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RESEARCH ARTICLE

Characteristics of sea trout spawners (*Salmo trutta*) in the Vistula River mouth in reference to the previous Vistula River stocks

Paweł Buras

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Abstract. The age structure and length distribution of sea trout spawners caught in the Vistula River mouth in the 1984-1986 period were analyzed in reference to previous Vistula stocks of summer spawning and winter spawning runs, and also to silvering sea trout. The comparison took into consideration two variants: the period when the sea trout summer spawning and winter spawning runs ascended the Vistula and when they gathered at spawning grounds. Statistically significant differences were confirmed in the age structure and length distribution of sea tout spawners caught in the Vistula River mouth in the 1980s and the previous Vistula stocks. The reason for these difference must be sought in management interventions and especially in the permanent cycle of smolt production, sea trout spawner selection when they ascended the Vistula, catches made for artificial spawning, and the periodic stocking of sea trout with material originating from Pomeranian rivers.

Keywords: sea trout, summer and winter spawning runs, scales, river age, sea age, body length

P. Buras [✉]
Department of River Fisheries, Inland Fisheries Institute
ul. Główna 48, Żabieniec, 05-500 Piaseczno, Poland
e-mail: p.buras@infish.com.pl

Introduction

The Vistula River was the main spawning migration route and fishing grounds for sea trout, *Salmo trutta* L. in Poland (Jokiel and Backiel 1960, Żarnecki 1963, 1964, Borzęcka 1998, Sych 1998). Among the sea trout populations of the Baltic Sea catchment basin, the Vistula sea trout were the largest with lengths exceeding 100 cm and body weights of up to 18 kg. They were also in excellent condition when ascending the river to spawn (Dixon 1931, Chrzan 1947). Vistula populations were divided into two seasonal groups in the Vistula River – the summer and winter spawning runs (Dixon 1931, Chrzan 1947, Żarnecki 1963, Borzęcka 1998). Differences in the occurrence cycle of these two seasonal groups of Vistula sea trout was linked with the timing of gonad maturation and the length of residence in the Vistula River (Żarnecki 1963, 1964). Summer sea trout ascended the Vistula in the July to September period with fully developed gonads and were ready to spawn that same winter. Whereas, well-fed winter sea trout ascended the Vistula in from November to January with immature gonads and were not ready to spawn until the following winter (Żarnecki 1963, 1964, Borzęcka 1998, 1999)

The construction of the Włocławek Barrage on the Vistula River in its middle segment curtailed access to the main spawning grounds of Vistula sea trout populations in Carpathian tributaries; this resulted in decreased fisheries catches of this species (Wiśniewolski 1987, Bartel 1993, Sych 1998, Dębowski 2018). Conducting regular stocking was the only way to maintain these populations (Bartel 1993). With this aim in 1968, the Spawner Base was put into operation in the Vistula River mouth at the Gulf of Gdańsk in Świbno, which operated until 2004, when it was closed (Kossakowski 1969, Bartel 2009, Bartel et al. 2019).

It is estimated that, initially, the natural escapement to the Baltic Sea from Polish areas was approximately 1–1.5 million sea trout smolts, while later this figure fell to about 80,000–100,000 (Bartel 1992, 1993). However, decreases in the numbers Vistula sea trout were evident even earlier. Stocking the upper Vistula River system with sea trout and salmon hatchlings and fry was conducted in the inter-war period from 1923 to 1941 and also later from 1942 to 1954 to compensate for the dam constructed on the Dunajec River in Rożnów (Kołder 1958).

In the 2007–2018 period, the quantities of sea trout released into the Vistula and its tributaries ranged from 540,000 to 730,000 smolts. Most of these fish (from 74 to 100%) were of a river age of 2+, while the share of smolts aged 1+ was from 0 to 18.5% (Bartel and Kardela 2009a, 2009b, 2010, 2011, 2012, 2014, Bartel et al. 2018a, 2018b, 2020). Moreover, sea trout fry were released into lower and upper Vistula tributaries including the Drwęca, Brda, and Wierzyca rivers as well as the San, Tanew, Dunajec, Wisłoka, and Łososina rivers in quantities from 577,000 in 2008 to about 2 million in 2017, and 1.5 million in 2018. Stocking sea trout hatchlings in the 2007-2018 period ranged from 150,000 to approximately 1.3 million individuals (Bartel and Kardela 2009a, 2009b, 2010, 2011, 2012, 2014, Bartel et al. 2018a, 2018b, 2020). The declining Vistula sea trout population was periodically supplemented with sea trout from Pomeranian rivers at as much as 30% of the material released into the Vistula (Borzęcka 1991, Dębowski 2018).

