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P. Prouzet, Pierre-Yves Le Bail, Micheline Heydorff. Sex Ratio and Potential Fecundity of Atlantic Salmon (*Salmo salar* L.) Caught by Anglers on the Elorn River (Northern Brittany, France) during 1979 and 1980. *Fisheries Management*, 1984, 15 (3), pp.123-130. 10.1111/j.1365-2109.1984.tb00843.x . hal-01600579

HAL Id: hal-01600579

<https://hal.science/hal-01600579>

Submitted on 2 Jun 2020

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Sex Ratio and Potential Fecundity of Atlantic Salmon (*Salmo salar* L.) Caught by Anglers on the Elorn River (Northern Brittany, France) during 1979 and 1980

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ABSTRACT

Analysis of the sex ratio of angling Atlantic salmon catches from March to mid-June on the Elorn river in 1979 and 1980 showed a majority of females among the spring salmon population. Comparison between serodiagnostic technique and visual observations of gonads indicated that the former method provided a very low error margin for sex ratio determination on all females in the early stages of maturation and entering rivers. Study of sexual characteristics of spring salmon bearing copepod parasites or not indicated that fish entering freshwater would initiate a new stage of the ovogenesis process characterized by a failure of about 30% of the oocytes and a correlation between fecundity and size that did not exist at the time of the entry into freshwater.

INTRODUCTION

Studies on Atlantic salmon populations undertaken since 1974 on the Elorn river allowed us to define some biometric characteristics of salmon caught by angling (Harache & Prouzet, 1977; Prouzet, 1979) and some characteristics of the dynamics of the stock (Prouzet, Harache & Branellec, 1978; Prouzet, 1979).

During the fishing season of 1979 and 1980, angling catches were examined post-mortem to evaluate sex ratio and potential fecundity (Prouzet, Harache & Jalabert, 1979) and to evaluate the technique of Le Bail & Breton (1981) for estimating the sex ratio of adult salmon independent of external secondary sexual characteristics.

The systematic utilization of this technique (Le Bail, Maise & Breton, 1981) may make it possible to estimate the sex ratios and reproductive potential of adult salmon populations entering a counting trap without killing the individuals. A survey of the variability of the sex ratio over long periods could be conducted easily.

According to Mathisen & Gunnerod (1969), sex ratio was the most important source of variation in the estimate of the reproductive potential of a Pacific salmon population (*Oncorhynchus nerka*) over a 10-year period.

Idler, Hwang & Crim (1981) used the presence of serum vitellogenin as an indication of whether or not Canadian Atlantic salmon caught at sea were undergoing sexual maturation at time of capture.

In the same way, the purpose of the present study was to use the serodiagnostic technique to determine the sex ratio and to observe the gonads of adult salmon caught by anglers from March to June on the Elorn River to evaluate the stage of sexual maturation of the Spring salmon population.

MATERIAL AND METHODS

A routine collection of data was made from Atlantic salmon angled in the Elorn River on fork length (± 0.5 cm), weight (± 10 g), scales for age determination, gonads and blood samples for determination of sex ratio, fecundity and gonadosomatic ratio (GSR) and presence of parasites. The presence of parasites (Copepods: *Lepophtheirus salmonis*) indicates a recent entry of salmon to fresh water.

In 1979, 60 salmon were caught. Of the 60, 37 were examined for biometric characteristics and 26 for sex ratio. In 1980, 320 were caught, of these, 150 were examined for biometric characteristics and 102 for sex ratio.

Potential fecundity (number of oocytes in the maximum size class), relative fecundity (number of oocytes/kg body weight) and mean diameter of oocytes were estimated by Jalabert's method (Prouzet *et al.*, 1979). All considered oocytes (except atretic ones) will give eggs in the next spawning season.

Serum vitellogenin was determined by immunoagglutination (Le Bail & Breton, 1981; Le Bail *et al.*, 1981) to estimate sex ratio for comparison with estimations made by post-mortem examination. Spawning females' ratio was estimated by the presence of vitellogenin in the blood. This protein gives the vitelic reserves of the eggs. Twenty μ l of blood taken in the caudal vessel was added to 10 μ l of latex particles which were sensitized by trout vitellogenin antiserum. The positive reaction takes place in 2 or 3 minutes. Details of this technique were given by Le Bail & Breton (1981) and Le Bail *et al.* (1981).

Statistical treatments

Comparisons of means were made by one way analysis of variance. Homogeneity of variances was tested according to Bartlett's test. The relationship between pairs of characters was tested by using a contingency table. Correlations were calculated by the usual parametric methods (Dixon & Massey, 1969; Sokal and Rohlf, 1969). Linear relationships were estimated by functional regression (Ricker, 1973).

