GROWTH OF PREMIGRATORY CHINOOK SALMON IN SEAWATER

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ABSTRACT

A potential demand exists in sea farming for premigratory juvenile Pacific salmon that have been acclimated to seawater. This paper reports experiments on growth of premigratory chinook salmon (*Oncorhynchus tshawytscha*) acclimated to water of 33‰ salinity and lower and describes a simple mathematical model to evaluate rate of growth. Although chinook salmon raised in these experiments experienced low mortality in water of high salinity, their growth slowed. Reasons for slow growth at high salinity are discussed.

Pacific salmon reproduce in fresh water, but only two species—pink (*Onchorhynchus gorbuscha*) and chum (*O. keta*) salmon—survive direct transfer as fry from fresh water to full-strength seawater (Weisbart, 1968). The ocean serves as the early nursery ground for these two species. The other species—including sockeye (*O. nerka*), coho (*O. kisutch*), and chinook (*O. tshawytscha*) salmon—require freshwater nursery areas.

Juvenile salmon undergo a period of adjustment when they first enter the sea in order to regulate water and salts in body fluids and tissues. This adjustive phase for chum salmon fry lasts about 30 hr and is characterized by an immediate depression of activity, increased concentration of salts in body fluids, and dehydration of body tissues (Houston, 1959). A slightly longer adjustive phase of 36 to 40 hr has been reported for yearling coho salmon (Conte et al., 1966; Miles and Smith, 1968).

Early exposure to water of low salinity can "trigger" the physiological adaptation to seawater of salmon species which typically remain in fresh water for several months as juveniles. Acclimation of premigratory young chinook salmon to water of 30‰ salinity by exposing them to gradual increments in salinity has been described by Wagner et al. (1969). Black (1951), Coche (1967), and Otto (1971) found also that coho salmon fry were better able to tolerate water of high salinity after having first been exposed to water of low salinity.

Other evidence suggests that the growth of juvenile coho and chinook salmon is influenced by salinity. Coho salmon fry were observed by Canagaratnam (1959) to grow faster in water of 12 to 18‰ than in fresh water. Otto (1971) reported faster growth of juvenile coho salmon at 5 and 10‰ salinity than at higher salinities or in fresh water. Bullivant (1961) found no significant difference in growth of juvenile chinook salmon in water of 0 and 18‰ salinity. However, Bullivant's fish grew more slowly at 35‰ salinity than at the two lower salinities.

This paper reports comparisons of the growth of juvenile chinook salmon raised in water ranging in salinity from 0 to 33‰. The experiments were conducted at the Oregon State University Port Orford Marine Research Laboratory, Curry County, Oreg.

GENERAL PROCEDURES

Two groups of chinook salmon used in these experiments were obtained as eyed eggs from the Fish Commission of Oregon, Elk River Hatchery, in winter 1969. Group I fish were divided into five subgroups of 200 each on February 24 (47 days after hatching). Group II fish were divided into six subgroups of 300 each on March 5 (18 days after hatching). Individual subgroups were introduced to water of

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Manuscript accepted August 1971.

increasing salinity according to the schedules outlined in Tables 1 and 2.

Both groups of fish received the Oregon Moist Pellet diet. The young salmon were fed five times daily beginning 30 days after hatching. After the fish had attained an average weight of 1 g, the frequency of feeding was reduced to three times daily. They were provided more food than they would consume at each feeding.

Fish were raised in 100-gal plywood tanks which were lined with fiber glass. Water was introduced to each tank at the rate of one-half gallon per min. Incoming fresh and salt water were premixed in head tanks to obtain desired salinities. Salinities were calculated from the proportions of premixed seawater and fresh water, and density of water in fish tanks was measured periodically with hydrometers to insure that salinities remained at their calculated levels.

The first experiment (Group I fish) began on January 8 with newly hatched alevins. Group I fish first received food on February 7, and selected subgroups were exposed to water of 9 or 17‰ salinity beginning on February 24. The five subgroups were first weighed on February 27. The experiment ended on May 7.

The second experiment (Group II fish) began on February 16 with newly hatched alevins. All six subgroups of fish were first exposed to water of 5 or 9‰ salinity on March 6 while still in the alevin stage, and they remained at these salinities for 18 days. The fish were first fed on March 18 and first weighed on April 7. The experiment ended on May 6.

Mortality of the 11 subgroups of fish during the test periods ranged from 0 to 6% of the original number of fish placed in the tanks. Even the maximum mortality (6%) was considered to have no appreciable effect on the comparisons of growth.

The average wet weight of fish in each subgroup was determined at 14-day intervals from random samples of 30 fish. Excess water was blotted from anesthetized fish before weighing. Fish were weighed separately in a flask containing a known weight of water and were returned to their respective tanks after each weighing.

TABLE 1.—Exposure of Group I chinook salmon to water of increasing salinity. Date of hatch—January 7, 1969.