Vistula sea trout has been the subject of extensive research on topics including scale reading, age, growth rate, and other life history information (Dixon 1931, Żarnecki 1963, Sych 1967, Borzęcka et al. 1990, Borzęcka 1999, 2001, 2010). These included not only studies on age and growth characteristics, but also investigations that focused on modeling Vistula sea trout populations that were managed with fisheries science strategies and studies that attempted to differentiate the Vistula sea trout stocks from others that occur in the Baltic Sea catchment basin (Sych 1967, Sych 1972, 1976, Borzęcka 2010). The latter studies were especially important when the original Vistula stock was supplemented with sea trout originating from Pomeranian rivers (Borzęcka 1991, Bartel 1993) and the two stocks became mixed.

The aim of this study was to track differences in the age and size structures of sea trout spawners caught in the Vistula River mouth following the damming of the river in reference to the stock of summer and winter spawning Vistula sea trout using material dating to before the damming of the Vistula in Włocławek (Borzęcka 1997, 1998, 1999). It was anticipated that these differences could have occurred as a result of the selection of caught sea trout spawners, the stocking material (smolts) production cycle, and also periodically stocking the Vistula with sea trout from coastal rivers.

Materials and methods

The material came from sea trout spawners caught in the Vistula River mouth in Świbno from July to September from 1984 to 1986, and comprised 47, 193, and 60 individuals, respectively. After being caught, the fish were held in tanks until spawning in November and December. Scales were collected from the fish from between the dorsal and adipose fins above the lateral line. Information about the individuals was also collected, namely: the length from the end of the snout to the end of the middle caudal fin ray and the date the samples were collected. Age readings were performed using from 3 to 5 non-regenerated scales that were attached to adhesive paper and impressed into cellulose acetate plates at a temperature of 100°C under 3 tons of pressure (Sych 1964). Fish age was determined by reading the scale impressions.

Four groups of information were used in the analyses: 1) age structure of the stocks during the river residence period; 2) age structure of the stocks during the sea residence period; 3) size structure; 4) sea trout fishing period in the Vistula River mouth in relation to periods in which the previous stocks ascended the river. The age structure of the sea trout spawners was divided into fish river age (A) and fish sea age (B) according to the notation A.B+. Fish sea age was read taking into account both the number of annual rings and the size of the marginal increments on the scale expressed by the distribution of the number of sclerites (Buras 1999).

Descriptions from the works of Borzęcka (1997, 1998, 1999) were used to compare the age structures of the river and sea periods and the size distribution of sea trout from Świbno and the previous summer and winter stocks in the Vistula. For this purpose, the summer and winter stocks were included in the age and size structure of the entire Vistula stock using the to the following formula:

$$U_{xi,l} \cdot U_l + U_{xi,z} \cdot U_z = U_{xi(l,z)} \qquad (1)$$

where:

U_l and U_z is the 1953–1968 shares (from Borzęcka 1998) of summer stocks *l* at 0.3 and winter stocks z at 0.7; U_{xi} is the share, *xi* – this age group, river age *1.B+…n* and sea age *A.1+…n* and size (shares of age groups and size frequency distribution according to Borzęcka 1997 and 1999). Shares were converted to percentages to illustrate the age and size distributions of the combined summer and winter stocks as follows: $U_{xi(l,z)} \times 100 = P_{xi(l,z)}$.

Combining the two stocks also took into consideration the period in which they ascended the river and the lengths of time winter sea trout were resident in the river and in spawning grounds, as follows:

$$U_{xi,l} \cdot U_l + U_{xi-1,z} \cdot U_z = U_{xi(l,z)} \qquad (2)$$

where: *xi* – 1 is the age group of winter stock fish ascending the river in the year preceding spawning. Shares were converted to percentages as described above.

The two-sample Kolmogorov–Smirnov test was applied to test differences in age and length distribution among samples of sea trout spawners caught in Świbno and samples of the previous sea trout winter and summer stocks; the results were considered significant at 0.05 (Łomnicki 1995).

