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Effects of Different Salinities on the Growth, Food Intake and Nutrient Composition in Underyearling Masu Salmon, *Oncorhynchus masou* (B.)

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Abstract

The effects of different salinities on the growth, food intake, conversion efficiency, and body carbon and nitrogen contents were investigated by rearing fry and parr of masu salmon, *Oncorhynchus masou* (B.), with a commercial diet in fresh water (dechlorinated tap water, FW), 1/4 sea water (8±1‰), 1/3 sea water (11±1‰) and 1/2 sea water (15±1‰). Weight gains in both fry (9 weeks) and parr (5 weeks) were significantly greater in FW than that in SW. However, no clear differences were observed among the SW groups. No significant differences in daily feeding rate were observed. The food conversion efficiency decreased significantly in the SW groups compared to the FW group. The body nitrogen content of fry after a 9 week rearing period was not different among the four groups, but the body carbon content was higher in the FW group than in the SW groups. Assimilations of carbon and nitrogen were not significantly different. The carbon assimilation efficiency in the 1/2 SW group, however, tended to be low compared to those in the FW and other SW groups.

Introduction

In Northern Japan, Masu salmon, *Oncorhynchus masou* (B.), spawn in autumn and offspring remain in the river one year or longer until smoltification occurs. After one year in the ocean, masu salmon return to their parent river to spawn (Kubo, 1980). Recently, culture of masu salmon parr and smolts are on trial throughout Japan.

The effect of salinity on the growth of salmonid fishes has been studied in several species. However, the results are inconclusive and seem to differ depending on the species, sizes, and their life stages (review by Brett, 1979). Rearing in salt water versus fresh water resulted in a better growth rate than in fresh water in presmolt coho salmon (*Oncorhynchus kisutch*) (Canagaratnam, 1959; Otto, 1971), a similar growth in parr of Atlantic salmon (*Salmo salar*) (Shaw et al., 1975a, b), and a reduced growth rate for juveniles of chum salmon (*O. Keta*) (Koshiishi, 1980) and adult rainbow trout (*S. gairdneri*) (Mackay et al., 1985). The growth of fish is a consequence of the rate of food intake and conversion (Otto, 1971; MacLeod, 1977; and Koshiishi, 1980) and assimilation efficiency of ingested food (Smith and Thorpe, 1976). However, from the aspect of metabolic processes, few studies have been conducted on the effects of salinity on the growth.

The present study was performed to investigate the effects of different salinities of rearing water on the growth and metabolism of masu salmon fry and parr.

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Time-course changes of body weight and total amounts of body carbon and nitrogen were traced while rearing the fish in four different salinities. The effects on food intake, food conversion, and assimilation of carbon and nitrogen also were studied.

Materials and Methods

Source and maintenance of fish

About a thousand three-month-old masu salmon fry, *Oncorhynchus masou* (B.), were obtained from the Hokkaido Fish Hatchery Kumaishi Branch and brought to the university laboratory (Faculty of Fisheries, Hokkaido Universioy, Hakodate, Japan). They were maintained in two 60 l glass aquaria ($30 \times 60 \times 35$ cm) containing aerated dechlorinated tap water, under a 10L-14D photoperiod at 11 ± 1°C until use.

In a preliminary experiment, the fry were unable to survive more than two weeks in full-strength sea water. Then, the following four salinities were used; fresh water (dechlorinated tap water, FW), 8 ± 1‰ (1/4 SW), 11 ± 1‰ (1/3 SW), and 15 ± 1‰ (1/2 SW). Waters of desired salinities were prepared by diluting natural seawater with dechlorinated tap water. The bottom of the aquaria was covered with sand for air lift filtering. To avoid accumulation of metabolites the aquaria were cleaned and the entire water volume changed on a weekly basis. In addition, about a half of the water in each aquarium was replaced every 3rd day.

