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The Effect of Salinity and Ration Level on Growth Rate and Conversion Efficiency of Atlantic Salmon (*Salmo salar*) Smolts

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ABSTRACT

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Atlantic salmon smolts were acclimated to three salinities (0, 10 and 30 ppt) and four ration levels (0, 0.8, 3.1 and 5.1% dry weight per day). Growth rates of fish in each group were measured during two, 2-week intervals. Both salinity ($P=0.03$) and ration level ($P<0.0001$) had a significant effect on growth rate, with ration level having the most pronounced effect. Fish at low ration (0, 0.8 and 3.1% dry weight per day) grew more slowly in 10 and 30 ppt relative to 0 ppt, but the differences were not statistically significant. At high ration (5.1% per day) fish in 30 and 0 ppt had higher growth rates than fish in 10 ppt ($P<0.05$). Growth rate and gross food conversion efficiency increased with increasing ration, but the rate of increase in gross food conversion efficiency diminished with increasing ration. There was no significant effect of salinity on gross food conversion efficiency ($P=0.22$). The results indicate that ration level is far more important than salinity in affecting growth rate, and that rearing of Atlantic salmon smolts in isosmotic salinity does not offer significant growth advantages.

INTRODUCTION

Theoretical calculation of the energetic costs of osmoregulation in salmonids suggest that they are negligible, less than 1% of resting metabolic rate (Eddy, 1982). In contrast, measurement of oxygen consumption in rainbow trout (*Salmo gairdneri*) indicates a substantial reduction in standard metabolic rate (20–28%) in isosmotic salinity relative to fresh water and seawater (Rao, 1968). Salinity has been shown to affect growth rate and conversion

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efficiency in several salmonid species. Canagaratnam (1959) found that maximum growth rate of pre-smolt coho salmon (*Oncorhynchus kisutch*) increased with increasing salinity between 0 and 18 ppt. Examining the same species at a similar developmental stage, Otto (1971) found that maximum growth rate was greatest between 5 and 10 ppt and decreased at salinities between 15 and 30 ppt. Shaw et al. (1975b) found that growth rate of Atlantic salmon (*Salmo salar*) parr at several ration levels was not affected by salinities between 0 and 20 ppt.

The studies cited above were carried out prior to the development of maximum euryhalinity in these species, which occurs during the parr–smolt transformation. Shaw et al. (1975a) and Smith and Thorpe (1976) examined the effect of ration size in fresh water and seawater on the growth of Atlantic salmon and rainbow trout smolts, respectively. The influence of isosmotic salinity (10 ppt) relative to fresh water and seawater was not examined in these studies. In the present study we examine the effect of salinity (0, 10 and 30 ppt) and a wide range of rations on the growth rate and gross food conversion efficiency of Atlantic salmon smolts.

MATERIALS AND METHODS

Fertilized Atlantic salmon eggs of St. John River stock were transported to St. Andrews Biological Station, N.B., Canada, just after hatching in April and reared in 1-m^2 Swedish style tanks supplied with fresh water at 12 l min^{-1}. All fish were exposed to simulated natural photoperiod during rearing and throughout the experiment. Overhead lighting to all tanks was by standard (cool white) fluorescent bulbs which provided light intensities at the water surface of 430–540 lx. Water temperature fluctuated seasonally (4–20 °C) during the first year.

Experimental tanks were 1-m^2 with a nylon mesh divider to obtain two ration groups per tank. Opaque blinds were placed around the tanks to minimize visual disturbance. Fish were fed through plastic tubes which deposited food at the water surface. This allowed us to observe feeding behavior with minimal disturbance to the fish, and to ensure that all food presented was eaten. The low ration (0.2%) was fed every other day so as to reduce competition for the small amount of food; other groups were fed daily. Corey No. 4 dry pellet was used throughout the experiment. Water was supplied to experimental tanks at a rate of 9 l min^{-1}, and directed so that the current was just sufficient to cause fish to orient toward the current, but did not necessitate constant swimming.

