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RESEARCH ARTICLE

Osteological characteristics of selected cranial bones of juvenile reciprocal hybrids of Atlantic salmon, *Salmo salar* L., and sea trout, *Salmo trutta* L.

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Abstract. Four cranial bones (supraethmoid, glossohyal, premaxilla, vomer) of nine-month-old reciprocal hybrids of *Salmo salar* and *Salmo trutta* and the arrangement of the opercular bones in reciprocal hybrids aged from 4 to 24 months were analyzed. The supraethmoid bone in the majority of the hybrids studied was similar to that of salmon. In some hybrids, an atypical additional process was found on the lower part of the supraethmoid bone. The large process of the premaxilla bone had a short base in the two groups of hybrids as in salmon, and it was low as in trout. The shape of the vomer plate was intermediate between a triangle (as in trout) and a pentagon (as in salmon) in the majority of salmon × trout hybrids and almost half of the trout × salmon hybrids. The glossohyal in some hybrids had an uneven number of teeth in each row, and these rows of teeth were uneven.

Keywords: morphology, bone, cranium, hybrids, salmonids, vertebrate

Introduction

In natural conditions, hybridization between *Salmo salar* and *Salmo trutta* is most often a result of anthropogenic stress (Crozier 1984, Verspoor 1988, Elo et al. 1995, Makhrov et al. 1998, Delling et al. 2000). Hybrids of these species have been caught in watercourses in Finland and Norway (Elo et al. 1995), Sweden (Jansson et al. 1991), Spain (Garcia de Léaniz and Verspoor 1989), Ireland (Crozier 1984), Great Britain (Jordan and Verspoor 1993), and in the Baltic Sea (Semenova and Slyn'ko 1988). Hybridization between these species is unfavorable because of introgression and the loss of spawning sites for pure species (Verspoor 1988, Garcia de Léaniz and Verspoor 1989). The hybrids can also have unfavorable traits that hinder their development (McGowan and Davidson 1992, Gray et al. 1993). The literature lacks precise information on cranial bone measurements of salmon and sea trout reciprocal hybrids. Osteological traits are important to species assignment among the family Salmonidae (Dorofeyeva 1975, 1989, Kazakov et al. 1982, Kacem et al. 1998). They permit identifying not only species but also interspecies forms and populations since the processes of adaptation to different environmental conditions are reflected in the structure of the skeleton (Šapošnikova 1975, Dorofeyeva 1979, Siergienko 1982). Despite their many differences, Salmonidae comprise a compact group, and their osteological structures have many common features that distinguish them as a family (Dorofeyeva 1975, Svetovidov et al. 1975, Brylińska 2000). The cranial bones that are most characteristic of these species and those which are analyzed most frequently are the

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supraethmoid, the glossohyal, the premaxilla, and the vomer (Dorofeyeva 1975, 1979, Kazakov et al. 1982, Siergienko 1982, Dorofeyeva et al. 1990, Kacem et al. 1998, Kirczuk 2002). The literature most often supplies descriptions of the shapes of these bones (Chełkowski 1970, Dorofeyeva 1975, Kazakov et al. 1982, Chełkowska, 1982, Brylińska 2000), but detailed measurements are scarce (Medvedeva-Vasil'eva, 1978, Dorofeyeva et al. 1990, Kacem et al. 1998, Kirczuk 2002, Kirczuk and Domagała 2003). The present paper is an analysis of selected cranial bones of nine-month-old reciprocal hybrids of salmon and trout.

