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Reproductive performance of cultured Atlantic salmon *Salmo salar* L. 1758 in Chile

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Abstract

Reproductive variables from 1529 females and 168 males of Atlantic salmon *Salmo salar* L. 1758 were recorded individually during the 1995 spawning season at a salmon farm in the south of Chile. The spawning period occurred in autumn and lasted 43 days, with a peak occurring in the first week of May. Average mature female and male body weights were 6.4 ± 0.9 kg and 7.0 ± 1.0 kg respectively. Average total and relative fecundity of females were 5998 ± 1404 eggs and 946 ± 210 eggs kg^{-1} respectively. Female body weight showed a similar pattern of correlation with total and relative fecundity observed in other salmonids. Average total and relative volume of ejaculate of males were $47.7 \pm 32.8\,cm^3\,kg^{-1}$ and $7.26 \pm 5.44\,cm^3\,kg^{-1}$, respectively, with the latter being lower than the values reported in the literature. Furthermore, male weight showed a negative correlation with these variables, in contrast to a positive value reported for these correlations in the northern hemisphere. Ejaculate volume showed a positive correlation with date of stripping. Average sperm density (5.83 ± 3.75 sperm cm^{-3} 10^{-9}) was lower than the values found in the literature and could be explained by the higher ejaculate volumes.

Introduction

The Atlantic salmon is found on both sides of the North Atlantic ocean. It occurs from the Connecticut River northwards to Ungava Bay on the east coast of North America and can be found in Iceland and Greenland. The species occurs in the British Isles and from northern Spain to Russia in the Pechora River flowing from the Ural Mountains (Stickney 1991).

The rearing of Atlantic salmon started around the 1950s, but major developments occurred in the 1960s (with the development of dry feeds) in Sweden, Ireland, Iceland, Canada, Faroes Islands, Norway and Scotland. By 1970, the production of Atlantic salmon in net-pens had reached 4000 metric tons and, since the beginning of the 1990s, over 95% of farmed Atlantic salmon are raised in this way (Isaksson 1991).

Atlantic salmon is the most important species for the Chilean salmon production industry. Since the beginning of their culture in Chile, farmers imported eyed eggs from different countries in the northern hemisphere, principally from Europe (about 56 million eggs during 1997); export of salmon has experienced a large increase from 19 114 tons in 1992 to 64 740 tons in 1997 (Lozano 1999).

The aim of this work is to describe the main reproductive variables of a cultured population of Atlantic salmon in Chile and to contrast the reproductive results with data from the northern hemisphere.

Material and methods

This work was carried out at a farm in the X^{th} Region (Chiloé Island, 42°E 30′S; 73°E 45′W) during the 1995 spawning season. A total of 1697 3-year-old fish, with 2 years of sea life (1529 females and 168 males), were sampled. The fish were transferred to freshwater 10–15 days before the beginning of spawning. Females were checked twice a week to detect ovulated females.

Table 1 Biometric variables of cultured Atlantic salmon in Chile

	Females		Males	
	Average ± SD	***n***	**Average ± SD**	***n***
Body weight (g)	6368 ± 850	250	6979 ± 995	167
Body length (cm)	79.7 ± 3.7	249	89.1 ± 4.2	168
Condition factor (K)	1.26 ± 0.13	249	0.98 ± 0.11	167

Table 2 Reproductive variables of cultured Atlantic salmon in Chile

	Females		Males	
	Average ± SD	***n***	**Average ± SD**	***n***
Total fecundity (eggs/female)	5988 ± 1404	250		
Relative fecundity (eggs/K female)	946 ± 210	250		
Total egg volume (L)	1.4 ± 0.3	250		
Egg diameter (mm)	6.46 ± 0.21	250		
Fertilization rate (%)	77.1 ± 18.2	250		
Eyed egg survival (%)	76.1 ± 23.6	250		
Volume of ejaculate (cm^3 milt/male)			47.7 ± 32.8	116
Relative volume ejaculate (cm^3 milt/K male)			7.26 ± 5.44	115
Sperm density (no. sperm $cm^{-3} \times 10^9$)			5.83 ± 3.75	82

Ripe females were anaesthetized, weighed and measured before being stripped in individual bowls. Fertilization was performed by the dry method (Billard 1992) using 2–3 mL of semen for the eggs of individual females. Total volume of male ejaculate was measured, and samples of semen were taken for sperm density determinations using a spectrophotometer; a calibration curve was made using the semen of one male.