On 1 May, 144 smolts (23–70 g) were randomly separated into 12 groups of 12 fish each. Eight of these were gradually acclimated to either 10 or 30 ($\pm$ 1) ppt, over a 2-week period. Ten ppt seawater was achieved by mixing preheated or precooled 30 ppt and 0 ppt water in 2:1 ratio in an insulated header tank.

Salinity and temperature of rearing tanks were checked daily. Water was maintained at 13 (± 0.2)°C. Dissolved oxygen was 8.3–9.3 mg l^{-1} and was approximately 5 and 10% lower at 10 and 30 ppt, respectively, than at 0 ppt. This difference is less than the inherent differences in oxygen solubility due to increased salt concentration. With this exception, all other rearing conditions were identical among the salinity groups.

For each salinity (0, 10 and 30 ppt), four ration levels of 0.0% (starvation), 0.2%, 0.8% and 1.6% (percent wet weight per day) were begun on 15 May. Fish were weighed every 2 weeks, and the ration was adjusted after each weighing. Following 24 h of starvation, fish in each group were anesthetized in 0.75% Tert-amyl alcohol and length and weight of fish were measured to the nearest mm and g, respectively. In our experience this procedure has little effect on the fish as feeding resumes soon after recovery from the anesthetic. The actual ration level given was calculated at the end of the experiment based on the wet and dry weights of both the feed and fish. After three, 2-week intervals, the experiment was terminated and a sample of five fish from each group was weighed and freeze dried to a constant weight. Percent moisture for each group was calculated and used to convert wet to dry weight. A sample of food was also dried and the ration calculated as a percent of dry body weight.

Instantaneous growth rate (expressed as percent change per day) was calculated as $(\ln W_{t2} - \ln W_{t1})/(t_2 - t_1) \cdot 100$, where W = average weight of a group at a particular time interval (t_1 or the later t_2). Gross conversion efficiency was calculated as $(G/I) \cdot 100$, where G = change in dry weight of fish and I = dry weight of feed consumed. An estimate of maintenance ration (the ration necessary to maintain a constant weight) for each salinity was obtained from the intersection of the growth versus ration curves with the zero level of instantaneous growth rate (Brett et al., 1969).

RESULTS

Survival was 100% in all groups except for the starved group in 30 ppt in which two of 12 fish died in the second 2-week interval (none died in this group in the third 2-week interval); no growth rate could be calculated for this former interval.

From a comparison of the three 2-week growth intervals, it was clear that the first interval was highly variable relative to the final two growth periods. This may have been the result of acclimation to new rations or salinity. Because of this disparity, only results of the final two growth periods are considered.

The effect of salinity and ration on instantaneous growth rate of Atlantic salmon smolts (expressed on a dry weight basis) from 30 May to 28 June is shown in Fig. 1. An identical pattern of response to salinity and ration is obtained if growth rate is expressed as a function of wet weight. The estimated

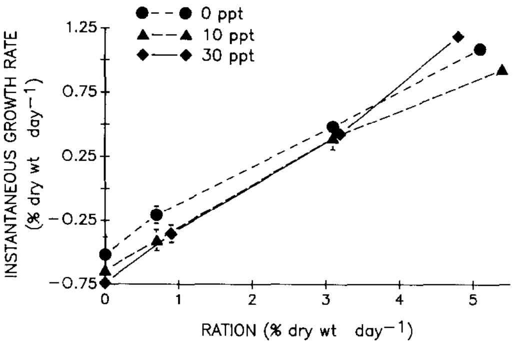

Fig. 1. Effect of salinity and ration on instantaneous growth rate of Atlantic salmon smolts. Values are the mean (±SE) of two sequential 2-week intervals with 12 fish in each group. Standard errors not shown are smaller than the value corresponding to the symbol size (less than 0.07% per day). Both salinity ($P=0.03$) and ration level ($P<0.0001$) had a significant effect on growth rate (two-way ANOVA). Instantaneous growth rate and ration are expressed as a proportion of dry fish weight (% per day).

wet weight rations of 0.2%, 0.8% and 1.6% per day corresponded to dry weight rations of approximately 0.8%, 3.1% and 5.1% per day, respectively.