Material and methods

The osteological analysis included evaluating the shape of selected cranial bones of 46 trout × salmon hybrids and 48 salmon × trout hybrids all nine months of age. The arrangement of the opercular bones was analyzed in 416 hybrids of female trout × male salmon and 158 hybrids of female salmon × male trout (Table 1). The reciprocal crossing between salmon and sea trout was done during the artificial spawning of salmon and trout. The salmon eggs and milt were obtained from individuals cultured at the Aquamar Fish Farm in Miastko and in the Wieprza River, while the trout eggs and milt were obtained from fish from the Rega River. The eggs were fertilized and incubated at the Polish Anglers' Association (PAA) Hatchery in Goleniów. The hatch was released into watercourses near Szczecin, Poland that flowed into the municipal sewage system, which ensured that the hybrids would not be introduced into the natural environment or come into contact with pure species. Additionally, there were no representatives of pure parent species or other predators in the watercourses into which the hybrids were introduced. The growing fish were caught regularly each month by electrofishing with an IUP-12 aggregate (approved by the Local Commission for Ethical Research no. 24/02 of 3.06.2002). The heads were boiled for 1-2 min., and the supraethmoid, glossohyal, premaxillar, and vomer bones were extracted with needles. They were prepared by washing in an H_2O_2 solution and then placed in test tubes. Measurements (Fig. 1, Kirczuk 2002) to the nearest 0.1 mm were performed with Leica Qwin microscopic image analysis computer program. The premaxillary bones were used to take measurements of the left bone. Photographs of the bones were taken with a Nikon digital camera. The arrangement of the opercular bones in fresh material was analyzed using the key for identifying salmon and trout (Hein and Schechtl after Gąsowska (1962)).

Pearson's correlation coefficient was used to analyze the relationship between fish length and the analyzed cranial bone indicators. The Kruskal-Wallis test was used to determine whether there were differences in bone and teeth number between the two groups of salmon and brown trout hybrids. Factor analysis was performed using cranial indicators for the two groups of hybrids. Factor analysis of these indicators showed that the two groups of hybrids were most differentiated by the cranium. Statistical analysis was done with Statistica 9.1 (StatSoft, Inc. Kraków, Poland). As is generally accepted in hybrid

Table 1
Data (sample size (N), age, mean ± SD caudal length, and caudal length range) on salmon and trout reciprocal hybrids

	trout × salmon				salmon × trout			
Analyzed bones	N	Age (month)	Caudal length (cm)	Range (cm)	N	Age (month)	Length (cm)	Range (cm)
supraethmoid glossohyal premaxilla vomer	48	9	11.68±1.14	7.9-14.2	48	9	12.18±1.84	8.0-15.8
arrangement of opercular bones	158	4-24	10.38±2.90	5.20-20.40	158	4-24	11.23±2.90	5.90-20.20

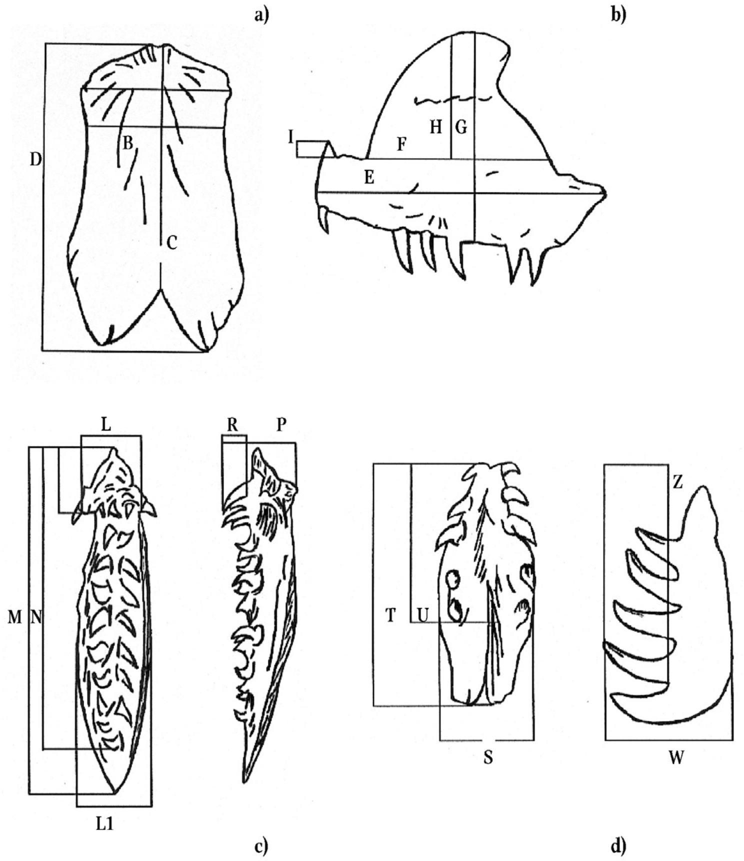

Figure 1. Measurements of mesethmoid (a); premaxillary (b); vomer (c); glossohyal (d).

names, the maternal species is given first and the paternal second (Chevassus 1979).

