Deformations in reciprocal hybrids of salmon (Salmo salar L., 1758) and trout (Salmo trutta m. trutta L., 1758) aged 0+ and 1+

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Abstract
The study was performed on 416 hybrids ♀ trout x ♂ salmon and 158 hybrids ♀ salmon x ♂ trout aged from 4 to 24 months. The fish was obtained in a series of 8 experiments in which reciprocal hybrids were grown of salmon and trout caught from the natural conditions. The hatch was introduced to the watercourses that had no outlet to open water. After catching the hybrids were weighed, measured, their appearance was described and they were fixed. In the fixed material the first arch branch and pyloric caeca were analysed. The analysis revealed morphological changes in the shorter arm of the gill arch that was narrower from the remaining part of the arch and some gill rakers were missing. The changes were observed in 52% hybrids of trout x salmon and 12% hybrids of salmon x trout. Changes were also noted in the pyloric caeca, which were untypical, tumorous and unevenly distributed. The deformations were identified in 94% of trout x salmon and 58% salmon x trout hybrids. The changes in the branchiostegal membrane and losses in the bones of the gills cover were observed in 27% trout x salmon and 22% salmon x trout hybrids. At least one type of deformation was noted in 95.3% of trout x salmon and 70% of salmon x trout hybrids.

Introduction
Hybridisation between salmon and trout in natural conditions at the sites of their common occurrence is rather frequent. It varies from 0.15% in Finland and Norway (Elo et al., 1995) to 18.8-31.4% in the Baltic Sea basin (Semenova & Slyn’ko, 1988). The reasons stimulating hybridisation between these species include a reduction of the spawning areas in the regions of common occurrence of salmon and trout caused by growing anthropopressure, (Hammar et al., 1991; Elo et al., 1995; Delling et al., 2000), excessive catch of fish (Makhrov et al., 1998) and restitution of salmon over a limited area (Jansson & Öst, 1997). Hybrids of salmon and trout are also increasingly often met in rivers where in the population of salmons a growing contribution of dwarf males appears. The number of dwarf males increases with decreasing abundance of the salmon population (Jansson et al., 1991; Elo et al., 1995) and they show aggressive reproduction behaviour (Beall et al., 1997; Garcia-Vazquez, et al., 2002). Hybridisation between these species is undesirable as it leads to the loss of spawning sites of pure

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species (Garcia-Vazquez et al., 2003) and can be responsible for considerable introgression (Verspoor, 1988; Garcia de Léaniz & Verspoor, 1989). This aspect has been previously studied in reciprocal hybrids between salmon and trout and in other species hybrids (Iuchi et al. 1975; Bakos et al. 1979). Such distortions can have a large influence on growth and survival of the hybrids (Bakos et al. 1978). Analysis in the presented study showed, that salmon and trout hybrids have a surprisingly high level of atypical features in external and internal morphology.

Material and methods
In the years 1994-2003 eight experiments were performed in which reciprocal crossing of salmon and trout was made during artificial spawning. The salmon spawn and milt were obtained from individuals grown in the Fish Farm in Miastko and in the River Wieprza, originating from the school imported from the River Dougava, while the trout spawn and milt were taken from the school brought from the River Rega. Fertilisation was performed at the PZW Hatchery in Goleniow, where the spawn was also incubated. The hatch was introduced into the watercourses near Szczecin, ending in the municipal sewage system, which ensures that the hybrids would not get into the natural environment to have contact with pure species. The growing fish were regularly caught with the help of electric current producing aggregate JUP-23 (Approved by the Local Commission for Ethical Research no. 24/02 of 3.06.2002). The study was made on 416 hybrids of ♀ trout x ♂ salmon and 158 hybrids of ♀ salmon x ♂ trout (Table 1) aged from 4 to 24 months. The hybrids grew up separately in neighbouring water–courses. Henceforth, as it is generally accepted, in the names of hybrids the maternal species is given first and paternal second (Chevassus 1979; Goudie et al., 1993; Galbreath & Thorgaard, 1994; Blanc, 2003).

All the hybrids caught were subjected to analysis of deformations that often appear in fish hybrids (Bakos et al. 1979; Beck et al. 1984; Kazakov et al. 1984; McGowan & Davidson 1992; Gray et al. 1993) and influence the number of rakers on the first gill arch and the number of pyloric caeca. The deformations were divided into the anomalies of the first gill arch, pyloric caeca and the external anomalies including deformations of the operculum covering the gill slits, branchiostegal membrane and the partition separating two branchiostegal membranes.

