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RESEARCH ARTICLE

Possibilities of using the length differentiation of hatchery sea trout, *Salmo trutta* m. *trutta* L., parr to predict numbers of one-year smolts

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Abstract. Growth and smoltification were followed during the first year of life in 14 full sibling families of sea trout, *Salmo trutta* m. *trutta* L., originating from the Vistula stock. Until January, the families were reared separately, and then together after they had been PIT tagged. The degree of smoltification was evaluated in the second spring. Smolts were noted in each family. The percentage of these, which ranged from 14 to 66%, depended on mean fish length in October (r^2 = 0.338) and January (r^2 = 0.346). In either October or January the fish that smolted next spring were, on average, longer than those that did not, but this difference was not manifested by the bimodality of length distribution, and it did not allow predicting the number of smolts based on division of distributions of fish length in autumn or winter into Gaussian components.

Keywords: sea trout, salmonids, smoltification, growth, length bimodality

Introduction

Fish from the family Salmonidae are characterized by phenotypic plasticity. All of the principal genera of this family include both anadromous and potadromous species, as well as those that form either migratory or non-migratory populations (Hoar 1976). The life paths undertaken within each population are varied. In anadromous fish, including sea trout, *Salmo trutta* m. *trutta* L., variety is noted in the age at which individuals migrate to the sea (the age at smoltification) and the age at which they attain sexual maturity (Thorpe 1989, 1994, L'Abee-Lund et al. 1989, L'Abee-Lund and Hindar1990, Dębowski 2002).

The sea trout of the southern Baltic rivers reach the smolt stage between the ages of 1+ and 3+ (Bartel 1988), and so the first split of their life paths begins in the second spring; some of the fish smoltify, and some do not. Actually, this differentiation is apparent as early as the end of the summer of the previous year. Some fish continue to grow despite decreasing temperatures and shortening days, and these are the fish from which future smolts are recruited. The phenomenon was described in Atlantic salmon, *Salmo salar* L. (Thorpe et al. 1980, Kristinsson et al. 1985, Rowe and Thorpe 1990, Skilbrei 1991). This difference in the size of future salmon smolts and non-smolts is so distinct that histograms of fish length in winter have a clear bimodal distribution (Thorpe 1977, Thorpe et al. 1982, Kristinsson et al. 1985, Nicieza et al. 1991, Shrimpton and McCormick 1998). This size differentiation is also noted among sea trout as the fish which

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later smoltify are larger in autumn than are those that do not (Dębowski and Radtke 1994, Tanguy et al. 1994, Dębowski 2002, Glover et al. 2003). Bimodality of the length distribution of juvenile sea trout in this period is, however, confirmed much less frequently. It was noted in sea trout from Norwegian rivers (Glover et al. 2003), and in those from the tributaries of the Słupia (Dębowski 1997), but not in sea trout from pond culture by either Tanguy et al. (1994) or Dębowski (2002).

Length frequency bimodality can be used to estimate the number of smolts, while the share of future smolts can be estimated thanks to the separation of the length distribution into components that reflect both size fractions. This method was used by Bagliniere and Champigneulle (1986) with salmon and by Dębowski (1997) with sea trout. In both studies, the Bhattacharya (1967) method was used to separate the length distribution into components.

The aim of this study was to verify whether or not under hatchery conditions size differences in future smolts and non-smolts occurred in groups of sibling fish, and whether or not the number of smolts can be predicted in these groups based on fish length in autumn and winter several months prior to smoltification.

Materials and Methods

The fish used in this experiment were the progeny of the Vistula River (Poland, Baltic catchment area) sea trout population. Their parents were selected from either the second or third generation reared at the hatchery of the Department of Salmonid Fishes of the Inland Fisheries Institute in Rutki from eggs and milt obtained from spawners caught in the river mouth.