Results

Supraethmoid

This cranial bone covers the upper part of the anterior section of the brain. It is a convex, elongated plate with side processes in the front and a cut in the back. In 80.5% of the trout × salmon hybrids and 87.5% of the salmon × trout hybrids, the supraethmoid had rounded sides, while in the rest the sides were sharp. In 34.78% of the trout × salmon hybrids and in 18.8% of the salmon × trout hybrids, the bottom part of the supraethmoid had an additional, atypical process on one (Fig. 2) or both sides (Fig. 3). Statistical analysis (Kruskal-Wallis test, $P < 0.05$) showed that neither group of hybrids differed significantly from each other with regard to the supraethmoid indicators (Table 2).

Premaxilla

The shape of the premaxilla in the Salmonidae is wing-shaped with two processes: one large and the other small. In 6.3% of the salmon × trout hybrids there was a small process on the premaxilla of a height equal to 4.9% of the bone length. The trout × salmon hybrids had 5-9 teeth on the premaxilla (Fig. 4), while the salmon × trout hybrids had 6-9 teeth (Table 3). The Kruskal-Wallis test ($P < 0.05$) confirmed statistically significant differences between the two groups of hybrids in the number of teeth (Table 3).

Table 2

Summary of measuring indicators (mean ± SD, range) on the cranial bone of the reciprocal hybrids of salmon and trout. *Data after Kirczuk and Domagała (2003)

Characters		trout × salmon	salmon × trout	salmon*	trout*
Supraethmoid	C/D	79.62±4.01[b]	79.90±3.65[b]	77.88±6.17[b]	74.39±2.20[a]
		67.89-101.76	71.95-86.90	65.85-92.11	73.25-97.73
	B/A	76.78±7.50[bc]	80.73±5.31[c]	79.20±5.26[b]	60.22±5.82[a]
		61.94-98.59	71.30-91.26	66.78-89.27	49.43-68.67
	A/D	51.15±2.98[ab]	49.33±4.05[b]	48.98±3.75[a]	57.61±8.14[c]
		44.69-57.50	40.59-61.77	41.98-58.65	47.65-74.78
Premaxilla	F/E	63.73±7.10[a]	61.26±8.57[a]	67.05±7.25[a]	79.05±5.35[b]
		47.42-77.05	33.80-77.69	53.03-84.13	43.65-82.98
	H/G	65.12±5.93[a]	63.14±8.06[a]	71.35±8.11[b]	62.38±10.38[a]
		47.70-78.35	49.27-102.21	56.33-104.43	28.02-87.63
	G/E	78.81±6.52[a]	80.34±9.37[b]	75.26±9.12[a]	79.06±8.05[b]
		65.76-97.75	46.29-104.33	48.15-93.81	62.22-97.34
Vomer	O/M	9.08±1.00[a]	9.11±1.18[a]	9.31±1.61[a]	12.23±2.43[b]
		6.16-10.91	6.82-13.73	5.94-12.26	8.94-22.20
	O/L	94.90±14.76[c]	82.52±12.32[b]	80.27±18.44[b]	74.73±11.14[a]
		66.77-130.39	63.25-122.21	58.22-101.14	55.56-105.71
	L1/M	12.22±1.51[a]	13.71±1.25[b]	16.03±2.26[c]	14.48±1.84[b]
		8.47-14.93	11.32-16.03	11.47-20.88	11.78-18.05
	P/M	17.26±1.46[a]	17.84±1.18[a]	21.27±8.51[b]	23.22±7.24[b]
		14.27-20.36	15.44-19.99	17.41-25.12	18.35-58.24
	M-N/M	10.74±2.81[d]	8.29±2.76[b]	7.95±3.80[a]	9.03±4.37[c]
		2.80-19.04	3.36-15.26	3.81-17.88	2.14-21.08
	M-O/M	90.92±1.00[a]	90.91±1.17[a]	90.69±1.61[a]	87.77±2.43[a]
		89.09-93.84	86.27-93.18	88.00-93.44	77.80-91.60
Glossohyal	U/T	71.40±4.85[a]	74.17±4.97[b]	76.77±5.57[b]	75.13±4.50[b]
		61.42-89.72	62.18-87.54	63.12-85.44	61.92-84.70
	S/T	36.55±2.96[a]	39.30±2.51[b]	37.55±3.55[ab]	36.77±3.33[a]
		29.03-43.31	34.85-44.03	28.69-47.28	31.28-44.61
	W/T	36.04±3.03[b]	37.99±3.95[b]	30.87±7.16[a]	46.33±4.80[c]
		30.44-44.35	30.53-50.51	23.12-38.80	34.24-56.06
	Z/T	23.28±2.09[b]	23.60±2.94[b]	19.41±3.48[a]	26.02±7.44[c]
		20.03-27.55	16.74-32.16	14.80-24.67	18.31-66.01
	T-U/T	28.60±4.85[b]	25.83±4.97[a]	23.23±3.48[a]	24.86±4.50[a]
		10.28-38.58	12.46-37.82	14.55-36.87	18.12-38.07
	T-U/U	40.67±9.21[c]	35.42±9.14[b]	31.06±9.69[a]	33.57±8.37[ba]
		11.45-62.82	14.24-60.82	15.19-49.39	18.05-61.49