Feeding

In all experiments but Experiment 3, the fish were fed twice a day, to the point of satiation on a commercial pellets for juvenile trout (Nos. 1C, 2C and 3C, Nippon-Haigoh-Shiryo, Co.). To ensure each fish an equal chance to feed, pellets were given at about 10 second intervals until most of the fish did not respond. The total amount given per feeding time was recorded as the ration ingested by the fish.

Measurements of body weight and total carbon and nitrogen

Fish were fasted for 48 hr before sampling. After anesthetizing with 0.01-0.02% ethyl m-aminobenzoate methanesulfonate (MS 222) diluted with the rearing water, the fish were carefully blotted and the wet body weight measured. The body dry weight and water content were determined after drying the fish in an oven at 60°C to a constant weight and stocking them in a desiccator. Total carbon and nitrogen contents of the whole body, diets, and feces were determined with dried and powdered materials using a C-N corder (Yanaco. MT-500).

Experimental design

Three series of rearing experiments were conducted to investigate the effects of different salinities.

Experiment 1: Growth and nutrient accumulation in fry

Two hundred fry, each weighing 0.3 to 0.6 g, were transferred to the aquaria containing the four different salinities. All fish were transferred directly from FW except those transferred to the 1/2 SW medium. Those fry were first placed in 1/4 SW for two days. The rearing experiment lasted for nine weeks, under a 10L-14D photoperiod, at 11 ± 1°C. Ten fish were randomly sampled weekly. Their wet body weight was measured, dried to determine the body water weight and the content of total carbon and nitrogen (mg carbon or nitrogen/mg dry body weight$\times$ 100). The ratio of carbon to nitrogen (C/N) was calculated based on the respective values obtained.

Approximately a hundred of the fish that survived each salinity were reared for use in following experiments.

Experiment 2 : Growth, food intake, and conversion efficiency in parr

Twenty parr of similar sizes (3.9 to 5.3 g), that had adapted in each salinity for more than three months were selected and reared for 5 weeks further in separate aquaria. They were maintained at a temperature of 14 ± 1°C under a 12L-12D photoperiod. All of these fish were weighed weekly and then returned to their respective aquarium.

The mean daily feeding rates and food conversion efficiencies were calculated from the gained body weight and food intake as averaged over this five week period.

Experiment 3 : Assimilation efficiencies of carbon and nitrogen in parr

Six to eight parr (9.0 to 11.0 g) that had been reared in each salinity for five months were used in this experiment. They were fed to satiation with the same commercial diet but contained 2% chromic oxide. When feces had fully turned green, it was collected and lightly washed with DW and then dried. The chromic oxide content in the dried diet and feces were determined by photometry at 350 nm after wet ashing with concentrated nitric acid and 60% perchloric acid (Furukawa and Tsukahara, 1966).

The assimilation efficiency of carbon or nitrogen was calculated from the ratio of the nutrient to chromic oxide in the dried diet and in the feces. This follows the procedure described in Nose and Mamiya (1963) and shown below:

$$100 \times (1-(Cr_2O_3/\text{C or N})\ \text{food}/(Cr_2O_3/\text{C or N})\ \text{feces}) \quad (\%).$$

Statistical analyses

Mean values among the four salinity groups were compared statistically using the Student-t test. Differences between slopes of regression lines were analyzed using analysis of co-variance.

Results

Growth of fry and parr in different salinities

No fry in any of the groups died during the entire 9 week period of Exp. 1. Compared to their initial weight (0.48 ± 0.03 g, mean$\pm$SE), the body weight at the 9th week increased to 2.46 ± 0.21 g, 1.72 ± 0.16 g, 2.02 ± 0.12 g, and 1.56 ± 0.13 g in FW, 1/4 SW, 1/3 SW, and 1/2 SW, respectively. The FW group showed a significantly higher growth rate ($P < 0.05$) than the SW groups. Growth in the 1/2 SW group was lowest, but not significantly different from those in other SW groups. The lower growth observed in the SW groups did not appear a results of osmotic water loss. Relatively higher water content was observed in fish of the SW groups.

