International Council for
the Exploration of the Sea

C.M. 1977/M:31
Anadromous and Catadromous
Fish Committee

Effect of water temperature on rate of embryonic development, growth and survival of Atlantic salmon *(Salmo salar)*

by

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ABSTRACT

This paper presents a comparison of the effect of five different temperature regimes on embryonic development, growth and survival of Atlantic salmon as they relate to the production of a 1-year smolt. Under an incubation temperature of 10°C and rearing temperature of 15°C fish attained a size of 17.7 cm ±1.7 from full swim-up fry in eight months. This was not achieved without a loss of 69% and a high incidence of deformities. Under a less costly and more natural temperature regime salmon attained a size of 15.2 cm ±1.7 by early May in the second year. Mortality under this regime was 45.5%. The results indicate that both incubation period and mortality from fertilization to the full swim-up fry stage vary inversely and directly with water temperature, respectively.

INTRODUCTION

Presently hatcheries in the three Maritime Provinces of Canada produce 80% to 100% of their smolts in two years, with the exception of one hatchery which has a one-year smolt program. The subject of rearing a higher percentage of 1-year smolts is being reviewed with increased interest by fisheries managers and Atlantic salmon culturists. While the net survival for 1-year smolts has not been as high as that recorded for 2-year smolts, recent results indicate that the gap in survival between 1-year and 2-year smolts is being reduced. Return data show that 1-year smolts produce proportionately more multi-sea-winter salmon than 2-year smolts (Ritter 1975). Experience indicates that 1-year smolts are superior with respect to fin conditions and generally demonstrate a higher resistance to diseases and parasites. Production costs for 1-year smolts are lower as food requirements are less and more can be reared in a given facility.

Because of the many advantages consideration is being given to altering rearing programs in some of our hatcheries to produce more 1-year smolts. In light of this the present study was undertaken to determine the extent to which the rate of growth of Atlantic salmon can be accelerated by heating water. This paper discusses the effect of five different temperature regimes on embryonic development, growth and survival as they relate to the production of 1-year smolts.

MATERIAL AND METHODS

The study was conducted at Mactaquac Hatchery in New Brunswick from November 1974 to April 1976. All eggs originated from one pair of wild salmon, Saint John River stock. The eggs were fertilized, water hardened and disinfected prior to being transferred from the main hatchery building to wet laboratory facilities for the entire duration of the experiment. The green eggs were divided into three separate lots. At the end of the swim-up stage, two of the lots were subdivided, with the result being five lots of salmon reared on different temperature regimes. These lots are designated as Groups 1-5 (Figure 1). Water temperature regimes were maintained through manipulation of well water, river water and by heating. Water was heated with power controlled stainless steel immersion heaters. Heated water was aerated by letting the water drop through perforated metal plates. During the incubation period the eggs were held on trays in rectangular fibreglass tanks. After hatch, the fry were transferred to 1.2 m circular fibreglass tanks in which they were maintained for the duration of the experiment. Density, water depth, water flow and feeding rates were adjusted to maintain optimum growing conditions. Fish were fed Silver Cup salmon dry feed.

RESULTS AND DISCUSSION

Results demonstrate that heating of water to accelerate the growth rate of Atlantic salmon is feasible provided several factors are considered: cost of energy required for heating, survival rate and timing of growth so that fish of a satisfactory size are attained at the proper time.

Under an incubation temperature of 10°C and rearing temperature of 15°C (group 1) fish attained a size of 17.7 cm $\pm$1.7 from full swim-up in eight months (Figure 1). This was not, however, achieved without a loss of 69% and a high incidence of deformities. The cost of heating water to achieve this rate of growth prohibits the utilization of this regime in a large scale 1-year smolt production program.

Fish in groups 2 and 3 were not reared beyond October as their growth was low relative to growth rates recorded for fish in groups 4 and 5.

The temperature regime under which group 4 fish were produced contributed to high loss during incubation and sac fry stage. The high losses during the early stages were attributed to high water temperatures while slow growth and high loss during the fry stage resulted from reducing the water temperature after full swim-up. The overall mortality in group 4 was 71.5% compared to 45.5% in group 5. Group 4 also had higher heating costs than group 5.