Supraethmoid: C/D, ratio of length to notch to total length; B/A, ratio of minimal to maximal width; A/D, ratio of maximal width to total length. Premaxilla: F/E, ratio of large appendix length to maximal length; H/G, ratio of large appendix height to maximal width without tooth; G/E, ratio of maximal width a tooth to maximal length. Vomer: O/M, ratio of plate length to total length; L1/M, ratio of maximal corpus width to total length; P/M, ratio of maximal profile width with tooth to total length; M-N/M, ratio of non-denticulated section length to total length; M-O/M, ratio of corpus length to total length. Glossohyal: U/T, ratio of denticulated section length to total length; S/T, ratio of maximal width to total length; W/T, ratio of maximal profile width with tooth to total length; Z/T, ratio of tooth length to total length; T-U/T, ratio of non-denticulated section length to total length; T-U/U, ratio of non-denticulated section length to denticulated section length

Values in rows marked with different letters indicate significant differences in cranial bone characteristics (Kruskal-Wallis test, $P < 0.05$)

Table 3
Data (mean ± SD, and range) of cranial bone teeth of reciprocal hybrids of salmon and trout. * Data from Kirczuk and Domagała (2003)

Vomer corpus	Glossohyal	Vomer corpus	Under vomer plate	Left premaxillary	Right premaxillary
trout × salmon	10.41±1.00[a]	19.64±1.33[c]	2.67±0.77[a]	6.67±0.73[a]	6.52±0.75[a]
	8-13	17-23	2-4	5-8	5-9
salmon × trout	9.84±1.35[ab]	16.32±2.38[b]	4.00±0.00[b]	7.59±1.00[b]	7.63±0.88[b]
	8-13	10-22	4	6-9	6-9
salmon*	10.20±1.96[a]	19.54±3.13[c]	3.87±0.95[b]	7.60±1.43[b]	7.20±1.58[ab]
	10-12	17-24	2-5	7-9	6-9
trout*	9.84±0.81[b]	10.88±2.34[a]	4.00±0.00[b]	8.65±0.53[c]	8.55±0.50[c]
	9-13	9-16	4	8-10	8-9

Values in columns marked with different letter indexes indicate significant differences in the number of teeth ($P < 0.05$; Kruskal-Wallis test)

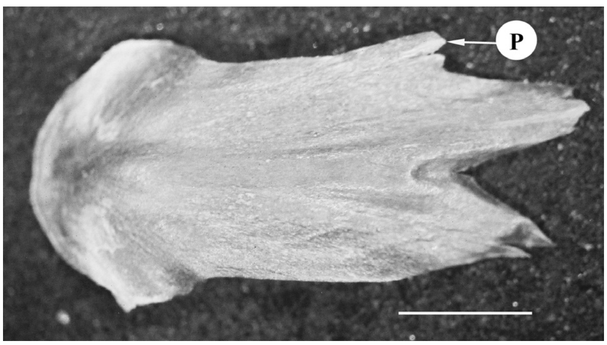

Figure 2. Hybrid female *Salmo salar* × male *Salmo trutta* supraethmoid with one side process (P). Scale bar 1 mm.