RESULTS

(1) *Age distribution* (Table 1). The majority of the fish examined were spring salmon, most of them had spent two winters at sea (94.2% and 87.9% of the individuals collected in 1979 and 1980). The proportion of salmon which had spent 1 or 2 years in freshwater varied significantly ($P < 0.05$) from one year to the next.

(2) *Weight and length* (Table 1). No significant difference was found between mean weights (4080 g \pm 190 ; 4218 g \pm 102), mean fork lengths (74.3 cm \pm 1.5 ; 74.1 cm \pm 2.1) and predictive regressions of weight versus length of the samples collected in 1979 and 1980 respectively.

A study done on the 1980 sample showed no significant variation between biometric characteristics of males and females.

(3) *Sex ratio*. The majority of the fish examined during the two fishing seasons were females (0.18 male for 1 female in 1979 and 0.34 male for 1 female in 1980). There is no significant difference between these two ratios ($P > 0.05$). The error in sexing by serodiagnostic is very low (2.5%) (Table 2).

(4) *Sexual characteristics of females* (Table 3). Total and relative fecundity remained stable from one year to the next with mean values of 9502 ($\sigma = 2394$) and 2359 ($\sigma = 512$) respectively. Gonadosomatic ratio, oocyte diameter and ovarian weight were significantly

TABLE 1. Age distribution, length and weight of catches in 1979 and 1980

Parameters	2-sea-winter fish			3-sea-winter fish		Grilse	Previous spawner	
	Number of winters in freshwater							
	1	2	3	1	2	2		
1979	Fork length (L _F) in cm	74.0±6.9* (18)	74.8±9.1 (8)	74.0 (1)	(0)	(0)	57.0 (1)	(0)
	Weight (P) in g	4119±272 (13)	4131±390 (8)	3690 (1)	(0)	(0)	2750 (1)	(0)
	Age distribution in %	56 (19)	35.3 (13)	2.9 (1)	(0)	2.9 (1)	2.9 (1)	(0)
Length-weight relationship	P = 0.097 L _F ^{2.473} ; V _b = 0.081						r = 0.86	
1980	Fork length (L _F) in cm	73.5±6.2 (41)	73.8±5.9 (76)	72.7±13.4 (5)	77.2±13.4 (7)	77.3±8.2 (9)	(0)	75.0 (1)
	Weight (P) in g	4142±208 (38)	4260±143 (60)	3945±1015 (4)	4312±750 (3)	4555±700	(0)	4000 (1)
	Age distribution in %	32.9 (49)	51.7 (77)	3.4 (5)	4.7 (7)	6.0 (9)	(0)	1.4 (2)
Length-weight relationship	P = 0.037 L _F ^{3.239} ; V _b = 0.047						r = 0.81	

V_b: variance of slope (*) Standard deviation of the mean r: correlation coefficient () Number of individuals

TABLE 2. Comparison of the results obtained by the gonad observation and by the serodiagnostic technique

Designation by serodiagnostic technique	♂		♀		Percentage of error using serodiagnostic technique
	♂	♀	♂	♀	
Gonad observation					
1979	4	0	0	18	0%
1980	19	1	1	55	2.5%

higher in 1979 than in 1980, although the average weight, length and age distribution of females did not differ significantly. No significant differences were found between characteristics of females recently entering freshwater (bearing parasitic copepods) and those entering the river earlier (without parasitic copepods).

(5) *Relationships between sexual and biometric characteristics* (Table 4). Among individuals without parasites, there is no linear relationship between ovarian weight and fork length or total weight, whereas this relationship is highly significant in those with parasites.

DISCUSSION

The serodiagnostic technique adapted to field conditions (Bagliniere, Le Bail & Maise, 1981) provided a very low error (2.5%) for sex ratio determination on all females in the early stages of maturation. Thus, this technique appears to be a useful management tool and offers some new prospects for the study of the variability in sex ratio.

In the Elorn river, a stable sex ratio was observed in 1979 and 1980 (this fact was also confirmed in 1981). A majority of females (85% and 75% in 1979 and 1980) was found in the spring salmon population caught by angling on the Elorn river.

This was also observed in the spring salmon population of other French rivers: Scorff river and Blavet river (Arribe, 1981), in Scotland (MacFarlane, 1931) and in Canada (Lee & Power, 1976). Thus unbalanced sex ratio in favour of females was also observed in grilse populations from a tributary of the Elorn river by Prouzet & Gagnon (1982) and by Dumas (1979) on the Nivelle river.

