

Growth of Wild Subyearling Fall Chinook Salmon in the Snake River

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Abstract.—Growth is an important determinant of life history development for juvenile anadromous salmonids. We collected juvenile fall chinook salmon *Oncorhynchus tshawytscha* in two reaches of the Snake River to describe growth in fork length (mm/d) and to test for a relation between growth and water temperature. Growth rate during shoreline rearing was significantly higher ($P = 0.003$) for parr in the warmer of these two reaches (grand means = 1.2 ± 0.04 and 1.0 ± 0.04 mm/d). Because smolts from the two reaches share a common, relatively warm downstream migration route, growth rates were similar between smolts from the two reaches ($P = 0.18$; grand means = 1.3 ± 0.04 and 1.4 ± 0.04 mm/d). By pooling data across reaches and life stages, we found that growth rate generally increased as water temperature increased ($N = 17$, $r^2 = 0.62$, $P = 0.0002$). The growth rates we observed were probably lower than for fall chinook salmon in a historical rearing area now inaccessible because of dams, but they were still rapid by comparison with those reported for ocean-type chinook salmon in presumably more productive brackish and saltwater habitats. We suggest that growth could be used as an index of the possible negative effects of hatchery supplementation or water management actions that decrease temperature during seaward migration.

The level of growth sustained by young, anadromous salmonids plays a role in life history development. Some researchers maintain that the age at seaward migration decreases as the water temperature during rearing increases because growth increases (Thorpe 1989; Metcalfe and Thorpe 1990; Taylor 1990; Beckman and Dickhoff 1998). One measure of the potential of a stream to provide the growth necessary to initiate seaward migration is called growth opportunity (Thorpe 1989). Streams along the Pacific coast of North America with low-growth opportunity tend to produce juvenile chinook salmon *Oncorhynchus tshawytscha* that migrate seaward as yearlings (a stream-type life history), whereas streams with high-growth opportunity produce juveniles that

migrate seaward as subyearlings (an ocean-type life history; Healey 1991; Taylor 1990).

The majority of wild, ocean-type chinook salmon that inhabit the Snake River from the Hells Canyon Dam to the upper end of Lower Granite Reservoir (Figure 1) are fall chinook salmon that migrate seaward as subyearlings during spring and summer (Marshall et al. 2000; Connor et al. 2001a). A small number of the offspring of wild, stream-type spring and summer chinook salmon disperse long distances from natal streams into the Snake River where they rear, grow rapidly, and then migrate seaward 1 year earlier than normal (Connor et al. 2001a, 2001b). For simplicity, we refer to the wild, subyearling chinook salmon that inhabit the shorelines of the Snake River during spring and summer as fall chinook salmon.

The upper reach (Figure 1) of the Snake River is warmer than the lower reach during winter through spring when fall chinook salmon eggs are incubating, and during spring when juveniles are rearing and starting seaward movement (Connor et al. 2002). Consequently, the life history of young fall chinook salmon progresses on an earlier time schedule in the upper reach of the Snake River than in the lower reach. Assuming life stage progression was a crude measure of growth, Connor et al. (2002) concluded that relatively warmer water temperatures and higher growth opportunity in the upper reach of the Snake River explained the differences in life stage development they observed.

In this management brief, we expand on the findings of Connor et al. (2002) by estimating and comparing the growth in fork length for fall chinook salmon in the upper and lower reaches of the Snake River. We also test for a relation between water temperature and growth in fork length.