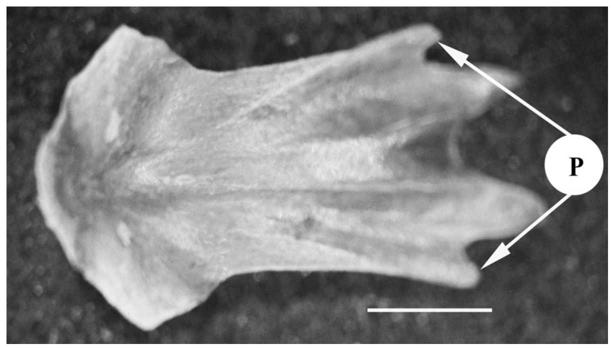

Figure 3. Hybrid female *Salmo trutta* × male *Salmo salar* supraethmoid with two side process (P). Scale bar 1 mm.

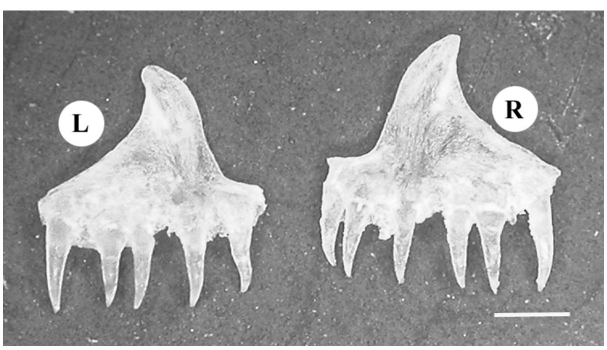

Figure 4. Hybrid female *Salmo trutta* × male *Salmo salar* left (L) and right (R) premaxilla (some teeth fell out). Scale bar 1 mm.

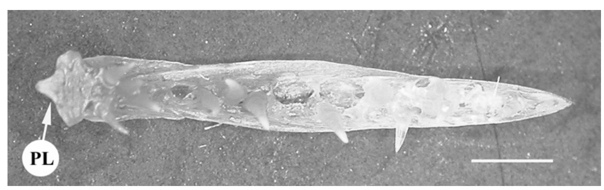

Figure 5. Hybrid female *Salmo salar* × male *Salmo trutta* vomer with plates (PL) with irregular shapes. Scale bar 1 mm.

Vomer

The vomer comprises a plate, column, and corpus. In the majority of hybrids, 48 and 66.7% of the trout × salmon and salmon × trout hybrids, respectively, the vomer plate was irregular in shape (Fig. 5). The vomer plate was triangular in shape in 29.0% of the trout × salmon hybrids and 12.5% of the salmon × trout, whereas a pentagonal shape was noted in 23.0 and 20.8% of the respective hybrids. The trout × salmon hybrids had 2-4 teeth at the base of the plate and 17-23 teeth on the core, while the reciprocal hybrid had 4 at the base and 10-22 teeth on the core. The teeth on the vomer were deployed in three different systems. In the trout × salmon hybrids, the teeth were arranged in one row followed by two rows (47.8% individuals), one row (39.1%) or two rows

(13.1%) in the front of the vomer core, while in the salmon × trout hybrids the analogous numbers were 83.3, 4.2 and 12.5%. In 89.1% of the trout × salmon hybrids, the vomer plate had a sharp top, while in the others it was rounded. The edges of the corpus in all hybrids of this type were sharp. In all salmon × trout hybrids the edges of the plate and the corpus were sharp. The Kruskal-Wallis test ($P < 0.05$) indicated that the two hybrids differed significantly in L1/M, O/L, M-N/M, and in the number of teeth under the plate and on the vomer corpus.