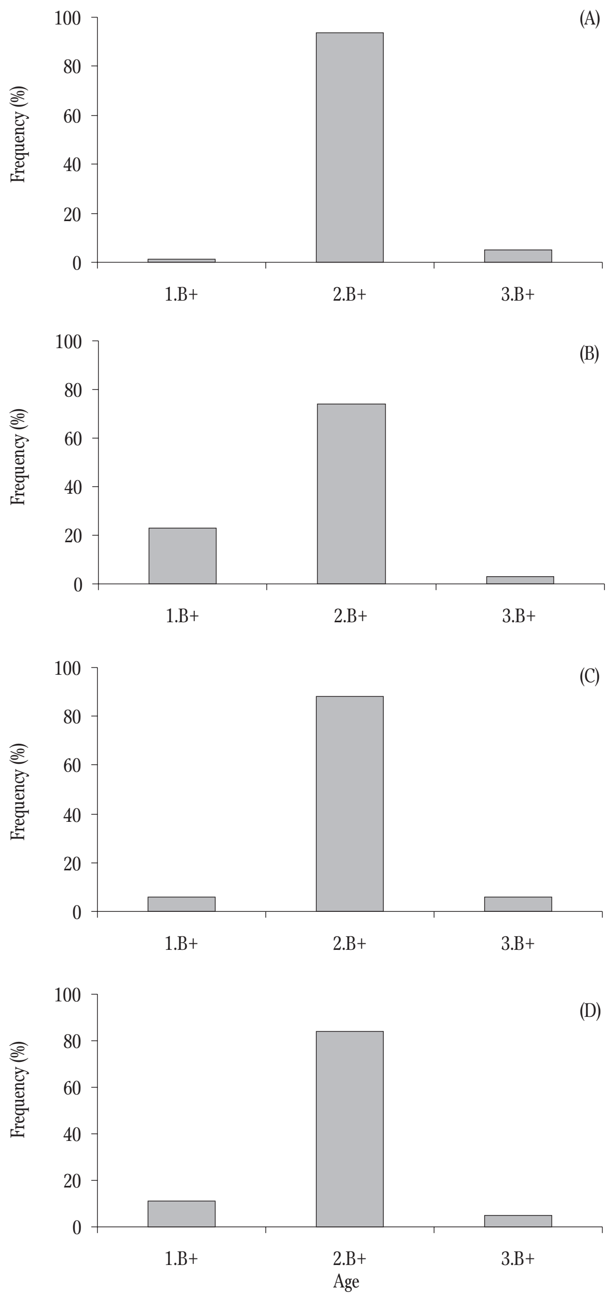

Figure 1. Age structure during the river period of life of sea trout (*S. trutta*) spawners at Świbno and in the previous summer and winter stocks of Vistula sea trout. A – sea trout spawners caught in the Vistula River mouth at Świbno (P_s), B – summer sea trout runs (P_l), C – winter sea trout runs (P_z), and D – summer and winter stock structures combined (P_{lz}).

