Effects of Summer Flow Augmentation on the Migratory Behavior and Survival of Juvenile Snake River Fall Chinook Salmon

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EFFECTS OF SUMMER FLOW AUGMENATION ON THE MIGRATORY BEHAVIOR AND SURVIVAL OF JUVENILE SNAKE RIVER FALL CHINOOK SALMON

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EFFECTS OF SUMMER FLOW AUGMENATION ON THE MIGRATORY BEHAVIOR AND SURVIVAL OF JUVENILE SNAKE RIVER FALL CHINOOK SALMON

ANNUAL REPORT 2002

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Table of Contents

Executive Summary

This report summarizes results of research activities conducted in 2002 and years previous to aid in the management and recovery of fall chinook salmon *Oncorhynchus tshawytscha* in the Columbia River basin. The report is divided into self-standing chapters. For detailed summaries, we refer the reader to the abstracts given on the second page of each chapter. The Annual Reporting section includes information provided to fishery managers in-season and post-season, and it contains a detailed summary of life history and survival statistics on wild Snake River fall chinook salmon juveniles for the years 1992-2002. Peer-review publication remains a high priority of this research project, and it insures that our work meets high scientific standards. The Bibliography of Published Journal Articles section provides citations for peer-reviewed papers co-authored by personnel of project 199102900 that were written or published from 1998 to 2003.

Acknowledgments

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CHAPTER ONE

Data and Analyses on Juvenile Snake River Fall Chinook Salmon 1992-2002

by

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Abstract.—In this chapter, in-season and post-season data are summarized as follows. Early life history timing and growth of wild Snake River subyearling fall chinook salmon in 2002 is described and compared to other years. A method for increasing the accuracy and precision of passage forecasts is developed. The efficacy of summer flow augmentation during 2002 is assessed with focus on the how saving some Dworshak Reservoir water for release in September affected survival of Snake River subyearlings. In 2002, fry emergence occurred earlier in the upper reach than in the lower reach of the Snake River based on time of fry presence. Fry emergence in 2002 in the upper and lower reaches was similar to other years except emergence timing was more protracted. Shoreline rearing by parr during 2002 occurred earlier in the upper reach than in the lower reach of the Snake River. Rearing timing in the upper and lower reaches of the Snake River in 2002 was a little earlier than during other years and was more protracted. Mean growth rate was higher for parr in the upper reach than in the lower reach of the Snake River. Growth rates in 2002 were rapid and similar to other years. Passage of smolts from the upper reach was earlier than that of smolts in the lower reach. Overall smolt passage was slightly earlier than normal. The revised forecast method performed better than the original forecast method. Modeling results indicated that releasing Dworshak Reservoir in September exposed Snake River juveniles to lower flows and warmer temperatures than would have been the case if all the water had been released in July and August. Survival of Snake River subyearlings was reduced slightly by saving some Dworshak Reservoir water for release in September, but this reduction was not statistically significant.

Introduction

Wild subyearling Snake River fall chinook salmon *Oncorhynchus tshawytscha* juveniles listed for protection under the Endangered Species Act (NMFS 1992) typically migrate seaward in the lower Snake River during late spring and summer when flow is low (Connor et al. 2002, 2003a). During recovery planning, it was determined that summer water conditions in Lower Granite Reservoir (Figure 1) were unfavorable for survival (NMFS 1995). In July of 1992, a small volume of stored reservoir water was released to increase flow and decrease water temperature in Lower Granite Reservoir. Thereafter, larger volumes of water were released annually between 5 July and 31 August from Dworshak Reservoir (Figure 1) and U.S. Bureau of Reclamation reservoirs in southern Idaho. Releasing this stored water is called summer flow augmentation.