The temperature regime for group 5 fish produced a 15.2 cm ± 3.0 1-year smolt by early May in the second year. The energy costs for this rearing regime were the lowest of the five. Under this regime, eggs were incubated at a low temperature which, according to Hayes (1945), favors precocious hatching, normal differentiation of the various organs, and the production of larger alevins. At the time fry were ready to feed, water temperature was 14°C. This stimulated active feeding and rapid growth. Losses in group 5 were lower than for the other groups and comparable to that reported for 1-year hatchery-reared Atlantic salmon (Peterson, 1971). Growth in this group would have been greater had the water temperature been maintained at 18°C (65°F) instead of 15.5°C (60°F) from the latter part of June through to September.

Data in Table 1 point to the presence of inverse relationships between water temperature and duration (in days) from fertilization to full hatch and full swim-up stage, respectively. These relationships are described by the regression equations:

$$Y_1 = 179.9 - 12.6X \ (r = -0.98)$$

$$Y_2 = 201.6 - 10.9X \ (r = -0.99)$$

where Y_1 and Y_2 are days from spawning to full hatch and full swim-up, respectively, and X is temperature °C.

The data also show direct relationships between water temperature and number of degree days from fertilization to full hatch and full swim-up stage, respectively. These are described by the regression equations:

$$Y_3 = 466.7 + 9.3X \ (r = 0.81)$$

$$Y_4 = 432.7 + 48.9X \ (r = 0.98)$$

where Y_3 and Y_4 are number of degree days from spawning to full hatch and full swim-up, respectively, and X is temperature °C.

These results agree with those reported by Peterson (1977) and confirm that at lower temperatures a longer incubation period is required although the number of degree days to full hatch and full swim-up stages are fewer than at higher temperatures.

Results indicate that water temperature during initiation of feeding is very crucial. Proper temperatures during that period accelerate growth and reduce losses. The theory that Atlantic salmon fry do not start feeding at water temperature below 7°C (Peterson 1971) was noted in group 3. As water temperature dropped below 7°C in groups 2 and 4 growth was slow relative to that recorded for fish in groups 1 and 5 maintained at 15.5°C (Table 2).

Losses during incubation period and sac fry stage were higher at higher temperatures (Table 1). At an average temperature of 4°C from spawning to full hatch mortality was less than 50% of the loss recorded during the same period at 10°C. By the end of the full swim-up stage (i.e., sac fry stage), the mortality at the lower temperature was less than one-third that recorded at the higher temperature. Peterson (1977) reported similar results where mortality at 10-12°C was significantly higher than at 4, 6, and 8°C. Hayes (1951) contributed high losses at high temperature during incubation to insufficient oxygen diffusion through the egg capsule. The secondary fungal infection observed in our experiment could have contributed to the losses we recorded.

ACKNOWLEDGEMENTS

The authors wish to thanks Messrs. T.G. Carey and J.A. Ritter for reviewing the manuscript.

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TABLE 1. Incubation period and mortalities for Atlantic salmon reared at different water temperature regimes.

Water Temperature (°C)[1]	Spawning to full hatch: Days	Degree days[2]	Mortality %	Spawning to full swim-up: Days	Degree days[2]	Mortality %
10	60(56)[3]	582(542)[3]	19.6	95(91)[3]	932(892)[3]	29.9
7.2	85(79)[3]	549(509)[3]	12.8	120(126)[3]	782(822)[3]	18.9
4	130(136)[3]	502(510)[3]	9.2	155(164)[3]	602(638)[3]	10.8

[1] The 7.2° and 10°C regimes were constant in temperature; the 4°C regime included variations between 1.5° and 8.5°C.

[2] Sum of daily-average water temperatures above 0°C.

[3] Data in parentheses are for studies conducted in 1975. Both sets of data were used to determine the regression equations.

TABLE 2. Average weight (g) of five groups of Atlantic salmon fry maintained on different temperature regimes. Groups 1 and 5 were maintained at 15.5°C and groups 2, 3 and 4 at 7°C.