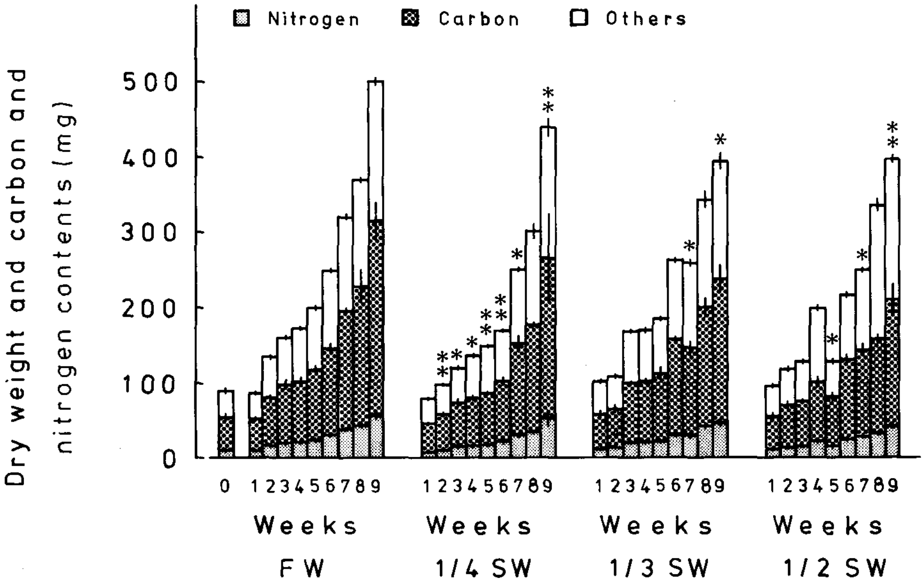

Fig. 1. Changes in dry body weight and body total carbon and nitrogen (means±S.E) of masu salmon fry reared in different salinities for 9 weeks (Exp. 1). The measurements were made with each 10 fish sampled randomly every week. * Significantly different from FW in dry weight ($P<0.05$). ** Significantly different from FW in dry weight ($P<0.01$).

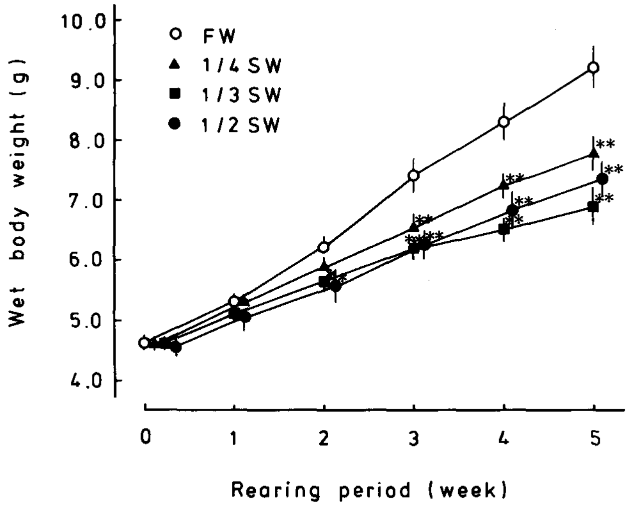

Fig. 2. Changes of body weight of masu salmon parr reared in different salinities for 5 weeks. The rearing started with similar sized fish which had adapted to each salinity for 3 months (Exp. 2). Values are means±S.E. of 20 fish. * Significantly different from FW ($P<0.05$). * Significantly different from FW ($P<0.01$).

When comparing their initial condition (83.02±0.17%) to the water content observed at the 9th week, the following results were noted. For the groups maintained in FW, 1/4 SW, 1/3 SW, and 1/2 SW their differences were 79.23±0.22%, 80.08±0.18%, 80.08±0.18%, and 80.67±0.11%, respectively. Impaired growth in diluted seawater was revealed through changes in dry body weight during the 9 week period (Fig. 1).