Glossohyal

There were 9-13 teeth on this bone in the trout × salmon hybrids, and in 70% of individuals they were arranged in two rows of equal length. An odd number of teeth on this bone was noted in 71.74% of the hybrids of this type. There were 8-14 teeth on this bone in the salmon × trout hybrids, and an odd number of teeth was noted in 46% of the individuals. In 80% of the hybrids of this type, the teeth on this bone were arranged in two rows of equal length, while in others the lengths of the rows were different (Fig. 6). The Kruskal-Wallis test ($P < 0.05$) indicated there were statistically significant differences between the two types of hybrids with regard to U/T, S/T, T-U/T, and the number of teeth.

Pearson's correlation coefficient did not indicate a correlation between the analyzed traits (Table 2) and the lengths of the hybrids. Factor analysis of the measurable features of the cranial bones and the number of teeth revealed two factors. The number of teeth on the premaxillar bones and on the head and corpus of the vomer had the greatest effect on factor 1; L1/M, S/T, T-U/T. The value of factor 2 was determined by F/E, H/G, and O/M. The analysis of the factor values showed that the features contributing to the two factors are those that differentiate the salmon × trout and trout × salmon hybrids (Fig. 7). According to the statistical analysis of the cranial bone features considered, the ranges of variation of the feature values in the salmon × trout hybrids are broader than in the reciprocal hybrid, which indicates the greater plasticity of the bones studied in this group of hybrids.

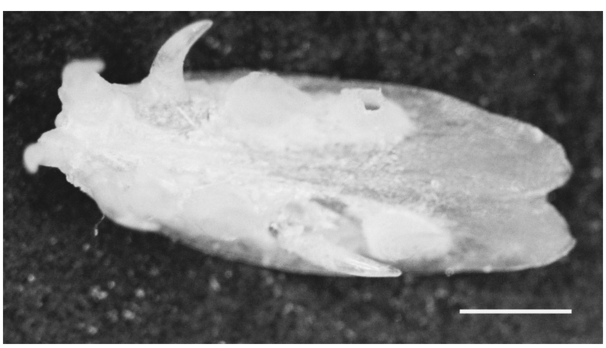

Figure 6. Hybrid female *Salmo salar* × male *Salmo trutta* lingual plate with teeth rows of different lengths. Scale bar 1 mm.

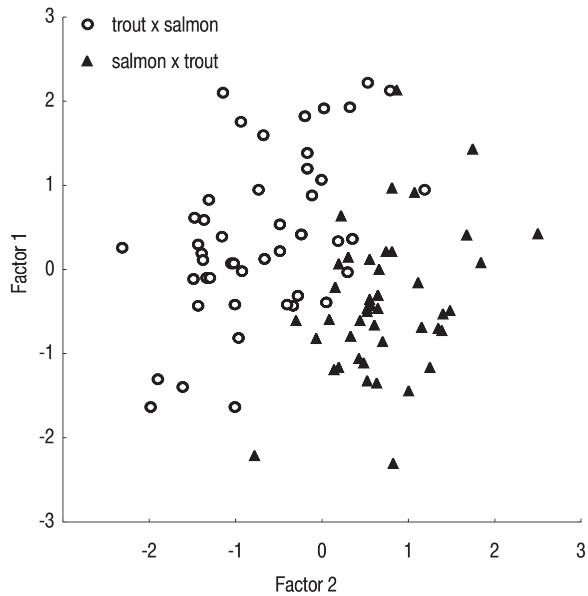

Figure 7. Values of the factors constructed in the Factor Analysis of the cranial bones of nine-month old trout × salmon and salmon × trout hybrids.

