	mm									
		g									
VIII.	2	mm									
		g									
IX.	2	mm									
		g									
XV.	1	mm									
		g									
XVI.	1	mm	1191								
		g	26980								
XX.	2	mm	1105	1143	1176	1209	1232				
		g	20334	23101	25720	28551	30656				
XXIV.	1	mm	1044	1072	1106	1148	1176	1211	1238	1266	1280
		g	16412	18135	20403	23484	25720	28730	31223	33972	35412
Mean		mm	1111	1119	1153	1188	1213	1211	1238	1266	1280
		g	20753	21323	23873	26724	28909	28730	31223	33972	35412

estimated as TL = 17.5225 + 1.07535 × SL ($P < 0.001$; $r=0.9986$; $r^2=99.72\%$). The LWR was calculated from the transformed regression equation as: $\log W = -7.176307 + 3.773629 \log L$, and $\log L = 1.901699 + 0.264997 \log W$ ($r = 0.995$; $P < 0.05$). The growth parameters of VBGM were estimated as

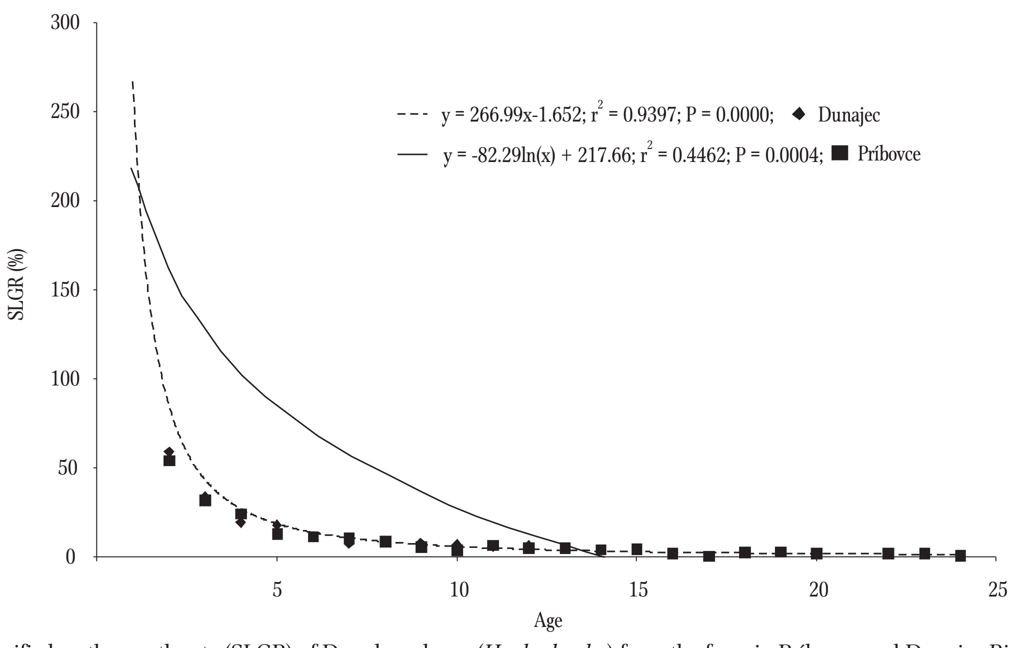

Figure 2. Specific length growth rate (SLGR) of Danube salmon (*Hucho hucho*) from the farm in Príbovce and Dunajec River.

Table 4
Back-calculated standard length at age (in mm) for Danube salmon populations from two sampling sites

Location	Váh	Orava	Danube	Turiec	Dunajec	Orava	Váh	Dunajec	Príbovce
Data source	Kirka (1963)	Kirka (1963)	Balon (1968)	Bastl et al. (1975)	Witkowski et al. (1985)	Krupka (1986)	Nevický (1989)	Our material	Our material
l_1	128	135	236	149	193	147	129	167	159
l_2	313	313	352	329	342	235	235	302	274
l_3	406	445	512	454	464	397	285	423	378
l_4	479	528	556	568	562	558	402	513	482
l_5	546	602			647	675	493	613	550
l_6		657			720	763	585	688	618
l_7		686			780	851	662	742	687
l_8					832	939	714	814	751
l_9					889	1013	766	880	798
l_{10}					927	1057	831	946	831
l_{11}					961	1086	883	1002	889
l_{12}						1101	948	1069	939
l_{13}							974		991
l_{14}							1013		1036
l_{15}							1039		1087
l_{16}							1078		1111
l_{17}							1117		1119
l_{18}							1156		1153
l_{19}									1188
l_{20}									1213
l_{21}									1211
l_{22}									1238
l_{23}									1266
l_{24}									1280