The growth curves of 20 parr measured for 5 successive weeks (Exp. 2) are shown in Fig. 2. The rearing experiment started with fish of similar sizes. These fish were acclimatized to each salinity for at least 3 months. The results again showed better growth to occur in FW than in SWs; a marked difference became apparent from the 3rd week ($P<0.01$). No clear differences were observed among the SW groups.

Body carbon and nitrogen contents

Changes of the body carbon and nitrogen content within the four study groups of Exp. 1 were investigated in relation to their different weight gains. Compared to their initial condition, body carbon at the 9th week increased 5.95-fold, 4.95-fold, 4.46-fold, and 3.93-fold in FW, 1/4 SW, 1/3 SW, and 1/2 SW, respectively (Fig. 1). The percentage of carbon was significantly lower in the SW groups than in the FW

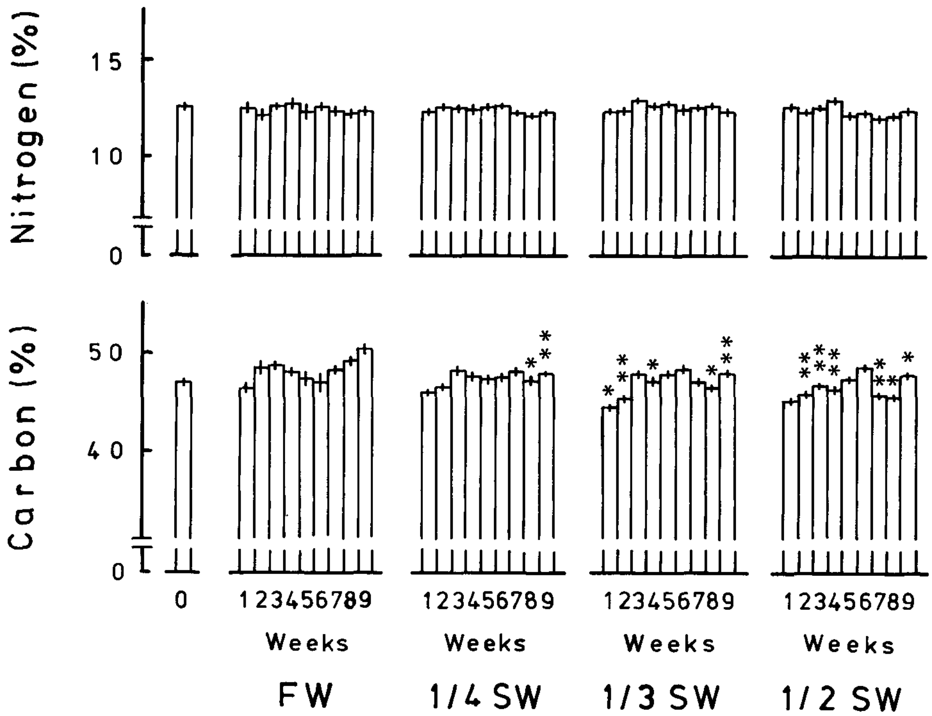

Fig. 3. Body carbon and nitrogen contents (%, means±S.E) in masu salmon fry reared in different salinities for 9 weeks (Exp. 1). * Significantly different from FW ($P<0.05$). ** Significantly different from FW ($P<0.01$).

Table 1. Comparison of the regressions between dry body weight (X) and body carbon content (Y) of masu salmon fry reared in different salinities for 9 weeks.