Methods

Water temperature.—Data were collected in the Snake River from 1995 to 1999 using hourly recording thermographs stationed known distances (river kilometers [rkm]) upstream from the river

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Received December 19, 2001; accepted July 22, 2002

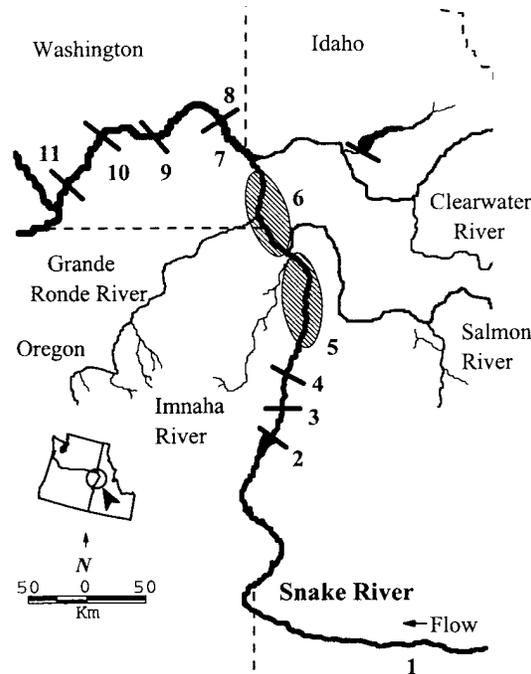


FIGURE 1.—Locations of the upper and lower reaches of the Snake River where adult fall chinook salmon spawn and their offspring were captured by using a beach seine (cross hatched ellipses), and Lower Granite and Little Goose dams and reservoirs. The locations are as follows: 1 = the historical spawning and rearing area near Marsing, Idaho; 2 = Brownlee Dam; 3 = Oxbow Dam; 4 = Hells Canyon Dam; 5 = Snake River upper reach; 6 = Snake River lower reach; 7 = Lower Granite Reservoir; 8 = Lower Granite Dam; 9 = Little Goose Dam; 10 = Lower Monumental Dam; and 11 = Ice Harbor Dam.

mouth. Thermographs were typically stationed offshore in relatively deep water to ensure submergence at all flow levels. Thermograph locations in the Snake River varied by year and flow level. Data were collected at rkm 383, rkm 369, rkm 325, and rkm 303 in the upper reach of the Snake River, and at rkm 290, rkm 287, rkm 274, rkm 265, and rkm 251 in the lower reach of the Snake River. No temperature data were available for the lower reach of the Snake River in 1996 or for either reach in 2000 because of thermograph failure.

The daily mean water temperature was calculated from thermograph output. Data for two or more thermographs in the Snake River were averaged within a reach to provide one daily mean water temperature value. Missing daily mean values were predicted by using ordinary least-squares regression ($r^2 = 0.94\text{--}0.99$). For example, missing

daily mean values were predicted for 30 June to 7 July 1999 by using a regression model fit from the observed day of the year (e.g., 1 January = 1) and daily mean water temperatures collected 3 weeks before 30 June and 3 weeks after 7 July 1999.

Daily mean water temperature data were also collected in the tailrace of Lower Granite Dam (Figure 1) from 1995 to 1998 (U. S. Army Corps of Engineers, Walla Walla District, unpublished data). We used data collected in the forebay of Lower Granite Dam when tailrace data were unavailable.

Two water temperature indices were calculated from the daily mean water temperature data. Mean spring (20 March to 20 June) water temperatures in each reach of the Snake River were used as an index of growth conditions during shoreline rearing. Mean spring–summer (20 March to 21 September) water temperatures at Lower Granite Dam were used as an index of growth conditions during seaward migration.

Growth.—Fall chinook salmon were captured in the upper and lower reaches of the Snake River from 1992 to 2000 (Connor et al. 2002). We analyzed data collected on fall chinook salmon from 1995 to 2000 because data sets were complete for both the upper and lower reaches of the Snake River. **Sampling** was conducted using a beach seine (Connor et al. 1998). **Beach seining typically started in April soon after fry began emerging from the gravel**, and was conducted 1 d/week at permanent stations in the upper reach of the Snake River and 2 d/week in the lower reach. Once a majority of fish were at least 60 mm fork length (FL), additional stations were sampled in each reach for three consecutive weeks. **Sampling was discontinued in June or July when the majority of fish had moved into Lower Granite Reservoir.**

Passive integrated transponder (PIT) tags (Prentice et al. 1990a) were inserted into fall chinook salmon parr 60 mm FL and longer (Connor et al. 1998). Tagged parr were released at the collection site after a 15-min recovery period. Some of these PIT-tagged parr were recaptured at beach seining stations up to 46 d after initial capture. We calculated growth in fork length (mm/d) for parr as fork length at recapture minus fork length at initial capture divided by the number of days between initial capture and recapture.