Eggs from different females were incubated separately in individual incubators provided with well and spring water of 9.9–10.3 °C, with a flow of 1.5 L min^{-1}. About 120 accumulated temperature units (ATUs) in °C-days after fertilization, 20 eggs were removed from each egg batch and tested with a 10% acetic acid solution to determine the fertilization rate. The eggs were shocked, and all dead eggs picked out 2–3 days after eye pigmentation, at about 270 ATUs. Fecundity and egg survival data were obtained volumetrically. Egg size was measured with a Von Bayer trough (Piper *et al.* 1983).

Data were subjected to regression and correlation analysis with SAS and STATGRAPHIC statistical programs.

Results and discussion

The spawning period lasted 43 days for the 1529 females registered, from 20 April to 1 June; the spawning peak occurred in the first week of May. The recorded spawning period is a little earlier than the spawning time of cultured salmon reared in net-pens (throughout December) in northern Europe (Isaksson 1991), corresponding to June in the southern hemisphere.

Biometrical and reproductive parameters measured in 250 females and 168 males are summarized in Tables 1 and 2. The condition factor of females was significantly ($P < 0.01$) higher (1.26 ± 0.13, $n = 249$) than that of males (0.98 ± 0.11, $n = 167$). Total fecundity exhibited a direct linear relationship with body weight. A significant ($P < 0.001$) linear regression coefficient of 648 eggs kg^{-1} was estimated (Fig. 1A) with a correlation coefficient of $r = 0.39$. Relative fecundity indicated a small negative correlation ($r = -0.19$) with body weight ($P < 0.001$) (Fig. 1B). Egg viability, measured by fertilization rate, and eyed egg survival rate were $77.1 \pm 18.2\%$ and $76.1 \pm 23.6\%$ respectively. Both variables showed