Subgroup	Age (days after hatching) at which fish were placed in water[1] of given salinity		
	47	66	80
	‰	‰	‰
Ia	0	0	0
Ib	9	17	17
Ic	17	17	33
Id	17	24	33
Ie	9	24	33

[1] Temperature of incoming water averaged 10.7° C for fresh water and 10.8° C for seawater.

TABLE 2.—Exposure of Group II chinook salmon to water of increasing salinity. Date of hatch—February 15, 1969.

Subgroup	Age (days after hatching) at which fish were placed in water[1] of given salinity			
	18	36	54	66
	‰	‰	‰	‰
IIa	5	18	18	18
IIb	9	18	18	18
IIc	5	18	25	33
IId	5	18	25	33
IIe	9	18	25	33
IIf	9	18	25	33

[1] Temperature of incoming water averaged 11.9° C for fresh water and 12.0° C for seawater.

OBSERVATIONS ON GROWTH

Growth rate was calculated for each subgroup from the periodic measurements of wet weight. Growth was assumed to be exponential over each period considered, and a value for the daily increment in body weight, which can be expressed as a percent of body weight per day, was obtained from the expression

$$\frac{W_t}{W_0} = (1 + h)^t \qquad (1)$$

where W_t = weight at the end of the period,
W_0 = weight at the beginning of the period,
h = the compounded daily increment of body weight, and
t = days.

It is convenient to solve equation (1) for $(1 + h)$ by converting the terms to common logarithms and taking the antilog, i.e.

$$\log (1 + h) = \frac{\log W_t - \log W_0}{t} \; . \qquad (2)$$

To clarify the concept of daily increment of body weight, fish that can maintain an increase in body weight of 2.0 and 3.0% per day, for example, will double their weight in approximately 35 and 23 days, respectively.

Fish held in water of 0, 17, and 18‰ salinity grew at a faster rate and were heavier at the end of the experiments than fish of the same age transferred to water of 24, 25, and 33‰ salinity. The observed mean weight of fish in individual subgroups is plotted against age of fish in Figure 1.

Equation (2) can be rewritten in linear form to calculate statistics which are useful for making comparisons of rate of growth among test groups of fish. The linear model is:

$$(\log W_t - \log W_0) = \log (1 + h) \cdot t \tag{3}$$

Slope of the regression line is given as log $(1 + h)$. This model requires the regression line to pass through the origin since $(\log W_t - \log W_0) = 0$ at $t = 0$.

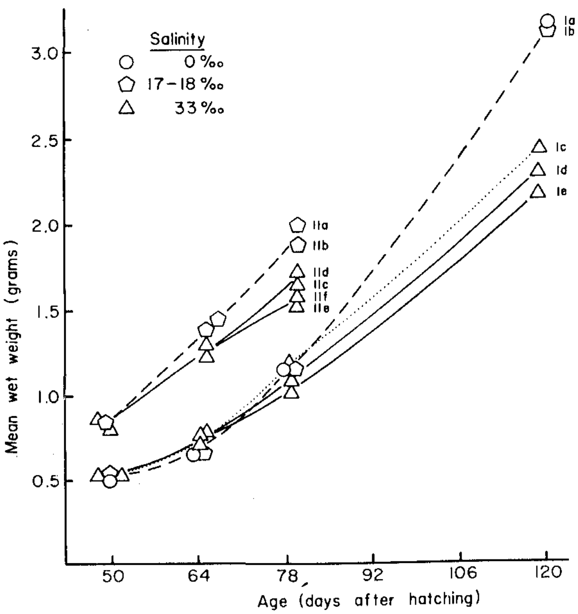

FIGURE 1.—Growth in weight of experimental subgroups of juvenile chinook salmon.

Group I fish were weighed on six occasions over a period of 70 days. We have estimated values of log $(1 + h)$ and h for each of the five subgroups of Group I by calculating the five regressions of $(\log W_t - \log W_0)$ on t. Because the weight of Group II fish was measured on only three occasions, we have not applied a similar analysis to the second experiment.

Application of regression methods to observations on Group I fish indicates that fish in fresh water and water of 17‰ salinity (Subgroups Ia and Ib) grew at a significantly faster rate than fish exposed to water of 33‰ salinity (subgroups Ic, Id, and Ie). Equations for the five subgroups are given in Table 3 along with the 95% confidence interval estimates of log $(1 + h)$ and the approximate confidence interval estimates of h. Figure 2 shows growth curves for the fastest (Subgroup Ia) and slowest (Subgroup Ie) growing fish. The periodic measurements of weight are plotted in Figure 2 to show their correspondence with the growth curves calculated by use of equation (1).

DISCUSSION

Chinook salmon used in these experiments were exposed to salt water much earlier in life than they normally would experience in nature. Group I fish were acclimated to high salinity (24‰) 66 days after hatching and 36 days after commencement of feeding. Group II fish were acclimated to high salinity (25‰) 54 days after hatching and 24 days after commencement of feeding. There were only 66 deaths (3.7%) among the 1,800 fish which had been exposed to salinities of 24, 25, and 33‰ for periods of 25 and 54 days.