In the autumn of 2001, 14 batches of eggs, each taken from one female and fertilized with the milt of one male, were placed in separate incubators. In May, 200 larvae from each batch (family) were moved to separate tanks with a surface areas of 1 m^2 and volumes of 0.3 m^3 each and supplied with 0.3 dm^3 s^{-1} of river water. On October 6, 2002 the fish were measured (*longitudo caudalis*). They were measured again on January 20, 2003, PIT tagged (Prentice et al. 1990, Dębowski et al. 1998), and moved into two tanks each with areas of 9 m^2, volumes of 3.5 m^3, and flows of 2 dm^3 s^{-1}. Each tank was stocked with half of each family. The fish were fed commercial trout feed automatically in quantities of 50% of the optimal dose for fattening rainbow trout (From and Rasmussen 1984). The fish were investigated on March 28, April 20, and May 13, 2003. They were measured, and their smoltification was evaluated based on the degree of silvering (Dębowski et al. 1999a, 1999c). They were classified as smolts if they demonstrated smolt characteristics during at least one of the inspections.

The length distribution of the individual families from October and January were divided into Gaussian components with two methods: Bhattacharya (Bhattacharya 1967, Gayanilo et al. 2005) and NORMSEP (Pauly and Caddy 1985, Gayanilo et al. 2005), which is based on the maximum likelihood concept. The FiSAT II (FAO, Rome, Italy) package was used for the analysis. When there were two components, that with the longer mean length was identified as future smolts, but if there were many components, those with a mean length longer than the mean length of all the fish in the family were identified as future smolts. Statistical analysis of the results was performed using the Statistica program (StatSoft Inc., Tulsa, OK, USA).

Results

Of the 200 larvae that were stocked into the tanks in May, from 58 to 141 fish per family survived until October, and from 52 to 109 until January (Table 1). Mean length ranged from 74 to 97 mm in October and 95 to 118 mm in January (Table 1). Mean family length was not dependent on the number of fish ($r^2 = 0.045$, $P = 0.467$), and the increase between the two measurements did not depend on the mean length in October ($r^2 = 0.000$, $P = 0.960$).

The following spring some of the fish from each group smolted. The percentage of future smolts

Table 1
Number (n) and mean length (L) of fish in particular families in October and January and the mean length and number of future smolts and non-smolts (P – significance of differences between smolt and non-smolt length: * P < 0.05, ** P < 0.01; test t)

	October		January						
			Total		Smolt		Non-smolt		P
Family	L (mm)	n	L (mm)	n	L (mm)	n	L (mm)	n	
1	74	105	95	77	106	29	88	48	**
2	85	141	104	109	113	18	103	91	**
3	81	99	101	61	116	11	98	50	**
4	84	110	106	89	118	22	101	67	**
5	81	70	102	61	125	13	96	48	**
6	88	69	107	53	115	24	100	29	**
7	82	100	102	71	116	17	98	54	**
8	89	90	109	77	114	51	99	26	**
9	97	82	118	64	120	39	114	25	*
10	80	80	100	69	119	21	92	48	**
11	85	139	104	107	115	22	101	85	**
12	91	58	112	52	124	15	107	37	**
13	79	86	98	59	111	8	96	51	**
14	83	75	103	63	117	16	98	47	**

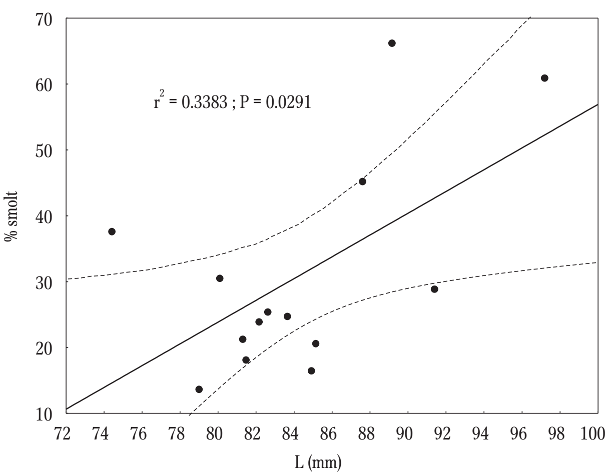

Figure 1. Dependence between the mean length of fish in October and the percentage of smolts in the subsequent spring in particular families.