follows: L_∞ = 1394.1 mm SL, K = 0.0997 $year^{-1}$, t_0 = 0.1249 year. According these data, the VBGM was described as: $L_{(t)} = 1394.1 \times [1 - \exp^{-0.0997 \times (t - 0.1249)}]$. The estimated CF was of a value of 1.35.

Annual length increments decreased with age, and the values recorded ranged from -2 to 159 mm (Fig. 1). The values recorded for the estimated SLGR were from -0.2 to 506.7%, and a decreasing trend was noted as age increased (Fig. 2). The annual weight growth increments were the opposite, with the absolute annual weight increments increasing as age increased. However, no statistical significance was recorded (Fig. 3). The values obtained ranged from -179 to 3,170 g. The estimated value of SWGR ranged from -0.6 to 263.9%.

Comparisons of the two groups of fish revealed that faster back-calculated growth for both length and weight was detected in the huchen from the Dunajec River, and from the fifth year these differences were statistically significant ($P < 0.05$). The mean annual absolute increments were generally higher for fish from the Dunajec River, but these were not statistically significant ($P > 0.05$). The values of specific length growth rates were higher for the

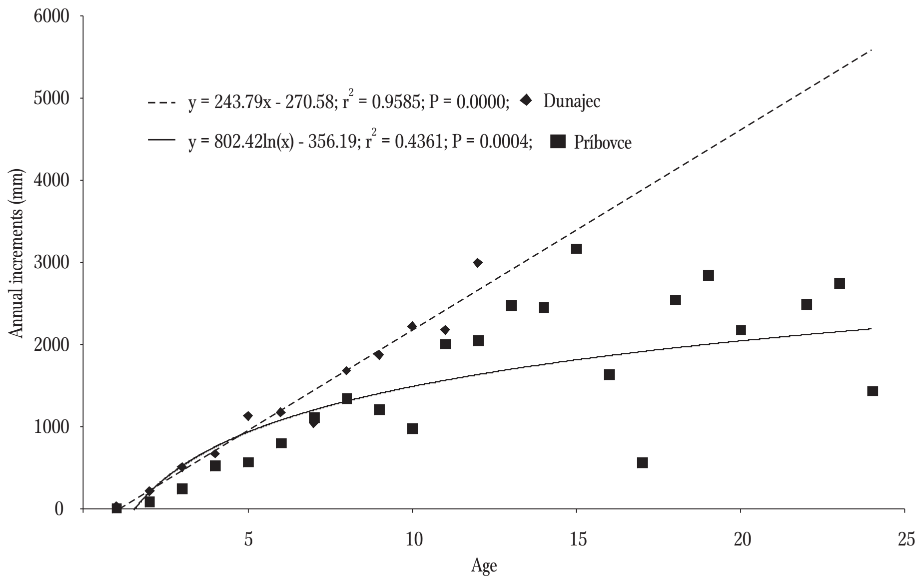

Figure 3. Annual weight increments of Danube salmon (*Hucho hucho*) from the farm in Príbovce and Dunajec River.