Statistical analysis of the final two 14-day intervals indicated a significant effect of salinity ($P=0.03$) and ration ($P<0.0001$); there was no significant interaction between the two ($P=0.30$, two-way ANOVA). Negative growth (weight loss) occurred at the two lowest rations, and positive growth occurred at the two highest rations (Fig. 1). For the most part, growth rate increased linearly with increasing ration. Under starvation, fish in 30 ppt lost more weight (−0.741% per day) than fish in 0 ppt (−0.519% per day), whereas weight loss of fish in 10 ppt was intermediate between the two (−0.642% per day; Fig. 1). At intermediate rations (0.2% and 0.8% wet weight per day, 0.8% and 3.1% dry weight per day), growth rate was similar in 10 and 30 ppt and lower than that of fish in 0 ppt. Although fish at low ration (0, 0.8 and 3.1% dry weight per day) grew more slowly in 10 and 30 ppt relative to 0 ppt, these differences were not statistically significant ($P>0.10$, one-way ANOVA at each ration level). At high ration (1.6% and 4.8–5.4% wet and dry weight per day, respectively) fish in 30 ppt (1.180% per day) and 0 ppt (1.018% per day) grew significantly faster than fish in 10 ppt (0.924% per day; $P<0.05$, one-way ANOVA with Student–Newman–Keuls test).

An estimate of maintenance ration at each salinity can be obtained from the intersection of the ration versus growth rate curves with the zero growth rate level (Fig. 1). This yields a value of 1.4% per day (dry weight basis) for 0 ppt and 1.9% per day for fish in 10 and 30 ppt. We cannot conclude that these differences are statistically significant, however, since there was no significant effect of salinity on growth rate at the two ration levels nearest to the maintenance ration.

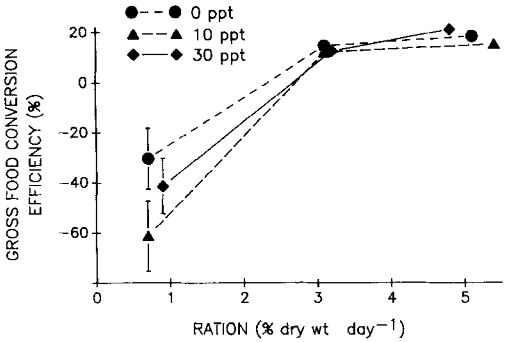

Fig. 2. Effect of salinity and ration on gross food conversion efficiency of Atlantic salmon smolts. Values are the mean (±SE) from two sequential 2-week intervals with 12 fish in each group. Standard errors not shown are smaller than the value corresponding to the symbol size. Ration level ($P<0.0001$; two-way ANOVA) had a significant effect on gross food conversion efficiency, whereas salinity did not ($P=0.22$).

Gross food conversion efficiency (dry body weight produced per unit dry weight of food consumed) as a function of ration and salinity is shown in Fig. 2. Ration level had a significant effect on gross food conversion efficiency ($P<0.0001$, two-way ANOVA), whereas salinity did not ($P=0.22$). Gross food conversion efficiency increased with increasing ration, and the rate of increase diminished with increasing ration. Although there was no significant effect of salinity on gross food conversion efficiency, at the highest ration the trend was similar to that for growth rate: gross food conversion efficiency was greater in fish in 30 ppt (19.0±1.0% at a ration of 4.8% dry weight per day) and 0 ppt (18.8±1.2% at 5.1% dry weight per day) than at 10 ppt (14.9±0.5% at 5.4% dry weight per day).

DISCUSSION

In the present study, salinity was found to have a significant effect on the growth rate of Atlantic salmon smolts. Under starvation, weight loss increased with increasing salinity, and at intermediate ration growth rate of fish in 10 and 30 ppt was similar and less than that of fish in 0 ppt. However, the only statistically significant effect of salinity was at high ration, where smolts had higher growth rates at 30 and 0 ppt than at 10 ppt. Although salinity had a significant effect on growth rate, we do not wish to exaggerate its influence; at all rations, salinity resulted in a maximum difference of 0.26% per day, less than 15% of the total range of growth rates produced by varying ration. Under most circumstances, ration level, temperature and nutritional quality will have more profound effects on growth rate of euryhaline salmonids than will salinity (Brett, 1979).