Medium	Sample size	Regression Y=AX−B	r
FW	33	Y=0.512270 X−0.579003	0.99915
1/4 SW	34	Y=0.483075*X−0.125416	0.99975
1/3 SW	32	Y=0.482826*X−0.208318	0.99865
1/2 SW	33	Y=0.480546*X−0.221103	0.99777

* Significantly different from FW ($P<0.05$).

group. This was particularly true for the later weeks. At the 9th week the following conditions were recorded; 50.37±0.37% carbon occurred in the FW group, 47.89±0.38%, 48.11±0.50%, and 47.88±0.82% were recorded in the 1/4, 1/3 and 1/2 SW groups (Fig. 3). Body nitrogen increased 5.39-fold, 4.74-fold, 4.23-fold and 3.81-fold, respectively (Fig. 1). No significant differences in the percentage of nitrogen were observed between the four groups at the 9th week (Fig. 3).

When regressed against the dry body weight of the separate groups, the amount of body carbon generated straight line regression, each with different slopes ($r>0.99$). The regression coefficients for the equations (Table 1) were significantly different ($P<0.05$) between the FW and the SW groups.

The ratio of carbon to nitrogen (C/N) tended to increase with growth in all the study groups. When compared to the initial ratio condition (3.72±0.05), the ratios at the 9th week in FW, 1/4 SW, 1/3 SW, and 1/2 SW were 4.10±0.07, 3.90±0.04, 3.94±0.05, and 3.85±0.04, respectively. The 1/4 and 1/2 SW groups showed significantly smaller values than that of the FW group ($P<0.05$).

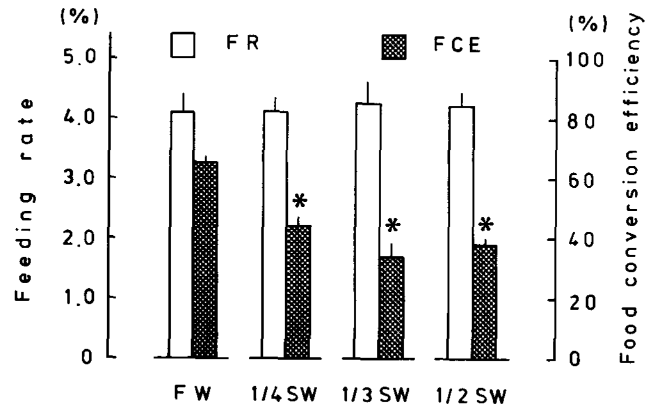

Fig. 4. Comparisons of the mean daily feeding rate (FR) and food conversion efficiency (FCE) in masu salmon parr adapted to different salinities (Exp. 2). Values are means±S.E. of 10 fish measured weekly during a 5 week rearing period. * Significantly different from FW ($P<0.01$).

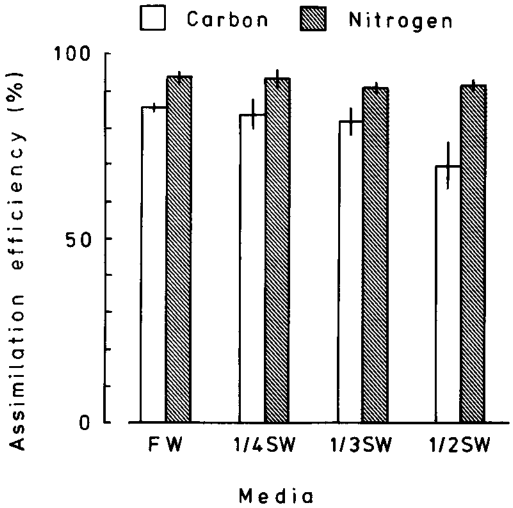

Fig. 5. Comparison of assimilation efficiencies of carbon and nitrogen in masu salmon parr adapted to different salinities (Exp. 3). Values are means±S.E. of 8-9 fish.

Food intake and conversion efficiency in parr

Food intake and food conversion efficiency were examined in parr reared in the different salinities (Exp. 2, Fig. 4). The averaged daily feeding rates in the four groups showed no clear differences.