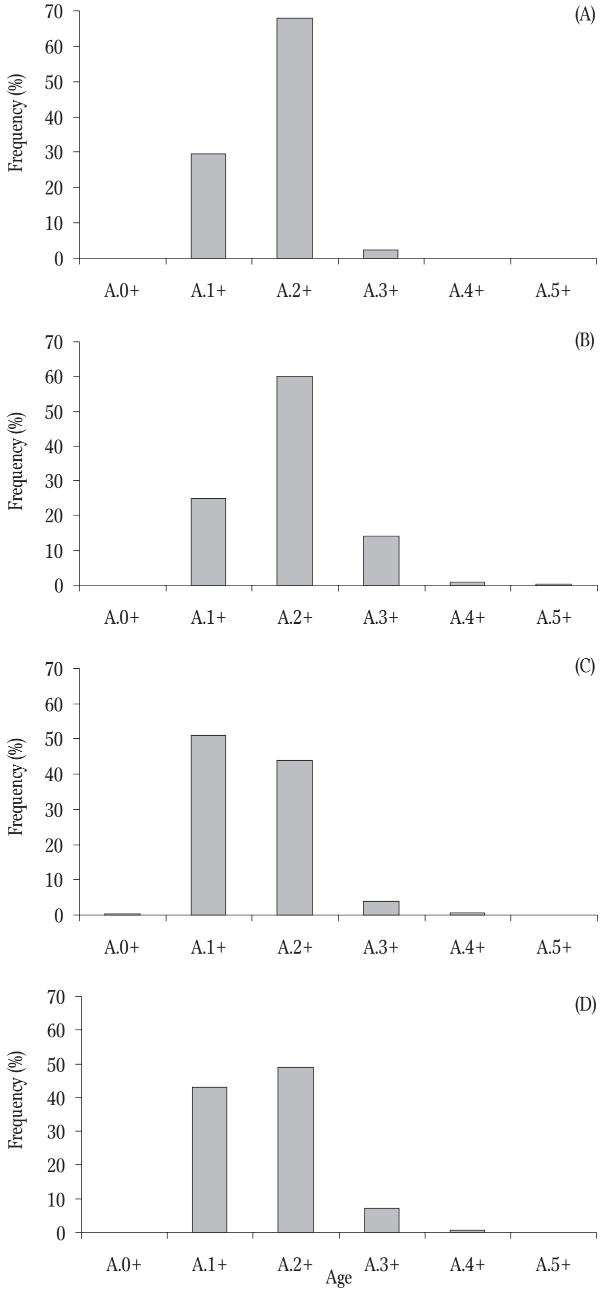

Figure 2. Age structure in the sea period of life of sea trout (*S. trutta*) spawners at Świbno and in previous summer and winter stocks of Vistula sea trout. A – sea trout spawners caught in the Vistula River mouth at Świbno (P_s), B – summer sea trout runs (P_l), C – winter sea trout runs (P_z), and D – summer and winter stock structures combined (P_{lz}).

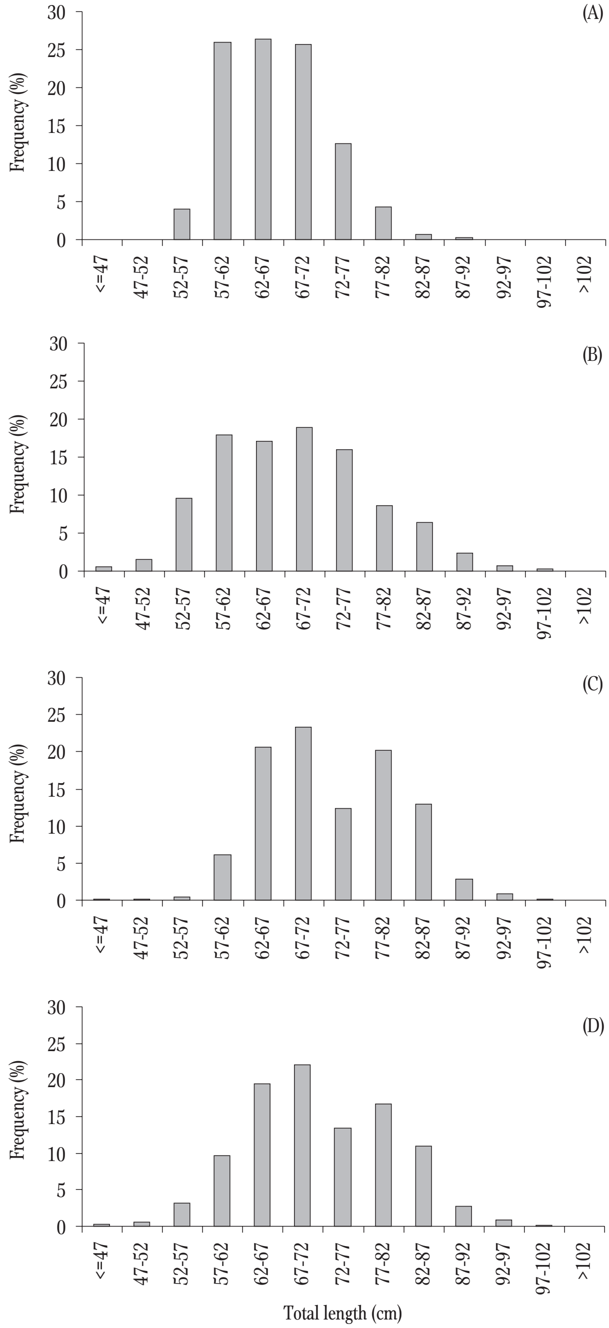

Figure 3. Total length structure of spawners at Świbno and previous summer and winter stocks of Vistula sea trout (*S. trutta*). A – sea trout spawners caught in the Vistula River mouth at Świbno (P_s), B – summer sea trout runs (P_l), C – winter sea trout runs (P_z), and D – summer and winter stock structures combined (P_{lz}).