The unbalanced sex ratio was observed in smolt populations (Lee & Power, 1976) and varied over migration time. Osterdahl (1967), Mitans (1973) and Leyzerovitch (1973) attribute this to higher rates of mortality of precociously mature male parr during the winter following maturity. These mortalities would originate, according to Pickering & Christie (1980), from a differential sensitivity to ectoparasites.

The low gonadosomatic ratio (mean: 0.89%) together with low mean oocyte diameter (between 1.5 mm and 2.2 mm; Prouzet *et al.*, 1979) does not necessarily indicate whether or not females are initiating vitellogenesis. However, the presence of blood vitellogenin implies that vitellogenesis is being initiated. This is in agreement with the observations made by Idler *et al.* (1981) on Atlantic salmon caught at sea and entering Canadian rivers.

Fish entering rivers show a strong homogeneity in their stage of ovarian development (there is a significant correlation between ovarian weight and fork length). The lack of correlation between ovarian weight and total weight or fork length in the group of salmon bearing no parasites probably indicates a heterogeneity of later stages in ovarian development. Therefore, fish entering freshwater would initiate a new stage of the ovogenesis process. This

TABLE 3. Comparisons of the principal sexual characteristics of Atlantic salmon females in 1979 and 1980

Year	Ovary weight (in g)	Total weight (in g)	G.S.R.* (%)	Total fecundity (No. of oocytes)	Relative fecundity (No. of oocytes/kg)	Oocyte diameter (in mm)
1979	41.74±12.27 (18)	3948±453 (18)	1.048±0.303	9918±1172 (18)	2522±231 (18)	1.795±0.171 (18)
1980	34.27±8.45 (48)	4095±624 (48)	0.840±0.172	9373±2732 (48)	2297±574 (48)	1.659±0.196 (48)
Comparison between years	significant $P < 0.025$	NS	significant $P < 0.01$	NS	NS	significant $P < 0.01$

* $\bar{X} \pm \sigma/\sqrt{N}$ () = Number of fish (*) G.S.R. = $\frac{\text{Gonad Wt} \times 100}{\text{Total Wt}}$

TABLE 4. Relationships between the metric and sexual characteristics (year 1980)

Relationships between X and Y	Total sample		Sample with parasites	Sample without parasites
	Correlation coefficient	Functional regression	Correlation coefficient	Correlation coefficient
Fork length/ovarian weight	0.54**	$Y = 2.43 X - 144.1$	0.81**	0.33 ^{NS}
Total weight/ovarian weight	0.51**	$Y = 1.35 \cdot 10^{-3} X - 21.12$	0.78**	0.29 ^{NS}
Fork length/fecundity	0.45**	$Y = 3.65 \cdot 10^{-3} X^{6.11}$	0.39 ^{NS}	0.51**
Weight/fecundity	0.42**	$Y = 2.57 \cdot 10^{-3} X^{1.81}$	0.39 ^{NS}	0.51**
G.S.R./oocyte diameter	0.56**	$Y = 1.83 X^{0.55}$	0.26 ^{NS}	0.70**
Fecundity/oocyte diameter	0.42**	$Y = 64.37 X^{-0.40}$	0.39 ^{NS}	0.44**
Relative fecundity/ oocyte diameter	0.46**	$Y = 48.35 X^{-0.44}$	0.54*	0.41*

** $P = 0.01$ * $P = 0.05$ NS: Not significant

hypothesis seems to confirm the relationship between gonadosomatic ratio and oocyte diameter in the non-parasitized group of fish.

The average relative fecundity estimated several months before the spawning period was much higher than for the same population during the spawning period (1662 oocytes/kg/body weight; Prouzet & Gaignon, 1982). Upon entering freshwater, spring salmon have a great number of oocytes, many of which do not develop during subsequent maturation as the number is greater than can be supported by the metabolic reserves of the fish. A similar interpretation has been given by Persov (1963) for pink salmon populations (*Oncorhynchus gorbuscha*), by Melnikova (1964) for Atlantic salmon populations, and by Scott (1962) who showed a degree of follicular atresia associated with a degree of starvation during the maturation period of *Salmo gairdneri*.

Failure of about 30% of the oocytes to develop could account for the change in fecundity following entry to the river.

ACKNOWLEDGMENTS

We are grateful to Dr R.L. Saunders, Dr E.B. Henderson, Dr G.Y. Conan and Dr J. Thorpe for constructive criticism of the manuscript.

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