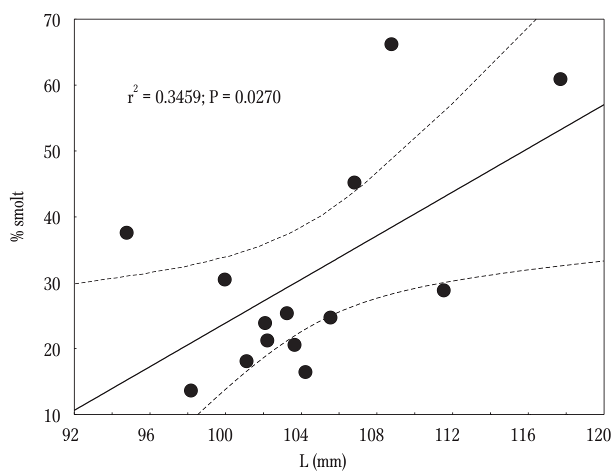

Figure 2. Dependence between the mean length of fish in January and the percentage of smolts in the subsequent spring in particular families.

ranged from 14 to 66% and depended significantly on the mean length of the fish in both October (r^2 = 0.338, P = 0.029) (Fig. 1) and in January (r^2 = 0.346, P = 0.027) (Fig. 2). In January, the future smolts were significantly longer, on average, than were the non-smolts. The differences among all fish was a total of 17 mm (Fig. 3), and in specific groups it ranged from 6 to 29 mm (Table 1), and was not

Table 2
Results of dividing the length distributions into Gaussian components (n – number, L – mean length in mm). Underlining indicates future smolts

	Bhattacharya's method – components								NORMSEP – components							
	1		2		3		4		1		2		3		4	
Family	n	L	n	L	n	L	n	L	n	L	n	L	n	L	n	L
October																
1	94	71	12	85					102	74	3	102				
2	142	84							141	86						
3	96	79	3	100					97	81	2	110				
4	101	83	5	105					105	83	5	111				
5	12	63	46	78	12	97			10	61	35	78	24	97		
6	54	84	11	101					57	85	12	103				
7	94	78	10	110					94	81	5	114				
8	87	87							90	90						
9	83	99							82	98						
10	77	80							80	81						
11	133	86	8	100					117	84	22	97				
12	52	90	4	118					55	91	3	119				
13	77	78	7	95					81	79	5	101				
14	69	80	5	112					71	81	4	115				
January																
1	39	86	29	100	3	125			59	90	15	106	3	129		
2	108	102							104	102						
3	48	99	5	115					56	101	5	107				
4	5	77	77	107					38	94	51	114				
5	11	72	23	98	13	116	8	135	13	81	30	99	11	116	7	134
6	43	105	7	120					52	106	1	120				
7	62	99	11	131					68	100	3	144				
8	31	98	31	116	4	130			15	92	57	110	6	134		
9	56	115	6	130					47	117	17	119				
10	34	87	33	106	11	125	3	146	35	87	22	107	8	120	4	140
11	99	102	6	120					101	102	6	129				
12	12	92	32	115	3	130			8	91	42	113	2	141		
13	24	87	29	104					7	85	52	100				
14	13	102	39	104					12	102	51	104				

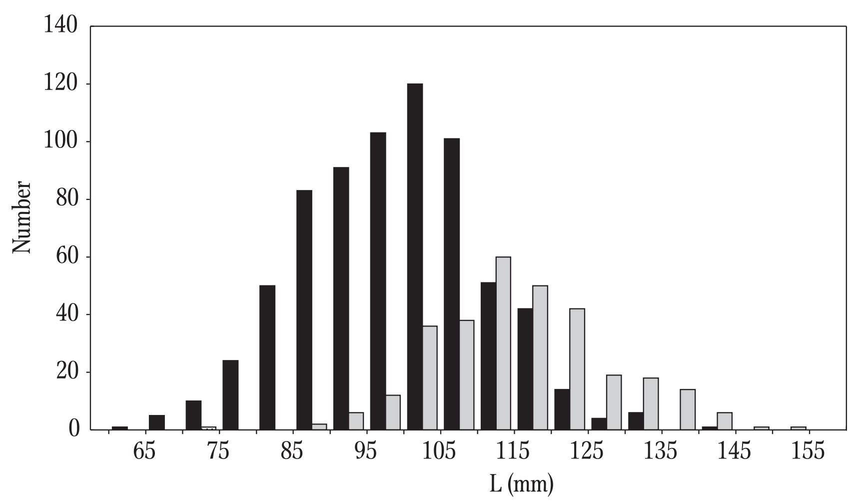

Figure 3. Size-distribution in 10 mm size classes of all fish in January. Black bars – fish that will not smolt in the subsequent spring; gray bars – future smolts.