Some of the PIT-tagged fish were detected as smolts as they passed downstream in the juvenile bypass systems of Lower Granite and Little Goose dams (Figure 1), which were equipped with PIT-

TABLE 1.—Mean spring water temperatures ($^{\circ}\text{C}$) measured in the upper and lower reaches of the Snake River and mean spring–summer water temperatures measured at Lower Granite Dam, 1995–1999. Grand mean water temperatures \pm SE are also given.

Year and mean	Snake River		Lower Granite Reservoir
	Upper reach	Lower reach	
1995	11.8	10.9	15.0
1996	12.7		15.3
1997	12.4	11.2	14.4
1998	12.0	11.5	15.5
1999	12.3	10.6	
Grand means	12.0 \pm 0.2	11.1 \pm 0.2	15.1 \pm 0.2

tag monitors (Matthews et al. 1977; Prentice et al. 1990b). We recaptured a subsample of the detected smolts using a diversion device (Downing et al. 2001) located in the fish bypass system of Lower Granite Dam in 1995, and Little Goose Dam from 1996 to 1998. We calculated the growth rate for smolts using the equation described for parr.

Statistical analyses.—We calculated grand mean growth rates by reach and life stage event. For example, grand mean growth rate for parr in the upper reach of the Snake River was calculated as the mean of the six mean annual growth rates for parr in the upper reach. The grand mean growth rate for the parr life stage was calculated as the mean of the 12 mean annual growth rates for parr of both reaches.

We used analysis of variance (ANOVA; $\alpha = 0.05$) with a randomized block design blocking on year to test three null hypotheses: (1) there is no difference in the growth rates of parr in the upper and lower reaches of the Snake River; (2) there is no difference in the growth rates of smolts originating from the upper and lower reaches of the Snake River; and (3) there is no difference in the growth rates of parr and smolts. Tukey-type pairwise comparisons ($\alpha = 0.05$) were made to test for significant differences between grand means.

We used ordinary least-squares regression ($\alpha = 0.05$) to test the relation between growth rate and water temperature. Mean growth rates were pooled across reaches and life stage events to provide the dependent variable in this regression. Spring water temperature was the independent variable paired with parr growth rates. Spring–summer water temperature was the independent variable paired with smolt growth rates.

Results

The water temperatures during spring were warmer in the upper reach of the Snake River than

TABLE 2.—Mean growth rates (mm/d \pm SD) for wild fall chinook salmon parr in the upper and lower reaches of the Snake River, 1995–2000. Sample sizes are in parentheses. The grand mean \pm SE growth rates were significantly different ($P = 0.003$).

Year and mean	Mean growth rate	
	Upper reach	Lower reach
1995	1.2 \pm 0.3 (148)	1.0 \pm 0.3 (78)
1996	1.1 \pm 0.2 (19)	0.9 \pm 0.4 (49)
1997	1.3 \pm 0.2 (20)	0.8 \pm 0.3 (80)
1998	1.1 \pm 0.3 (112)	0.9 \pm 0.3 (129)
1999	1.3 \pm 0.3 (171)	1.1 \pm 0.3 (92)
2000	1.3 \pm 0.2 (90)	1.0 \pm 0.3 (40)
Grand means	1.2 \pm 0.04	1.0 \pm 0.04

in the lower reach (Table 1). Water temperatures measured at Lower Granite Dam during the spring–summer period were warmer than those measured in both reaches of the Snake River during spring (Table 1).