Results

Figures 1, 2, and 3 present the age structure for the river and sea periods of life and the length structure for samples of sea trout spawners caught in the Vistula River mouth at Świbno (P_s) and for the sets of summer (P_l) and winter (P_z) sea trout runs. The lower sections of the figures illustrate the summer and winter stock structures combined ($P_{l,z}$).

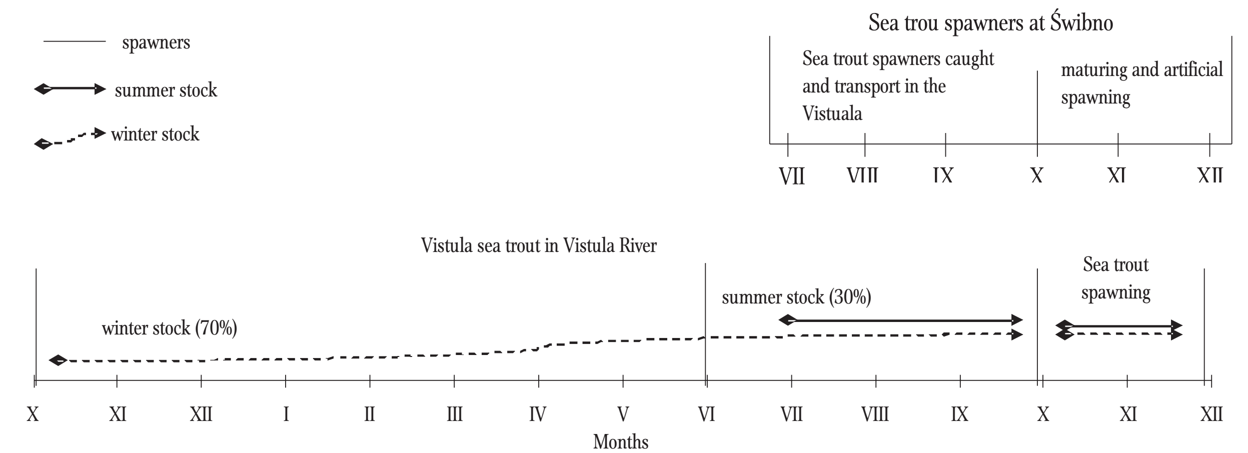

Figure 4. Diagram of ascending sea trout (*S. trutta*) spawners and summer and winter stocks ascending the Vistula River mouth.

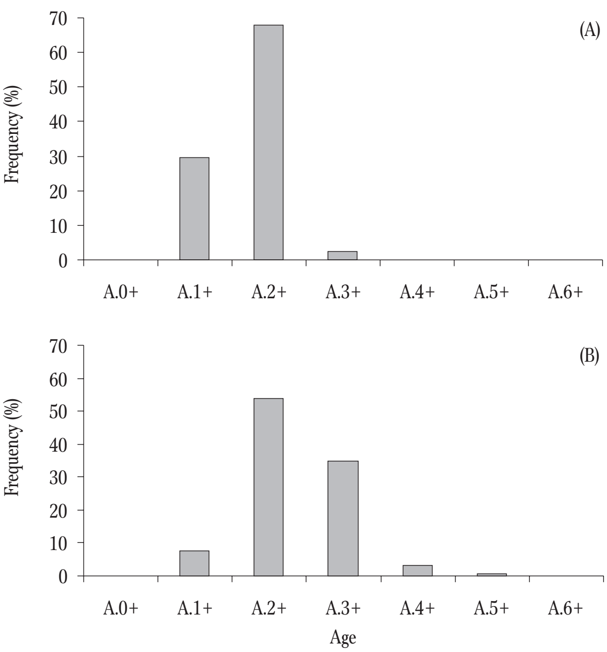

Figure 5. Comparison of age structure in the sea period of life of sea trout (*S. trutta*) spawners and the two stocks combined with reference to the timing of spawning. A – sea trout spawners caught in the Vistula River mouth at Świbno (P_s), B – summer and winter stocks ($P_{l,z\text{-}1}$)

Table 1
Values calculated with the Kolmogorov–Smirnov test, critical values $D_{0.05}$ = 0.111. P_s – sea trout (*S. trutta*) spawners caught in the Vistula River mouth at Świbno, P_l – summer sea trout runs, P_z – winter sea trout runs, and P_{lz} – summer and winter stock structures combined.