Discussion

Osteological criteria are crucial for the identification of species, subspecies, and populations of the family Salmonidae (Dorofeyeva 1975, 1979, Siergienko 1982, Brylińska 2000). According to Dorofeyeva et al. (1990), differences in measurable features of cranial bones are much greater among isolated populations of salmon than among non-isolated populations. This is why measurements of cranial bone features of salmon and trout (Kirczuk and Domagała 2003) from the same school and of the same age as the hybrids in the current study are discussed The Kruskal-Wallis ($P < 0.05$) test indicated statistically significant differences between the two groups of hybrids, salmon, and trout (Table 2). The supraethmoid bone in the hybrids was similar in the width and the shape of small cuts on the side and in the rear to the analogous bone in salmon (Kirczuk and Domagała 2003). In the majority of individuals from the two types of hybrids, the edges of the supraethmoid bone were rounded as in salmon; similar observations were reported by Dorofeyeva et al. (1990) for the salmon × trout hybrids. An atypical feature found in some individuals was an additional process on the one or both sides of the lower part of the supraethmoid bone. This process was not noted in trout or salmon from rivers in Pomerania (Kirczuk and Domagała 2003). In some hybrids, the supraethmoid bone had a rounded shape and smaller side cuts than in salmon, while in others the bone had sharp edges as in trout (Dorofeyeva 1975, 1989, Šapošnikova 1975, Kazakov 1998, Dorofeyeva et al. 1990, Kirczuk and Domagała 2003). These features were combined in some individuals with sharp edges like in trout and small cuts like in salmon (Kirczuk and Domagała 2003).

According to some researchers (Dorofeyeva 1975), premaxilla bone features are reliable criteria for Salmonidae species identification. Both groups of hybrids have a higher premaxilla (G/E) than salmon, in which the G/E is 75% (Kirczuk and Domagała 2003), and 6.3% of the salmon × trout individuals had a small process on the premaxilla bone that is noted in trout but not salmon (Kirczuk and Domagała 2003). According to Dorofeyeva et al. (1990), this small process was not present on the premaxilla bones of salmon, trout, or their hybrids aged 0+ from the Narova River, while the premaxilla bones of the hybrids and pure species were indistinguishable. The vomer plate was shaped intermediately between triangular (as in trout) and pentagonal (as in salmon) in 48% of the trout × salmon hybrids and 66.7% of the salmon × trout hybrids whereas according to Dorofeyeva et al. (1990) the intermediately shaped vomer plate occurred in 66.7% of the salmon × trout hybrids. The vomer plate was either pentagonal (as in salmon) or triangular (as in trout) in the other salmon × trout hybrids. Dorofeyeva et al. (1990) reported that 23.72% of the salmon × trout hybrids had triangular vomer plates, and no individuals with pentagonal plates were noted. In the two types of hybrids, the width of the vomer corpus (expressed as a percentage of vomer length) was similar to that in trout, while the length of the vomer plate (expressed as a percentage of vomer length) was close to that in salmon (Kirczuk and Domagała 2003). In almost half of the trout × salmon and over 80% of the salmon × trout hybrids, the teeth on the vomer corpus were arranged in one row followed by two deeper-set rows. Almost 39.1% of the trout × salmon hybrids and 3.2% of the salmon × trout hybrids had one row of teeth along the whole length of the vomer corpus as in salmon, while 13.1 and 16.7% of the respective hybrids had teeth arranged in two rows as in trout. The arrangement of the teeth on the vomer corpus observed in the current study differed from that reported by Dorofeyeva et al. (1990). The salmon × trout hybrids at the age of 0+ from that study had one row of teeth on the vomer corpus. The number of teeth under the vomer plate was 2-4 in the trout × salmon hybrids and four in the reciprocal hybrid, which was similar to that of salmon and the same as for trout, (Table 3, Kirczuk and Domagała 2003). The number of teeth on the vomer corpus in salmon × brown trout hybrids was similar to that of salmon, but in the reverse hybrid it differed from salmon and sea trout (Kirczuk and Domagała 2003). Both groups of hybrids had narrower vomer profiles (P/M) in relation to this trait in salmon (21.3%) and trout (23.2%), (Kirczuk and Domagała 2003). The length of the segment with teeth on the glossohyale (U/T) in salmon × trout hybrids was similar to that in salmon (76.8%) and trout (75.1%), (Kirczuk and Domagała 2003). In some hybrids, the two rows of teeth on the glossohyal ended unevenly, which resulted from the different number of teeth in the rows or from their uneven distribution. The rows usually ended evenly in both parent species (Dorofeyeva et al. 1990, Kirczuk and Domagała

2003). The variation range in the number of teeth on this bone were slightly greater in the two groups of hybrids than in the parent species (Table 3). According to Dorofeyeva et al. (1990), salmon × trout hybrids had five teeth in each row. Different numbers of teeth in the two rows and their irregular distribution were noted in hybrids of the family Cyprinidae (Smith 1973). The comparative analysis of the cranial bones of the hybrids studied and the description by Dorofeyeva et al. (1990) revealed some differences; however, these could have resulted from erroneous identification by the latter authors since no clear criteria of hybrid differentiation is presented in their paper.