During the 6 years, PIT tags were inserted into 7,506 fall chinook salmon parr. Of these, 1,028 were recaptured (Table 2). Approximately 80% of the parr used to calculate growth rates were tagged and then recaptured during the spring. Fork length of PIT-tagged parr during shoreline rearing averaged 69 ± 8 mm (SD). Growth rate was significantly higher ($P = 0.003$) for parr in the upper reach than for parr in the lower reach (Table 2).

In all, 677 PIT-tagged smolts were recaptured at both Lower Granite and Little Goose dams (Table 3). Approximately 99% of these recaptured smolts passed the dams during the spring and summer. The fork length of recaptured smolts averaged 142 ± 17 mm (SD). The reach of the Snake River where smolts were initially captured and PIT tagged had no effect on growth rate ($P = 0.18$; Table 3).

Grand mean growth rates were 1.1 ± 0.05 mm/d (SE) and 1.3 ± 0.03 mm/d (SE) for parr and smolts, respectively. Parr growth rates were sig-

TABLE 3.—Growth rates (mm/d \pm SD) for wild fall chinook salmon smolts originating from the upper and lower reaches of the Snake River, 1995–1998. Samples sizes are in parentheses. The grand mean \pm SE growth rates were not significantly different ($P = 0.18$).

Year and mean	Mean growth rate	
	Upper reach	Lower reach
1995	1.3 \pm 0.2 (132)	1.4 \pm 0.2 (156)
1996	1.3 \pm 0.1 (9)	1.3 \pm 0.2 (48)
1997	1.2 \pm 0.1 (19)	1.3 \pm 0.2 (62)
1998	1.4 \pm 0.1 (105)	1.4 \pm 0.2 (146)
Grand means	1.3 \pm 0.04	1.4 \pm 0.03

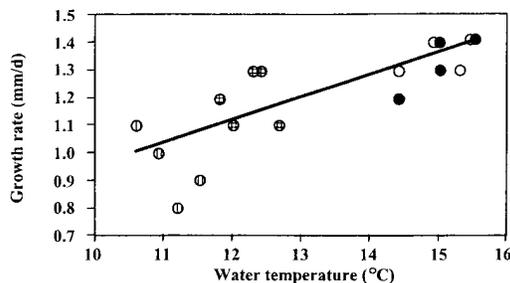


FIGURE 2—The relation between Snake River fall chinook salmon parr (upper reach, vertical and horizontal lines; lower reach, vertical lines) and smolt (upper reach, solid circles; lower reach, open circles) growth rates and water temperature. The regression equation given as: growth rate = $0.184 + 0.077 \times \text{temperature}$ ($N = 17$, $r^2 = 0.62$, $P = 0.0002$). Data for the regression are given in Tables 1, 2, and 3.

nificantly lower ($P = 0.002$) than smolt growth rates.

Growth rate was positively correlated with water temperature ($N = 17$, $r^2 = 0.62$, $P = 0.0002$; Figure 2).

Discussion

Our study was subject to several limitations. Sample sizes of parr and smolts used to calculate growth rates were small in some cases because of low abundance, difficult sampling conditions, and logistical constraints imposed by the dams. We did not analyze all the factors that affect the growth of juvenile anadromous salmonids. Water temperature was a logical variable to study because it regulates the growth of young fall chinook salmon (e.g., Banks et al. 1971; Marine 1997). We used thermograph data collected offshore in the Snake River and at Lower Granite Dam as indices of the water temperatures experienced by young fall chinook salmon. The actual water temperatures experienced by parr during rearing and smolts during seaward migration were not completely represented by these indices. Local water temperature data collected where fall chinook salmon rear and pass downstream would have improved our regression analysis, but such data would be difficult to collect and were not available from 1995 to 2000.