There is not enough stored reservoir water available to optimize passage conditions in Lower Granite Reservoir (Figure 1) throughout the 5 July to 31 August time period. Consequently fish and water managers meet in the forums of the Fish Passage Advisory Committee (FPAC) and the Technical Management Team (TMT) to formulate a management plan. A 2000 decision by the State of Idaho to deny waivers for exceeding dissolved gas levels above 110% in the tailrace of Dworshak Dam reduced the complexity of the water management plan and the ability of fish and water managers to shape summer flows. To avoid exceeding this “gas cap,” the maximum flow of water that can be released from Dworshak Dam was reduced to approximately 397 m^3/s. Thus in some years, the full 1.2 million acre feet of stored water in Dworshak Reservoir available for summer flow augmentation cannot be released by the end of August. In 2002, fishery managers decided to release less than 397 m^3/s during periods in early July and late August so that flows could be augmented during the first 10 d of September. The assumed benefits of September releases were increased survival of juvenile fall chinook salmon that hadn’t passed Lower Granite Dam by the end of August, and increased survival of immigrating adult fall chinook salmon and steelhead *O. mykiss*. The mechanism for this increased survival was the prevention of rapid warming in Lower Granite Reservoir that can occur when summer flow augmentation is discontinued at the end of August.

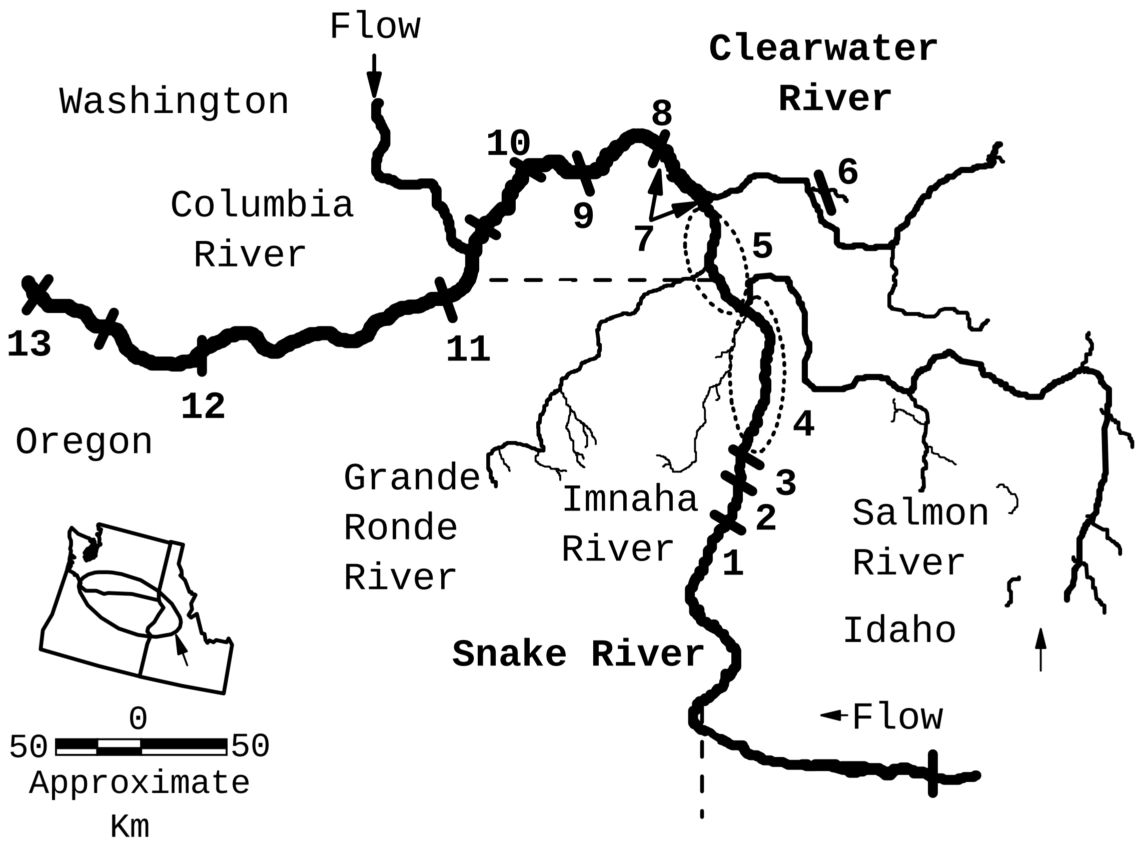

Figure 1.—Locations of the upper and lower reaches of the Snake River where adult fall chinook salmon spawn and their offspring were captured by using a beach seine (cross-hatched ellipses) and dams where PIT-tagged smolts were detected during seaward migration. The locations are as follows: 1 = Brownlee Reservoir; 2 = Oxbow Reservoir; 3 = Hells Canyon Reservoir; 4 = Snake River upper reach; 5 = Snake River lower reach; 6 = Dworshak Reservoir; 7 = Lower Granite Reservoir; 8 = Lower Granite Dam; 9 = Little Goose Dam; 10 = Lower Monumental Dam; 11 = McNary Dam; 12 = John Day Dam; and 13 = Bonneville Dam.

Since 1992, personnel of project 199102900 have been assisting fish and water managers during planning, implementation, monitoring, and evaluation of summer flow augmentation. Much of the data provided to fishery managers are in the form of records compiled on wild fall chinook salmon juveniles that were tagged with Passive Integrated Transponder (PIT) tags (Prentice et al. 1990b). The PIT-tag data are provided weekly each year via the PIT-tag Information System, where in turn, it is downloaded, analyzed, and posted in real time on Internet services (e.g., DART; Program RealTime, Burgess and Skalski 2001) to allow managers to track the progress of the smolt migration.