Results
The first arch of the gills
Some of the trout x salmon hybrids were found to have untypical first gill arch. Morphological analysis revealed a shorter arm of the first gill arch, narrower than the remaining part of the gill arch and missing some gill rakers (Figure 1). Along the remaining section of the gill arch the gill rakers grew off the sides of the arch, were accumulated in the arch curvature and irregularly distributed (Figure 2). The changes led to a decreased number of the gill rakers on the first gill arch; in the trout x salmon hybrids aged 0+ this number was 17.15 (7-22), while in the hybrids aged 1+ it was 14.82 (9-23). Anomalies of the first gill arch were noted in 44% of individuals aged 0+ and 75.3% of individuals aged 1+, so in total 52% of all trout x salmon hybrids. In the reciprocal hybrid, salmon x trout, similar deformations
Figure 1. The arch of the gills from ♀ trout x ♂ salmon hybrid aged 15 months, the missing gill rakers over the section a (a), scale of 1 mm.

Figure 2. The arch of the gills from ♀ trout x ♂ salmon hybrid aged 10 months, with gill rakers missing over the section a (a) and of different lengths (w), scale of 1 mm.

Figure 3. A section from the alimentary track of a 7-month old trout x salmon hybrid with pyloric caeca (pc) of different lengths, scale of 1mm.

Figure 4. A section of the alimentary track of a 7-month old trout x salmon hybrid with irregularly distributed pyloric caeca of different lengths, scale of 1mm.
**Figure 5.** ♀ Trout x ♂ salmon hybrid aged 21 months, the losses in the opercular and subopercular bones, scale of 1.5 cm.

**Figure 6.** ♀ Trout x ♂ salmon hybrid aged 22 months, the losses in the opercular, subopercular and interopercular bones, scale of 1.5 cm.

**Figure 7.** ♀ Trout x ♂ salmon hybrid aged 19 months, the losses in all bones of the opercular bones deshielding the gill arches, scale of 1.5 cm.

**Figure 8.** ♀ Trout x ♂ salmon hybrid aged 21 months, the deformations in the gill cover and extended partition, scale of 1 cm.
of the first gill arch were observed in 12% of all salmon x trout hybrids (10 and 16% of the individuals aged 0+ and 1+). The mean number of gill rakers on the first gill arch in this group of hybrids aged 0+ was 18.40 (13-23) and in those aged 1+ it was 18.82 (11-23).

**Pyloric caeca**
Analysis of the pyloric caeca has revealed deformations in their structure in the majority of individuals. The deformed pyloric caeca were of different length, from very short and tumorous (slightly bulging the wall of the alimentary track) (Figure 3) to long thread-like and were unevenly distributed (Figure 4). The deformations were observed in 92.5% of trout x salmon hybrids aged 0+ and 99% of those aged 1+ (94% of all trout x salmon hybrids). The mean number of pyloric caeca in trout x salmon hybrids aged 0+ was 24.97 (5-55), while in those aged 1+ it was 21.02 (9-54). Similar anomalies in pyloric caeca were observed in salmon x trout hybrids; in 57% of those aged 0+ and 60% of those aged 1+ (in total 58% of all hybrids of this type). In the hybrids aged 0+ the average number of pyloric caeca was 33.66 (14-45). Similarly as in the trout x salmon hybrids, in individuals aged 1+ this number was 29.03 (11-41) and lower than for those aged 0+.

**Internal deformations**
In the hybrids of both types also internal deformations in the branchiostegal membrane and the opercular bones were also observed. The membrane suffered some shortening and in some individuals it was folded up or down. In the operculum there was loss in individual bones: opercular, interopercular or subopercular (Figure 5), or in all opercular bones (Figure 6). The deformed bones exposed the margins of one or a few gills arches (Figure 7). These deformations were accompanied by the presence of thin and plicate margin of the branchiostegal membrane. The deformations and losses were most often seen in one and rarer in two opercular bones. Distinct deformations were also identified in the partition of the branchiostegal membrane which was much overgrown and swollen downwards causing distortions to the oral cavity and the profile of the fish (Figure 8). In many hybrids these changes were accompanied with the loss in the lamellae arch branch or their underdevelopment. Often, the deformations in the gill sac occurred together with those in the branchiostegal membrane leading to a shortening of the interopercular bone.