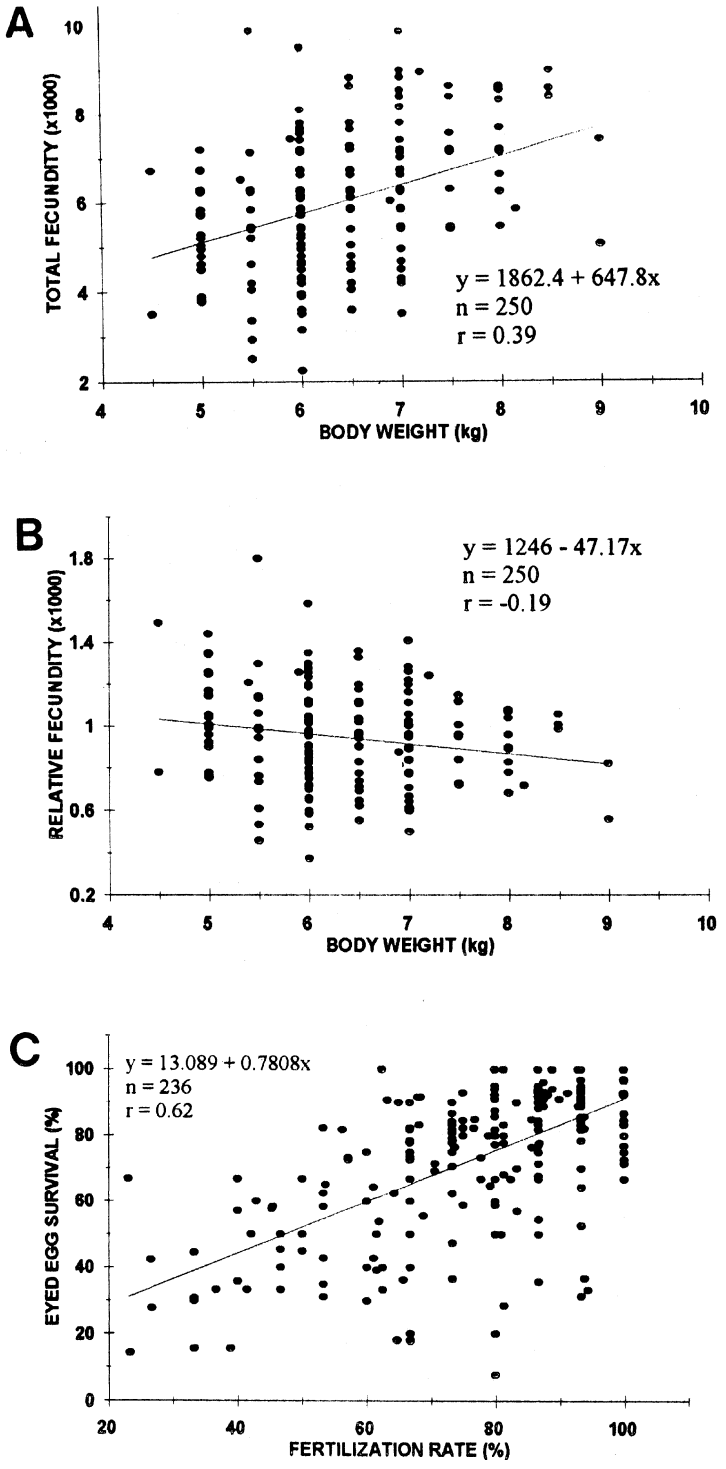

Figure 1 (A) Regression of total fecundity (y) on female body weight (x). (B) Regression of relative fecundity (y) on female body weight (x). (C) Regression of eyed egg survival (y) on fertilization rate (X).

a positive correlation ($r = 0.62$, $P < 0.001$, $n = 236$) (Fig. 1C).

Total fecundity in Atlantic salmon varies considerably, but is frequently 1–2 L in farmed females of 5–7 kg (Isaksson 1991). The average total fecundity corresponding to fish from six Scottish rivers ranged from 4943 to 6067 eggs (Mills 1971). Total fecundities obtained in this study were 1.4 ± 0.3 L and 5988 ± 1404, both being inside the above-mentioned ranges.

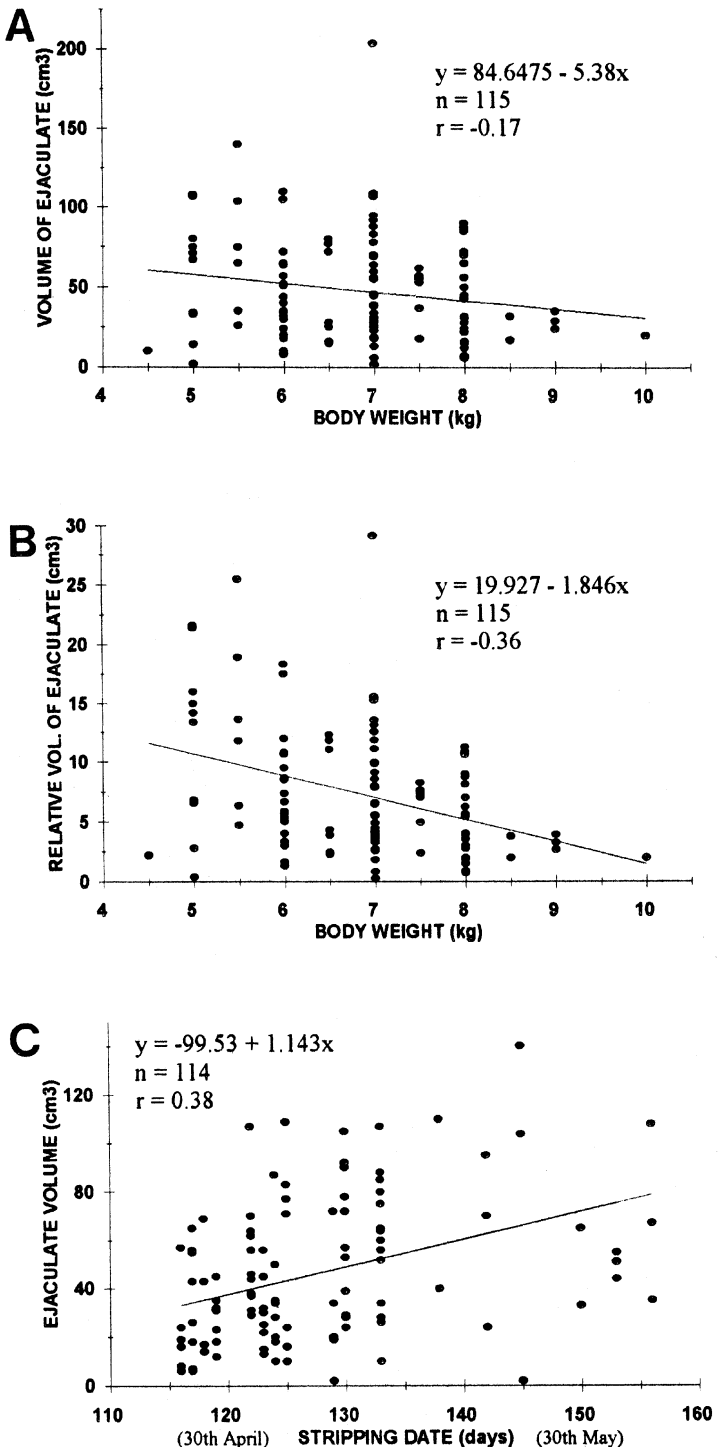

Figure 2 (A) Regression of ejaculate volume (*y*) on male body weight (*x*). (B) Regression of relative ejaculate volume (*y*) on male body weight (*x*). (C) Regression of ejaculate volume (*y*) on stripping date (*x*).