Sample		P_s river	P_s sea	P_s length
P_l	river	D_{emp} = 0.2167		
	sea		D_{emp} = 0.2166	
	length			D_{emp} = 0.1640
P_z	river	D_{emp} = 0.0467		
	sea		D_{emp} = 0.2167	
	length			D_{emp} = 0.3200
$P_{l,z}$	river	D_{emp} = 0.0967		
	sea		D_{emp} = 0.1367	
	length			D_{emp} = 0.2667
$P_{l,z\text{-}1}$	sea		D_{emp} = 0.3610	

In each group examined, fish dominated that had spent two years in the river (Fig. 1). The share of these fish in the spawner sample exceeded 93%, while in the summer and winter sea trout they were 74% and 88%, respectively, for a combined share of 83.8%. The share of smolts aged 1+ in the sea trout spawner sample from Świbno was the lowest. The shares of summer and winter sea trout were 23% and 6%, respectively. When the two stocks $P_{l,z}$ were combined, the share of fish that had been resident in the river for one year was 11%. The share of smolts that was resident in the river for three years was similar in all sample groups examined — for spawners 5%, for summer and winter sea trout 3% and 6%, respectively, and for the combined stocks 5.1%. Significant differences in age structure in the river were only noted between P_s and P_l (Kolmogorov–Smirnov test , statistics D_{emp} against the critical value of $D_{0.05}$, Table 1).

During the sea period of life, the greatest share of fish was those aged A.1+ and A.2+ (Fig. 2). In the spawner sample P_s, the share of fish aged A.1+ was

29.66% and that of fish aged A2+ was twice as high. The shares of sea trout summer and winter stocks were as follows: fish aged A.1+ 25% and 51% and fish aged A.2+ 60% and 44%. After combining the summer and winter stocks, these share were 43.2% and 48.8%, respectively. The share of fish aged A3+ in the sea trout summer stock was 14%, while that of the remaining groups was less than 10%. The share of fish aged A.4+ in P_l and P_z was very low, and the share of fish aged A.0+ and A.5+ was negligible. No fish were noted in the sea trout sample from Świbno from sea age groups A.0+, A.4+ or A.5+. Differences in sea age distribution between sea trout spawners P_s and sea trout stocks P_l, P_z, and $P_{l,z}$ were statistically significant (Table 1).

Three size groups (57–62, 62–67, and 67–72 cm) dominated the sea trout spawners P_s (Fig. 3). The body size distribution ranges for the summer sea trout P_l, winter sea trout P_z , and the two stocks combined $P_{l,z}$ were quite wide from 57–62 to 82–87 cm. The length distribution range of the sea trout summer and winter stocks was bimodal, which can be explained by summation of the age groups in these sets of fish (Fig. 3). Differences in length distribution between P_s, P_l, and P_z and the two combined $P_{l,z}$ were statistically significant (Table 1).

Figure 4 is a diagram of current sea trout ascending the Vistula River and spawning under controlled conditions, sea trout spawners, and the periods of the previous summer and winter stocks ascending and spawning in the Vistula. Winter sea trout that were resident in the river for one year gathered at spawning grounds in Carpathian tributaries with summer sea trout that spawned in the same year that they ascended the river. The sea age structure diverged clearly among the sample of spawners from Świbno and the summer and winter stocks with regard to the timing of spawning (Fig. 5). Combining the summer and winter stocks taking into consideration the timing of the fish gathering at spawning grounds and spawning produced a high share of fish aged A.2+ and A.3+. Differences in the distribution of sea age among the spawners in sample P_s, which were combined with procedure 2 with the summer and winter stocks $P_{l,z-1}$ were statistically significant.