Dates	Weight (g): Group 1	Group 2	Group 3	Group 4	Group 5
March 12/75	1.0	-	0.3	0.4	-
April 10/75	2.5	0.2	0.4	0.5	0.2
May 10/75	3.4	0.5	0.6	0.8	1.1

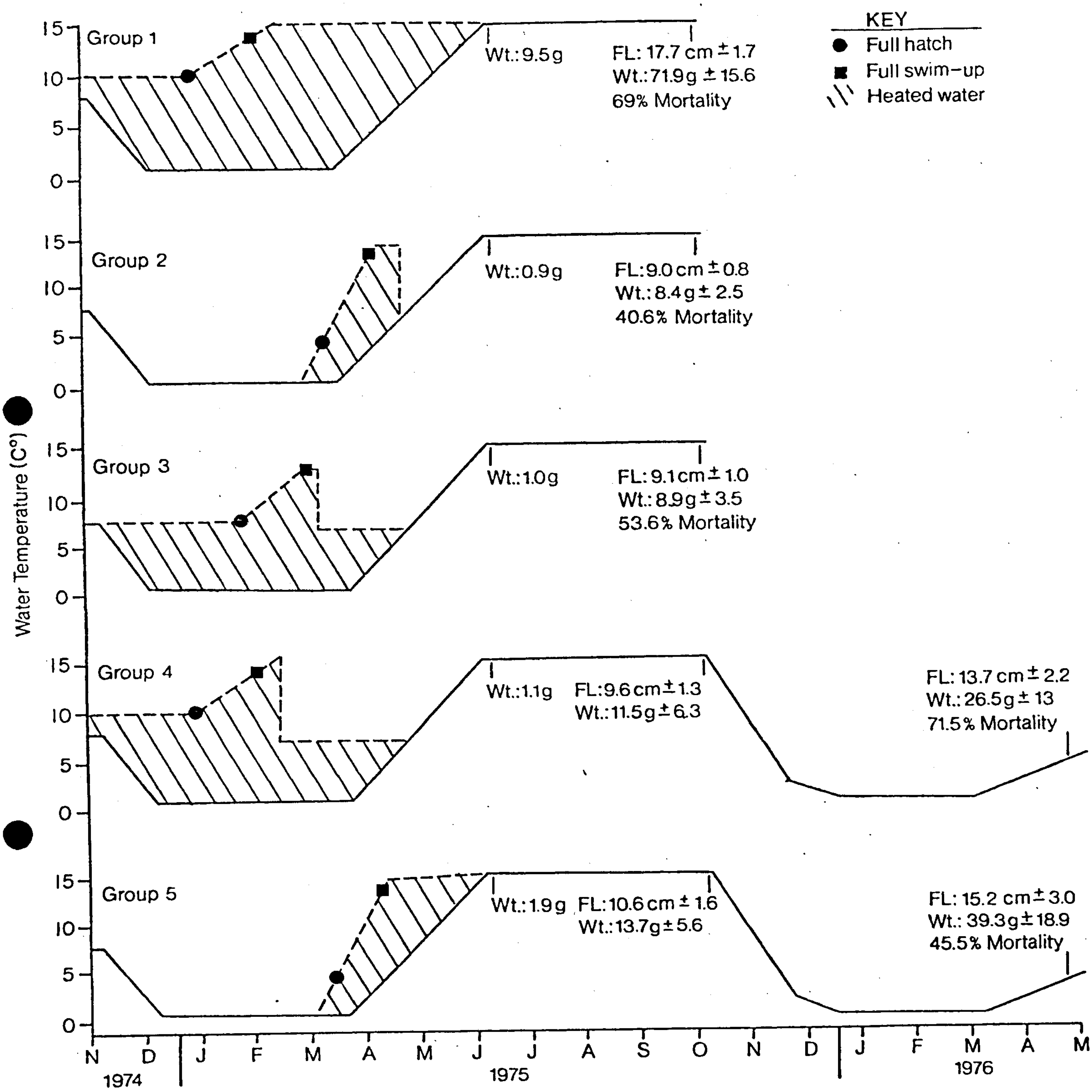

FIGURE 1. Five different water temperature regimes with related development and growth data for accelerated groups of Atlantic salmon.