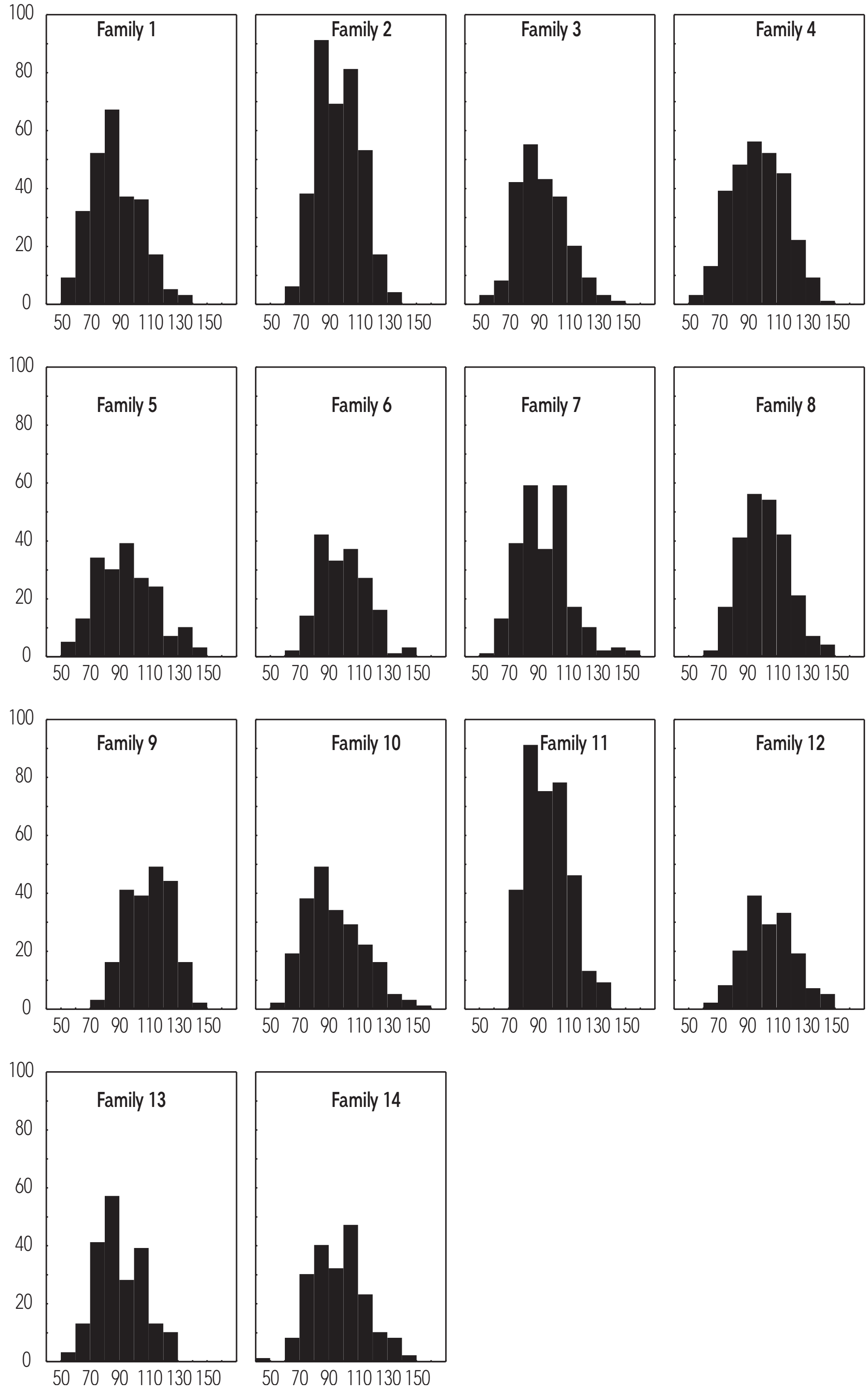

Figure 4. Size-distribution in 10 mm size classes of fish length in particular families in January.

correlated with the percentage of smolts in the family (Spearman correlation, r = -0.332, P = 0.246).