The averaged food conversion efficiency in FW group showed a significantly larger value compared to those in the SW groups ($P<0.01$), among which there were no clear differences (Fig. 4).

Assimilation efficiencies of carbon and nitrogen in parr

The assimilation efficiencies of carbon and nitrogen in parr adapted for 8 months to the four different salinities (Exp. 3) ranged between 90.80 to 93.75%, and between 77.77 to 84.90%, respectively (Fig. 5). No significant differences in carbon or nitrogen were observed among the four groups. The assimilation efficiency of carbon in the 1/2 SW group tended to be lower compared with the other groups.

Discussion

In both fry and parr of masu salmon, the best growth was obtained in FW in spite of no obvious differences in the daily feeding rate between the FW and the SW groups. Since parr of this species spend a long freshwater life compared to other anadromous salmonid fishes, the results seem to show their inherent physiological preference to fresh water.

An obvious salinity effect was observed in the food conversion efficiency in parr. A higher salinity caused a lower food conversion efficiency accompanied with reduced growth. Varying results were generated from similar studies for a limited number of salmonids. For example, reduction of food conversion efficiency in high salinities was reported in Atlantic salmon parr (Shaw et al., 1975a, b) and chum salmon fry (Koshiishi, 1980), whereas the reversed was observed to occur in pre-smolt coho salmon (Otto, 1971) and yearling rainbow trout (Smith and Thorpe, 1976). These results in salmonids suggest that some metabolic processes are affected by a high salinity of the ambient water.

The body carbon content of masu salmon fry was lower in diluted sea water than in fresh water. However, the body nitrogen content was not different between the four salinity groups. This indicates that reduced growth rates of fry and parr in the diluted sea water solutions correlated with reduced carbon accumulation. This was caused by either enhanced carbon utilization, reduced carbon assimilation, or both. The assimilation efficiencies of both carbon and nitrogen were not significantly different between the four salinity groups. Therefore, the enhanced carbon utilization in the SW groups seems more likely. However, the carbon assimilation in the 1/2 SW group tented to show a larger depression compared to the other groups. The possibility that a high salinity affects the carbon assimilation can not be completely abandoned.

The accumulation of more carbon in the FW fish is considered to be caused by deposition of more fat, because carbohydrate storage is more difficult in fishes (Van Waarde, 1983). Daikoku et al. (1982) showed that total lipid content in the body of the guppy, *Poecillia reticulata*, was decreased by seawater adaptation. The standard or basal aerobic metabolism in fishes is almost completely covered by protein catabolism (Brett and Zala, 1975). However, when the metabolic rate increases, lipids become more important as an energy source (Kutty and Peer Mohamed, 1975). Zeitoun et al (1973) showed that a little increase of protein requirements occurred in rainbow trout juveniles in conjunction with increased osmotic concentrations of water. According to Jürss et al. (1985), a hyperosmotic salinity (20‰) tends to inhibit growth of rainbow trout by reducing the food conversion efficiency. However, a higher protein concentration in the diet can partly compensate for this effect. These results also suggest that the protein requirements differ in different salinities. The observed difference of the C/N ratio between the FW and SW groups could alternatively be explained as a result of larger protein consumption in salt water that caused a decrease of fat converted from protein. Further studies are needed to discuss the interaction between lipids and protein metabolisms in association with the body growth.

The plasma electrolyte concentrations were generally higher in the SW groups than in the FW group (data not shown). It is possible that before smoltification the fish require more energy to maintain their internal ionic and osmotic environment. This is because they possess physiological properties directed to freshwater adaptation. It is presumed that some physiological changes elicited by salt water adaptation may affect nutrient metabolism which, in turn, influences the overall growth of the fish.

In summary, the present results provided evidence for multiple effects of salinity on growth, digestion, and nutrient composition in masu salmon fry and parr. Further work using fish after smoltification is necessary for physiological analyses of the effects of different salinities on nutrient metabolism.

Acknowledgments

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