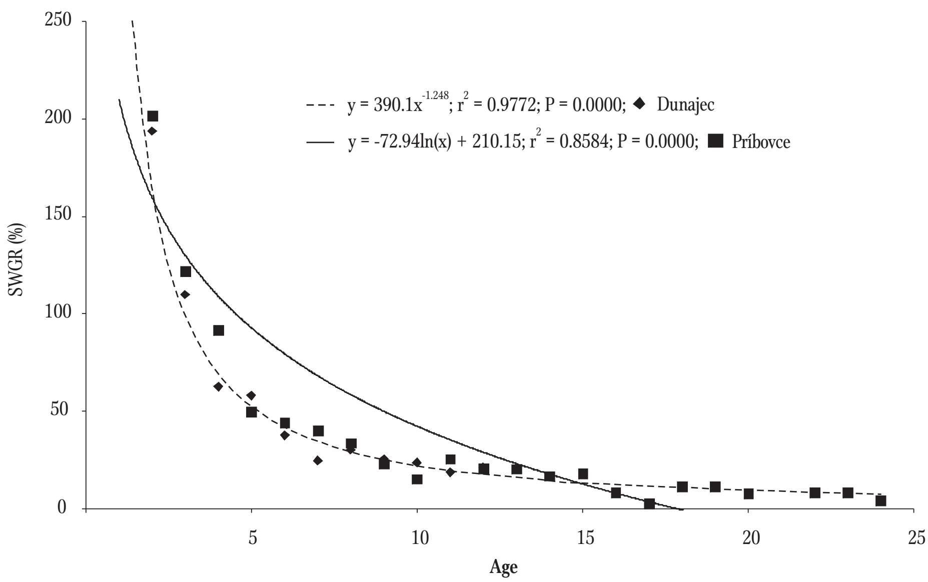

Figure 4. Specific weight growth rate (SWGR) of Danube salmon (*Hucho hucho*) from the farm in Príbovce and Dunajec River.

Dunajec River fish, while specific weight growth rate values were higher among the individuals from the Príbovce farm, but none of these differences were statistically significant ($P > 0.05$).

The dependence of body weight on standard length (Fig. 5) in huchen also differed between the two groups. Up to an SL of approximately 1 m, increases in weight were greater in the fish from the Dunajec River than they were in the Príbovce farm fish; however, above this length, slightly greater weight increases were noted in the fish from the Príbovce farm.

Discussion

The huchen is the largest salmonid in Slovak waters, and it can grow to gigantic sizes (Holčík et al. 1988).

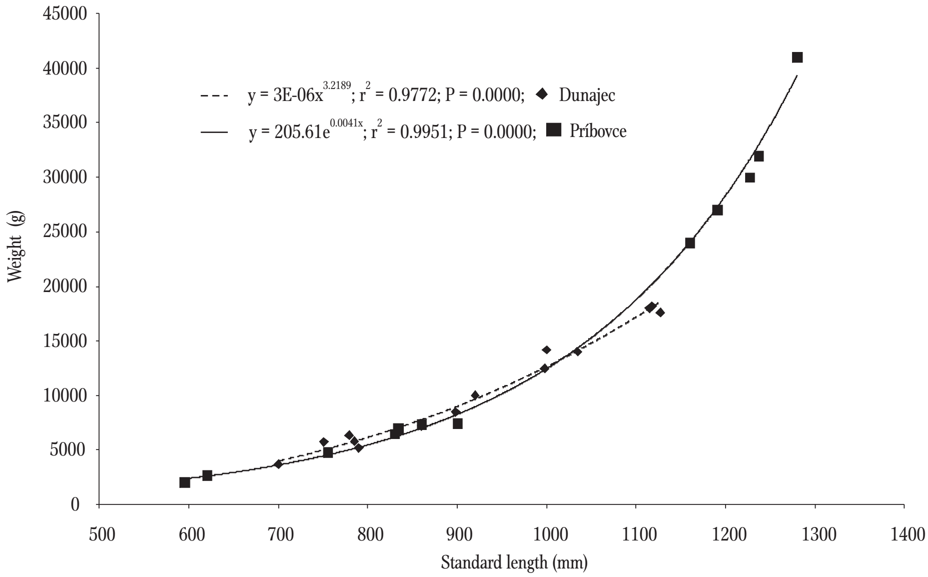

Figure 5. Dependence of Danube salmon weight on length (*Hucho hucho*) from the farm in Príbovce and Dunajec River.

According to data published to date, the largest huchen from Slovakia was recorded following the Hron River poisoning in 1949 at a weight of 46 kg (Ivaška 1951). The second largest huchen, which weighed 32 kg, was caught in the Váh River near the Skalka in the 1930s (Holčík et al. 1988). An even considerably larger huchen than these from Slovakia was caught in the Danube River near Tulln in 1873 with a recorded weight of 60 kg (Harsányi 1982, Hensel and Holčík 1983). It is postulated that historically huchen in Slovak waters have been as large as 160-170 cm in total length and 55-66 kg in weight (Rothschein 1980, Pavlík 1998). Currently, specimens no larger than 40 kg are thought to be possible to catch, and this is primarily because of pollution, river regulation, and shrinking areas of occurrence and decreases in abundance that affect the poorer results of fishing trophy catches (Holčík 1980a). Among the individuals analyzed in the present study, the largest sizes of huchen were 1217 mm SL and 18 kg in weight for fish from the Dunajec River, and 1280 mm SL and 41 kg in weight for those from the Príbovce farm (one dead female just before stripping).