Discussion

The sample collections of many years of sea trout from the summer and winter spawning runs represented well the Vistula population Borzęcka (1997, 1999) described. In her analysis of both the summer and winter stocks, Borzęcka (1998) determined that, in the previous period, winter sea trout dominated catches in the lower Vistula (54%) and that summer trout was 30%. In the winter sea trout spawning run, a certain part of the fish occurred in the spring catches, and these were identified as the silver winter spawning run, which was 16%. Differences were noted between the summer and winter stocks in the shares of river age groups and sea age groups and also in body size. Fish of river age 2.B+ dominated the populations, while more than 20% of the sea trout individuals in the summer spawning run were aged 1.B+ (Borzęcka 1999). With regard to the sea period of life, the share of fish that had spent two (age A.1+) and three (age A.2+) years in the sea dominated the summer and winter stocks. Fish aged A.1+ dominated those aged A.2+ in the winter stock, but in the summer stock this proportion was the opposite (Borzęcka 1999). The share of younger and older individuals in the summer and winter stocks described by Borzęcka (1999) were also lower, but the range of this age structure was wider than that in the sea trout samples from Świbno. The length distribution in the stocks described by Borzęcka (1997, 1999) was substantially wider (and included at least six size classes) than that of the sea trout spawners caught at Świbno. When the summer and winter stocks were ascending the Vistula, Borzęcka (1999) took into consideration the number of years the fish had spent in the sea. Referencing the spawning period shifted the age of the sea trout from the winter spawning run by one year, when these fish gathered with the sea trout from the summer spawning run at the spawning grounds because the sea trout from the winter spawning run had ascended the river one year earlier in November and December and had spent the entire year in the river maturing to spawn. Thus, the sea trout from the winter spawning run at the spawning grounds were one year older than the number of years spent in the sea visible on the scales.

The differences in age and size distribution noted between the sea trout samples caught at Świbno and the Vistula sea trout stocks could have been a result of sea trout management in Świbno, including spawner selection, the two-year smolt rearing cycle, and the periodic mixing in of sea trout from Pomeranian rivers. As described by Żarnecki (1963) and later Borzęcka (1998, 1999), this contributed somewhat to the loss of population biological diversity and a narrowing of the age and length distributions to those of fish that most frequently occurred in the populations at Świbno. The offspring of parents kept in controlled conditions can grow to significantly larger sizes than that of parents living in the wild (Kallio-Nyberg and Koljonen 1997, Skrupskelis et al. 2012). Faster growth could also be the result of higher survival in hatcheries and then in the sea. Moreover, the offspring of wild salmon with one sea year that achieved first sexual maturity was 37% and in the second year it was 50%, while in the offspring of cultured parents, this proportion was the opposite (Kallio-Nyberg and Koljonen 1997). Differing sizes and the initial developmental states of sea trout in the first months of life can be used to forecast the number of fish that will smolt in the subsequent year and permits following the behavior in further life history stages when the fish are in the sea, for example, when they return to their native streams (Dębowski et al. 2010, delVillar-Guerra et al. 2019). These facts can be important to current sea trout stocking management practices, for example, to strengthen populations by releasing into rivers sea trout in various developmental stages.

The materials from Świbno described in this article are currently of historical importance, so it is worthwhile to compare the results of the present work to data on the sea trout that are currently being caught in the lower Vistula (Bernaś et al. 2019). The share of fish that spent one year in the sea (1+) exceeded those with two years in the sea (2+) at 53.5 to 59% and 39 to 40%, respectively. Fish with a sea age of 0+ and 3+ comprised from 1 to 1.7% and 1 to 4.7%, respectively. Fish older than 4+ and 5+ were not noted. A considerable share of immature silver individuals was also observed (Bernaś et al. 2019).

The fish passes at the Włocławek Dam were reconstructed and improved to allow sea trout ascending the Vistula to undertake spawning migrations and reach spawning grounds (Wiśniewolski et al. 2014a, 2014b, 2015). After fish pass modernization in 2014, sea trout were once again observed using them and moving upstream in the Vistula (Dębowski 2017, 2019, Bartel et al. 2019). The annual number of sea trout observed migrating through the fish pass ranged from 388 to 850 individuals (Dębowski 2017, 2019). However, maintaining Vistula sea trout populations will always require systematic stocking measures because of changes in river environments, river regulation, the construction of infrastructure projects in rivers, and the degradation of Carpathian spawning grounds. In this regard, the Spawner Base in Świbno (1968–2004) played a very important role in supplying adequate quantities of spawn for rearing sea trout smolts (Bartel 1993, 2009, Bartel et al. 2019). Simultaneously, extensive work was conducted on developing criteria based on studies of sea trout life histories using scales that provided the foundation for attempting to restore the two stocks of Vistula sea trout (Sych 1998, Borzęcka 1991, 1997, 1999, 2010). In reference to other studies on Atlantic salmon stocks (Sych 1976, Reddin 1981, Borzęcka et al. 1990, Hiilivirta et al. 1998, Lacroix and Stokesbury 2004), the methods for distinguishing between sea trout and salmon stocks and also between cultured and wild fish have been tested and should continue to be applied.

ORCID iD
Paweł Buras https://orcid.org/0000-0002-5460-2547

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