Relative fecundity of 1200–2000 eggs kg^{-1} fish reported for wild Atlantic salmon by Gordon, Klotin, Campbell & Cooper (1987) is higher than the average obtained for farmed Atlantic salmon in this study (946 ± 210 eggs kg^{-1}). Negative values for the correlation of the relative fecundity with body weight have also been reported in farmed rainbow trout *Oncorhynchus mykiss* (Springate & Bromage 1984, Bromage & Cumaranatunga 1988; Estay, Diaz, Neira & Fernández 1994) and farmed coho salmon *Oncorhynchus kisutch* (Estay, Diaz, Neira & Garcia 1997).

Egg size, which was estimated according to the average egg diameter (6.46 ± 0.21 mm), is nearly the same average described by Gordon *et al.* (1987) (6.4 mm) for this species.

The positive correlation showed by the fertilization rate and the eyed egg survival rate in this study ($r = 0.62$) is consistent with the same correlation observed by Estay *et al.* (1994) in farmed rainbow trout ($r = 0.75$).

Variation of ejaculate volume showed an increasing trend over the reproductive season and reached a peak volume during the last week in May. Both total and relative ejaculate volume indicated a significant negative correlation with body weight ($r = -0.17$ and -0.36, $P < 0.01$) respectively (Fig. 2A and B). Ejaculate volume showed a significant positive relationship with the stripping date ($r = 0.38$, $P < 0.01$, $n = 114$) (Fig. 2C).

Data on the yield of semen from Atlantic salmon has been reported by Kazakov (1981) for wild salmon ($15.06 \pm 1.49\,cm^3$ of ejaculate from individuals with 2 years of sea life), and by Gjerde (1984) for farmed salmon ($41.8 \pm 17.0\,cm^3$ volume of ejaculate from the same aged individuals, at first stripping).

Volume of ejaculate obtained from our farmed males averaged $47.7 \pm 32.8\,cm^3$ and is a little higher than Gjerde's males' performance. Relative volume of ejaculate reported by this last author ($20\,cm^3\,kg^{-1}$ body weight) is, however, considerably higher than the average obtained in this study ($7.26 \pm 5.44\,cm^3\,kg^{-1}$ body weight). Furthermore, in Gjerde's males, the correlation between volume of ejaculate and body weight was positive, while in our males, both total and relative ejaculate volume indicated a negative correlation with body weight ($r = -0.17$ and -0.36 respectively). On the other hand, in this study, ejaculate volume showed a significant positive relationship with the stripping date ($r = 0.38$).

In spite of the fact that the levels of analysis are different, data are consistent with the increasing volume of ejaculate reported by Gjerde (1984) in serial stripping of farmed males of Atlantic salmon.

Several authors have reported values of sperm density in Atlantic salmon, for both wild and farmed salmon. Kazakov (1981) reported an average of 14.84 ± 3.04 sperms cm^{-3} milt $\times 10^9$ in wild salmon with 2 years of sea life. Aas, Refstie & Gjerde (1991) reported a mean of $9.54 \pm 3.2 \times 10^9\,cm^{-3}$ in farmed Atlantic salmon. This concentration ranged from 3.5 to $17.9 \times 10^9\,cm^{-3}$. These authors described a gradual decrease in this variable during the spawning season. In contrast, Piironen (1985), working with wild landlocked Atlantic salmon, reported a sperm density of about $4 \times 10^9\,cm^{-3}$ during the first third of the period, but the maximum values ($12 \times 10^9\,cm^{-3}$) were obtained at the end of the spawning period. Piironen's values ranged from 0.19 to $55 \times 10^9\,cm^{-3}$. Sperm density obtained in this study (mean $5.83 \pm 3.75 \times 10^9\,cm^{-3}$ and range from 0.12 to $33.41 \times 10^9\,cm^{-3}$) is a little lower than the values mentioned above. Although no spermatocrit measures were performed, low density could be related to the high ejaculate volumes obtained.

Compared with Atlantic salmon farmed in the northern hemisphere, in Chile, we found a slightly earlier spawning period, with the females being similar in size and total fecundity, and males being different because of a large volume of ejaculate, but showing smaller relative ejaculate volume and sperm density.

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