The average rate of growth in water of high salinity (24‰ and above) varied between 2.1 and 2.3% increment in body weight per day. These fish doubled their weight in 30 to 33 days. The average rate of growth in water of low salinity (17‰ and 0‰) was 2.6 and 2.7% per day. These fish doubled their weight in 26 to 27 days.

Although these experiments demonstrate that juvenile chinook salmon can be acclimated to full-strength seawater in an early age, it is apparent that water of high salinity causes a reduced rate

TABLE 3.—Regression of ($\log W_t - \log W_0$) on time for Group I fish. The approximate 95% confidence interval estimates of h are taken from the confidence limits of $\log(1 + h)$.

Subgroup	Regression equation	95% confidence limits of $\log(1 + h)$	Approximate 95% confidence limits of h
Ia	$(\log W_t - \log W_0) = 0.01168t$	0.01168 ± 0.00099	2.7 ± 0.2%/day
Ib	$(\log W_t - \log W_0) = 0.01118t$	0.01118 ± 0.00084	2.6 ± 0.2%/day
Ic	$(\log W_t - \log W_0) = 0.01006t$	0.01006 ± 0.00087	2.3 ± 0.2%/day
Id	$(\log W_t - \log W_0) = 0.00945t$	0.00945 ± 0.00077	2.2 ± 0.2%/day
Ie	$(\log W_t - \log W_0) = 0.00880t$	0.00880 ± 0.00042	2.1 ± 0.1%/day

of growth. Reduced growth may come about in part because the young salmon expend more energy to maintain an osmotic homeostasis in water of high salinity than in water of low salinity.

Chinook salmon blood is isotonic with water of salinity between 10 and 13‰ (Coche, 1967). Houston (1959) thought that the increased energy demands for osmoregulation combined with possible inhibition of electrolyte-sensitive components of the neuromuscular system might contribute to reduced growth of young salmon in water of high salinity. There is the further possibility that endocrine systems which are associated with osmoregulation and growth in water of high salinity are not fully functional in premigratory juvenile salmon (Saunders and Henderson, 1970).

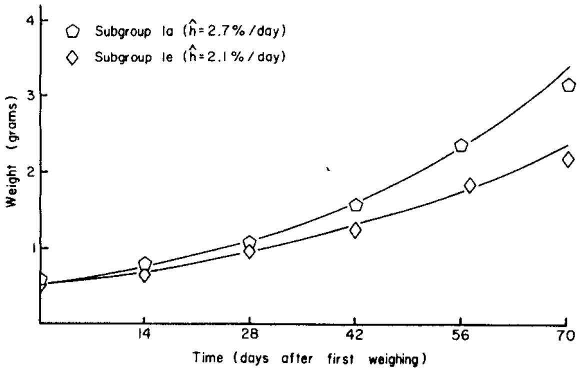

FIGURE 2.—Calculated growth curves for chinook salmon from subgroups Ia and Ie as calculated from equation (1). The observed growth is plotted to illustrate correspondence with calculated curves. "h" is the compounded daily increment of body weight.

The acclimation of premigratory chinook, coho, and sockeye salmon to seawater may find future applications in aquaculture. Possibilities include the early release of young salmon from hatcheries into open ocean pastures to reduce costs of feeding and handling and to increase hatchery production. Other possibilities are to pen young salmon in saltwater bays or estuaries (Garrison, 1965; Mahnken et al., 1970) or to place them in raceways receiving waste salt water from coastal thermal-electric stations (McNeil, 1970).

Large-scale aquaculture systems, similar to one under development in the Canadian Maritime Provinces (Gunstrom, 1970), would most likely benefit from early acclimation of juvenile salmon to seawater. The release of premigratory juvenile chinook salmon acclimated to seawater should also be tested at hatcheries equipped with seawater pumping systems. The effects of early acclimation on ocean survival is unknown, but the greater availability of food and space in the ocean than in freshwater conceivably would provide potential advantages to juvenile salmon which had been acclimated to seawater.

ACKNOWLEDGMENTS

Research on acclimation of juvenile salmon to seawater is administered by the Oregon State University Agricultural Experiment Station. Funds are provided by the National Oceanic and Atmospheric Administration's Sea Grant Program (Contract No. GH97) and National Marine Fisheries Service (Project No. AFC-55).

We wish to express our appreciation to Robert Courtright, Director of the Oregon State University Port Orford Marine Research Laboratory, for assistance and guidance with this project. We also wish to acknowledge helpful comments on the content and organization of this paper by Dr. Lauren R. Donaldson, University of Washington, Anthony J. Novotny, National Marine Fisheries Service, and Harry H. Wagner, Oregon State Game Commission.

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