The length distribution in October and January (Fig. 4) did not indicate the occurrence of any discernible bimodality. However, with Bhattacharya's method (the NORMSEP method uses the number of components estimated with this method) it was possible during the two inspections in most groups to divide the distribution into Gaussian components (Table 2): one group was divided into three groups and nine were divided into two components in October, while in January they were divided into four (two groups), three (four groups), and two (eight groups) components.

Based on the criteria established, the anticipated number of smolts in each family was predicted. These estimates were compared to the actual number of fish that smoltified in the subsequent spring (Table 3). Both of the methods produced estimations that differed significantly from the actual number of smolts per family. Nearly all the estimations based on the October inspection were hugely underestimated; this was particularly evident in the families for which the estimated number of smolts was zero and, which, in fact, had the highest number of smolts. The accuracy of the predictions made based on the January inspection were not better, and underestimates were made as frequently as overestimates.

Table 3

Comparison of the actual percentage of smolts compared to the estimated percentages obtained with the two methods (BM – Bhattacharya's method, NO – NORMSEP) based on measurements in October and January

		October		January	
Family	Actual	BM	NO	BM	NO
1	38	11	3	42	23
2	17	0	0	0	0
3	18	3	2	8	8
4	25	5	5	87	57
5	21	17	34	34	30
6	45	16	17	13	2
7	24	10	5	15	4
8	66	0	0	45	82
9	61	0	0	9	27
10	30	0	0	68	49
11	21	6	16	6	6
12	29	7	5	67	85
13	14	8	6	49	88
14	25	7	5	62	81

Discussion

Each group of fish described in the experiment was the progeny of different sets of parents. In each family, some of the fish smoltified in the second spring, but the number varied. The variation is the realization of genetic differences among the fish of different parentage and, to some extent, about 30% in the current experiment, resulted from differences in growth rates. This is confirmed by the results of other studies which indicate that inherited traits influence smoltification (Jonsson 1982, Bailey and Friars 1990, Herbinger and Newkirk 1990, Tanguy et al. 1994, Glover et al. 2003). The dependence of smoltification on fish size, that was apparent and anticipated, was not, in fact, distinct enough to manifest itself in the clear bimodality of growth. Conversely from the studies by Glover et al. (2003), but concurrent with prevailing opinion, the current study indicated that during smoltification sea trout exhibit less distinct changes in comparison to those occurring in salmon (Soivio et al. 1989, Okland et al. 1993, Tanguy et al. 1994, Dębowski et al. 1999a, 1999b). It is possible that this is connected to the intense growth that sea trout experience in spring during the period immediately preceding smoltification (Fahy 1990, Bohlin et al. 1993, Dębowski and Radtke 1994).

The conclusion from the current experiment is that differences in growth of cultivated sea trout in autumn preceding smoltification do not result in length bimodality and do not permit using length measurements taken in either autumn or winter in the first year of life to predict the number of these fish that will smoltify in the subsequent spring.

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Streszczenie

Możliwości przewidywania liczby jednorocznych smoltów troci (*Salmo trutta* m. *trutta* L.) w warunkach stawowych na podstawie zróżnicowania długości parr

Potomstwo 14 par troci pochodzących z populacji z rzeki Wisły podchowywano przez pierwszy rok życia, w warunkach rzecznej termiki, początkowo oddzielnie, a następnie, po poznakowaniu znaczkiem PIT, razem. Wiosną drugiego roku życia dokonano oceny smoltyfikacji ryb w poszczególnych rodzinach. Smolty stwierdzono we wszystkich rodzinach, a ich udział wynosił od 14 do 66% i zależał od średniej długości ryb w rodzinie zarówno poprzedniej jesieni, w październiku (r^2 = 0,338), jak i zimy, w styczniu (r^2 = 0,346). Mimo tej zależności, długości parr troci, w przeciwieństwie do parr łososia, nie wykazywały w poszczególnych rodzinach wyraźnej bimodalności. Nie powiodła się także próba oszacowania przyszłej liczby smoltów poprzez podział rozkładów długości jesienią i zimą na składowe gaussowskie metodami Bhattacharya i NORMSEP.