The oldest age of a huchen thus far determined is 20+ in an individual from the Dráva River (Schulz 1985, Pavlík 1998). The maximum size this species can attain is much larger, and the data presented above do not indicate that these individuals reached the maximum longevity possible of this species (Holčík et al. 1988). The current findings confirmed this hypothesis, and the maximum age observed among the captive individuals examined was 24 years.

One of the characteristic features of huchen is its very rapid growth rate, which surpasses that of species such as pike *Esox Lucius* L., pikeperch, *Sander lucioperca*, and Wels catfish, *Silurus glanis* L. (Holčík 1980b). This is attributed to the huchen beginning predatory feeding very early (Bastl and Kirka 1958), which confers high growth potential and supports continued rapid growth (Rothschein 1980). This growth rate is determined by species specificity, but also by environmental factors including the quantity and quality of available food, amounts of space, water temperature, hydrological regime, etc. (Jungwirt 1978, Holčík 1980b, Adámek et al. 1985, Jungwirth et al. 1989). The current study results concerning growth indicate differences between the two sampling sites (Tables 2 and 3, Figs. 1-4). Higher values were recorded among individuals from the Dunajec River than in those from the farm at Príbovce, and beginning in the fifth year these differences were statistically significant.

The comparison of individuals from the two sites indicated that fish growth in the first year was approximately equal and was classified as slow. This reflects the stocking of running waters with 1+ fish cultured on fish farms (Rothschein 1980, Pavlík 1998, Vinarčík 1999). From the second year, growth among the Dunajec River fish was faster and was classified as average, while that of the fish from the farm at Príbovce was classified as slow. This stemmed primarily from differences in food and quantities of space, as has been demonstrated in other studies published previously (Bastl and Kirka 1958, Jungwirth 1978, Holčík 1980b, Příhoda 1990, Pavlík 1998). By the seventh year of life, growth decreased at both sampling sites, and this was likely linked to sexual maturation (Peňáz and Příhoda 1981, Příhoda 1990); however, some authors reported this phenomenon occurring between the third and fourth year (Harsányi 1982) and/or the fifth year of life (Holčík 1980b). In the next year, the growth of the fish from the Dunajec River was classified as slow, while that of the fish from Príbovce farm was very slow. Comparing the present results with those of other authors is difficult and complicated (Table 4). The present results are comparable with some huchen populations only for a few back-calculated years, while for subsequent years the differences are incomparable and *vice versa*. This is a known phenomenon that is linked with the rapid growth rates of huchen that causes great differences among individual age groups (Holčík 1980b, Holčík et al. 1988). Generally, both huchen groups exhibited positive allometric growth (b-value > 3), which corresponds to findings of other authors (Holčík 1980a, Witkowski et al. 1984, 1985, Krupka 1986, Holčík et al. 1988, Nevický 1989).

Negative results were noted in the evaluation of annual mean increments and specific growth rate estimates for fish from the Príbovce farm for the 21+ age group. This was linked primarily to the absence of some fish age classes and the small sample size of the fish analyzed. The values of the estimated condition factor were higher for the individuals from the Príbovce farn (1.35) than they were for the fish from the Dunajec River (1.24). This difference likely stems from the different age categories of the two fish groups analyzed, where it is known the value of this increases with age (Holčík et al. 1988). The condition factor is highly variable and depends on season and sex (Witkowski et al. 1985), and values for females are generally higher than those for males (Holčík et al. 1988). These factors could have impacted the present study results, because the fish from the Dunajec River were caught during the fishing season in the November - December period, while the fish from the Príbovce farm were obtained during the spawning season in April.

Acknowledgments. This study was supported financially by the projects VEGA 1/1101/11 and 1/0243/11 and KEGA 035SPU-4/2012.

Author contributions. I.S. acquired and provided the vertebrae, I.S. and J.A. prepared and read the samples and also analyzed the data, J.A. performed the statistical evaluations and wrote the paper.

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