In spite of these limitations, we found that differences in fall chinook salmon growth observed between reaches and life stage events could be partly explained by water temperature as proposed by Connor et al. (2002). The upper reach of the Snake River fostered higher rates of growth for

parr than the lower reach partly because it was warmer. Parr growth was slower than smolt growth partly because water temperatures during shoreline rearing were cooler than during seaward migration. The smolts originating from the upper and lower reaches of the Snake River grew at approximately the same rates partly because they shared a common, relatively warm migration environment.

Numerous dams were constructed along the Snake River during the 20th century that reduced the potential of the Snake River to support fall chinook salmon. Brownlee, Oxbow, and Hells Canyon dams eliminated spawning and rearing in the most productive habitat near Marsing, Idaho (Connor et al. 2002; Figure 1). There is no historical information on the growth rate of Snake River fall chinook salmon, but water temperatures were warmer near Marsing than presently observed in the upper and lower reaches of the Snake River. Spring water temperatures in the Snake River near Marsing averaged 14.2°C in 1961, 14.4°C in 1962, and 13.5°C in 1963 (Connor et al. 2002), which were the last 3 years this reach of river supported fall chinook salmon. Based on our regression equation, these temperatures would result in growth rates of 1.3, 1.3, and 1.2 mm/d compared with the average rates of 1.2 and 1.0 mm/d we observed in the upper and lower reaches, respectively, of the Snake River from 1995 to 2000. Fall chinook salmon parr probably grow more slowly in the upper and lower reaches of the Snake River than they did in the relatively warmer water of the Snake River near Marsing.

Although parr in present-day rearing areas might grow more slowly than their historical counterparts, they still exhibit rapid growth by comparison with those of other present-day stocks of ocean-type chinook salmon. Growth rates reported for juvenile, ocean-type chinook salmon in presumably productive brackish and saltwater habitat along the Pacific coast of North America ranged from 0.4 to 1.3 mm/d (Healey 1980; Kjelson et al. 1982; Buckman and Ewing 1982). The rapid growth we observed occurred during the critical spring time period associated with successful smoltification (Dickhoff et al. 1997; Beckman and Dickhoff 1998), and it likely contributes to the maintenance of an ocean-type life history by young Snake River fall chinook salmon.

We suggest that our results have an important implication for the management of Snake River fall chinook salmon listed for protection under the Endangered Species Act (NMFS 1992). Manage-

ment activities with the potential to decrease growth rates below 1995–2000 levels should be monitored. Releasing large numbers of hatchery fall chinook salmon into the Snake River to supplement wild production might eventually reduce growth through intraspecific competition (e.g., McMichael et al. 1997). Releasing cool water from reservoirs upstream of Lower Granite Reservoir to improve the downstream migration rate and survival of fall chinook salmon smolts (e.g., Connor et al. 1998) might reduce growth by reducing water temperature. Growth rate could be used to monitor the effects of these two recovery measures on the well-being of wild fall chinook salmon in the Snake River basin.

Acknowledgments

Employees of the U.S. Fish and Wildlife Service, Idaho Fishery Resource Office, and Idaho Power Company collected data. Personnel of the Pacific States Marine Fisheries Commission maintained the PIT-tag database. We express special thanks to T. Andersen, S. Bradbury, C. Eaton, P. Groves, A. Garcia, S. Downing, D. Marvin, R. Nelle, D. Rondorf, J. Sneva, D. Steele, C. Stein, K. Tiffan, P. Verhey, and R. Waitt. Early drafts of the manuscript were reviewed by D. Bennett, T. Bjornn, P. Bigelow, J. Congleton, R. Graves, and K. Steinhorst. The editor, an associate editor, David Fast, and two anonymous reviewers improved the manuscript. Funding was provided by the rate payers of the Bonneville Power Administration through contract number DE-AI79-91BP21708 administered by D. Docherty and D. Praest.

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