Among the trout x salmon hybrids the internal deformations were noted in 23% of individuals aged 0+ and 36.6% of those aged 1+, whereas among the salmon x trout ones the internal deformations were detected in 26% of those aged 0+ and 16% of those aged 1+. Statistical analysis of the Pearson linear correlations STATISTICA (data analysis software system), version 8.0. www.statsoft.com., StatSoft, Inc. (2007) between the body length and the number of gill rakers, mass of the fish and the number of gill rakers, the body length and the number of pyloric caeca and the body mass and the number of pyloric caeca in particular hybrids aged 0+ and 1+ proved no correlations, the correlation coefficient > 0.2). The exception is a correlation between the mass of salmon x trout hybrids aged 1+ and the number of pyloric caeca, characterised by the correlation coefficient $r=0.6$. 
Fig. 9. Deformations in the ♀ Salmo trutta m. trutta x ♂ Salmo salar hybrids (a) and ♀ Salmo salar x ♂ Salmo trutta m. trutta hybrids (b) in the first and second year of life.
To sum up, the deformations observed in reciprocal hybrids of salmon and trout concerned most often the pyloric caeca (94% of trout x salmon hybrids and 58% of salmon x trout hybrids). The anomalies in the first arch branch were noted in 52% of trout x salmon hybrids and 12% of salmon x trout ones, whereas the internal deformations in 27% and 22%, respectively. The percent of trout x salmon hybrids with at least one type deformation increased with age and reached 94% of individuals aged 0+ and 99% individuals aged 1+ (95.3% of all trout x salmon hybrids). Among the salmon x trout hybrids the deformations were observed in 66% of individuals aged 0+ and 77% of individuals aged 1+ (altogether in 70% of salmon x trout hybrids), Tab. 2.

Discussion

Characteristic features of many fish hybrids are the anomalies appearing at different stages of development. The disturbances leading to total mortality prior to the stage of hatching have been reported to occur, e.g. in the hybrids of *Oncorhynchus kisutch* x *Salmo gairdneri*, *Oncorhynchus kisutch* x *Salmo trutta*, *Salmo trutta* x *Salmo gairdneri* (Blanc, Chevassus 1979; Chevassus 1979). Also Gray et al. (1993) on the basis of analysis of a few dozens hybrids of the salmonids have reported high proportions of hybrids with deformations, in particular in the groups of a low percent of survivability. Our analysis of the salmon and trout hybrids has shown that nearly 100% of trout x salmon and 70% of salmon x trout hybrids revealed deformation of at least one type: pyloric caeca, first gill arch or external head deformations. As follows from the study by McGowan & Davidson (1992) and Gray et al. (1993) more deformations including those in the head and consequently higher mortality were found in the trout x salmon hybrid than in the reciprocal one. The anomalies of the first arch branch in the form of the lack of gill rakers and their irregular distribution were reported by Kazakov et al. (1984) in the reciprocal salmon x trout hybrids but of unknown direction of hybridisation. Changes in the first gill arch are related to a lower number of the gill rakers on the first arch. The hybrids we studied had the number of gill rakers lower than trout aged 0+ and 1+ having 15-20 ones (Kirczuk & Domagała 2003) and than salmon having 16-22 ones (Domagała & Kirczuk 2004). The deformations of the oral cavity observed in the reciprocal hybrids of salmon and trout were observed in 17% of the hybrids of *Hypophthalmichthys nobilis* x *Ctenopharyngodon idella*, which also had deformed fins, twisted head and bent body preventing further development (Bakos et al. 1978). Numerous hybrids of *Oncorhynchus rhodurus* x *Salvelinus fontinalis* (Iuchi et al. 1975) were found to have deformations in the head and spine, while the hybrids of *Ctenopharyngodonidella* x *Hypophthalmichthys nobilis* had mainly deformations of the spine and jaw, rarely of the opercular bones and the gills (Beck et al. 1984). According to Bakos et al. (1979) and Hardy (1999), the shortening of the gill cover and deformations of the jaw joints in the salmon causing impairment in the function of oral cavity, which implies problems with food intake and increased mortality. The hybrids of *Ictalurus punctatus* x *I. furcatus* revealed deformations in the caudal fin, but they were considered to be related to the less than optimal conditions in the fish farming as the same anomalies were noted also in the parent
species of *I. punctatus* (Goudie et al. 1993). Also Sutterlin et al. (1987) related the deformations in the opercular bones and jaw of the hybrids of not migrating to the sea and anadromic salmon with the conditions of growth (poorer condition, stress, reduced content of oxygen and limited motion) and to some degree with the triploidal character of the hybrids. This interpretation is supported by the results obtained for salmon cultured in the farms revealing deformations of the opercular bones and jaw being a consequence of improper diet (Hardy 1999). The reciprocal hybrids of salmon and trout studied were found to have deformed pyloric caeca occurring in a lower number than trout (29-69 pyloric caeca) (Kirczuk & Domagała 2003) and salmon (51-77) (Domagała & Kirczuk 2004). None of the deformations observed in these hybrids had been reported earlier in any of the pure species (Kirczuk & Domagała 2003), (Domagała & Kirczuk 2004) incubated and growing in the same conditions, in watercourses in the Pomerania district. Results of the studies performed on so numerous group of hybrids collected from many experiments have shown that the deformations observed are the consequence of crossing, which confirms that this process is undesirable and should be prevented. The analysis indicates that hybrids should be treated as a threat to pure species and points to the necessity of developing and applying measures to prevent this undesirable phenomenon.

**References**


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