An estimated maintenance ration of 1.4% dry weight per day for Atlantic salmon smolts in 0 ppt (present study) is similar to the 1.5% dry weight per day calculated by Shaw et al. (1975a) for Atlantic salmon at a similar developmental stage and season. Our estimate of maintenance ration in 30 ppt (1.9% dry weight per day) is substantially lower than the 3.0% dry weight per day reported by Shaw et al. (1975a). The measurements of maintenance ration in 30 ppt by Shaw et al. (1975a) were made at a later time and on larger fish than both their own measurements in 0 ppt and those of the present study, which may partially account for the disparity in maintenance ration estimates for 30 ppt between the two studies.

Maintenance rations at 10 and 30 ppt were indistinguishable from one another, and suggest that at this ration level there is no energetic saving to be gained from residence in 10 ppt relative to 30 ppt. These results conflict with studies of rainbow trout in which oxygen consumption was found to be lowest in isosmotic salinity relative to 0 and 30 ppt (Rao, 1968). Although this difference may be ascribed to species-specific differences, there is some evidence that estimates of energetic costs based on measurements of oxygen consumption and growth rate studies are incompatible. Jurss et al. (1984) found that starvation of tilapia (*Oreochromis mossambicus*) resulted in increasing weight loss with increasing salinity (0, 10 and 33 ppt), whereas Farmer and Beamish (1969) found oxygen consumption of tilapia to be lowest at 10 ppt. McCormick et al. (1989) have recently reported that metabolic capacity of Atlantic salmon gill and kidney is altered by less than 20% by salinity, being lowest at 10 ppt in gill and decreasing with increasing salinity in kidney. Much larger increases in metabolic capacity (up to 200%) would be expected if the gill and kidney, major sites of ion regulation in teleosts, were responsible for salinity-induced increases in resting metabolic rate of 20%. The resolution of these apparent incongruities may lie in the interaction of salinity and digestion, which would be apparent in growth studies but not in measurements of oxygen consumption.

The relatively poor growth rate and gross food conversion efficiency of Atlantic salmon smolts at high ration in 10 ppt relative to those in 0 and 30 ppt may be peculiar to this development stage. Shaw et al. (1975b) found no difference in growth rate of Atlantic salmon parr due to salinity (0, 10 and 20 ppt) over a broad range of rations. Saunders and Henderson (1969) found that growth rate of Atlantic salmon post-smolts fed maximum rations and exposed to seasonally varying temperatures had increasing growth rates with increasing salinity (0, 15 and 30 ppt) in spring and early summer, and vice versa in fall and winter. These observations suggest that there may be few, if any, long-term benefits to rearing Atlantic salmon in isosmotic salinity.

Growth rate of Atlantic salmon smolts in 30 ppt at the highest ration (4.8–5.4% dry weight per day) was higher than that of fish in either 0 or 10 ppt, though statistically different only in comparison with the latter. In their study of rainbow trout, Smith and Thorpe (1976) found identical growth rates in fresh water and seawater at low ration but elevated growth rate at high ration in seawater-adapted fish (using rainbow trout of a similar size, during the same season and using similar temperatures as in the present study). The 0.2% per day higher growth rate of fish in seawater relative to those in freshwater (compared to 0.1% per day difference in the present study) was due to an increase in the efficiency of nitrogen conversion efficiency. These authors also found that the difference between growth rates of fish in fresh water and seawater at high ration was seasonal; in autumn the difference was no longer detectable. Smith and Thorpe (1976) suggested that the seasonal differences in growth response at maximum ration may be due to endocrine changes that accompany development. This seems particularly likely in light of recent findings that hormones putatively involved in seasonal changes in osmoregulation and development of salmonids (e.g. cortisol, growth hormone, and thyroid hormones; McCormick and Bern, 1989; Young et al., 1989) have substantial effects on salmonid metabolism (Sheridan, 1986).

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