As to the opercular bones, the majority of the two types of hybrids analyzed revealed an arrangement typical of trout (Hein and Schechtl after Gąsowska (1962)). However, it should be noted that the arrangement of these bones is not always possible to determine in salmon and trout in the first year of life, and that their arrangement in young salmon individuals is often the same as in trout (Domagała and Kirczuk 2004). Thus, the arrangement of opercular bones as a criterion of hybrid identification is of limited value for hybrids in the first year of life.

The analysis of the selected cranial bones indicates that their features in hybrids were intermediate between those of the parent species, similar to those of the parent species, or different from those of the parent species (one to two additional processes on the supraethmoid bone; the irregular shape of the vomer plate; uneven rows of teeth on the lingual bone; different numbers of teeth in each row). The atypical features of the cranial bones was reflected in the external appearance of the head. Head deformations in salmon and trout hybrids were reported by McGowan and Davidson (1992), Gray et al. (1993), and Kirczuk and Domagała (2009). Atypical features of the head have also been noted in hybrids of *Hypophthalmichtys nobilis* × *Ctenopharyngodon idella*, (Bakos et al. 1979), *Oncorhynchus rhodurus* × *Salvelinus fontinalis* (Iuchi et al. 1975), *Ctenopharyngodon idella* × *Hypophthalmichthys nobilis* (Beck et al. 1984). The current analysis of cranial bones in reciprocal hybrids of trout and salmon indicated there is great variation in shape, and it is hypothesized that hybridization caused disturbances in the development of cranial bones in the hybrids studied.

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Streszczenie

Charakterystyka osteologiczna wybranych kości czaszki juwenilnych, obustronnych hybrydów łososia *Salmo salar* L. i troci *Salmo trutta* L.

Hybrydyzacja pomiędzy łososiem *Salm salar* i trocią *Salmo trutta* w warunkach naturalnych ze względu na introgresję jest zjawiskiem niekorzystnym. U hybrydów zaobserwowano nietypowe zmiany dotyczące cech osteologicznych. Analizie poddano cztery kości czaszki (sitową, językową, przedszczękową i lemiesz) 9-miesięcznych obustronnych hybrydów łososia i troci oraz układ kości wieczka skrzelowego hybrydów w wieku od 4 do 24 miesięcy. Obustronne skrzyżowanie łososia i troci wykonano podczas sztucznego tarła łososia i troci. Zapłodnienie nastąpiło w wylęgarni PZW w Goleniowie, gdzie też inkubowano ikrę. Wylęg wsiedlono do cieków okolic Szczecina, które kończą swój bieg w kanalizacji miejskiej. Po odłowieniu ryb wypreparowano kości czaszki, które poddano analizie. Pomiary wykonano przy pomocy programu komputerowego do analizy obrazów mikroskopowych Leica Qwin. Kości mierzono z dokładnością 0,1 mm. Wyniki wykazały, że u większości badanych hybrydów kość sitowa zaokrąglonym kształtem i niewielkim bocznym wcięciem była podobna do tej kości u łososia. U niektórych hybrydów w dolnej części kości sitowej był obecny nietypowy, dodatkowy wyrostek. Kilka hybrydów troć × łosoś na kości przedszczękowej miało niewielki wyrostek, który jest charakterystyczny dla kości przedszczękowej troci. Większość hybrydów łosoś × troć i prawie połowa troć × łosoś miała blaszkę lemiesza kształtu pośredniego pomiędzy trójkątnym a pięciokątnym. Pozostałe osobniki miały kształt blaszki lemiesza trójkątny jak u troci lub pięciokątny jak u łososia. Kość językowa w obu grupach hybrydów była podobna do tej kości u gatunków rodzicielskich. U niektórych mieszańców nierówno kończyły się dwa rzędy zębów na kości językowej, co wynikało z różnej liczby zębów w każdym szeregu.