In 2002, personnel of project 199102900 provided members of the FPAC and TMT an in-season update in early July that included: 1) a summary of 2002 catch and tagging data; 2) a comparison of observed time of fry and parr presence among the years 1992 to 2002; 3) a comparison of parr growth among the years 1992 to 2002; and 4) a forecast of passage at Lower Granite Dam (Figure 1) for wild fall chinook salmon PIT tagged in the Snake River. The TMT was also provided with a post-season briefing in late October, 2002 that included a review of the factors that affect migration behavior and survival of fall chinook salmon juveniles.

In this chapter, in-season and post-season data collected in 2002 are summarized as follows. Early life history timing and growth in 2002 is described and compared to other years. A method for increasing the accuracy and precision of passage forecasts is developed. The efficacy of summer flow augmentation during 2002 is assessed with focus on the survival effects of five scenarios including saving some Dworshak Reservoir water for release in September.

Methods

Data collection.—The Snake River can be divided into two reaches based on differences in water temperature (Connor et al. 2002). The upper reach extends from the Salmon River confluence to Hells Canyon Dam, and the lower reach extends from the upper end of Lower Granite Reservoir to the Salmon River confluence (Figure 1). Juvenile fall chinook salmon were captured in these two reaches using a beach seine (Connor et al. 1998). Sampling began in the upstream reach in 1995, and in the lower reach in 1992. Beach seining typically started in April soon after fry began emerging from the gravel, and was conducted weekly at permanent stations within each reach. From 1992 to 1999, additional non-permanent stations were sampled for three consecutive weeks once a majority of fish was at least 60 mm fork length. Only permanent stations were sampled after 1999. We discontinued all sampling in June or July when the majority of fish had moved into Lower Granite Reservoir or to points further downstream.

Field personnel inserted PIT tags into parr 60-mm fork length and longer (Connor et al. 1998). Tagged parr were released at the collection site after a 15-min recovery period. Some of the PIT-tagged fish were detected as smolts as they passed downstream in the juvenile bypass systems of dams equipped with PIT-tag monitors (Matthews et al. 1977; Prentice et al. 1990a; Figure 1). Operation schedules for the fish bypass systems varied by dam and year. Most of the detections were in the fish bypass systems of Lower Granite, Little Goose, and Lower Monumental dams operated from early April to early November, and at McNary Dam (Figure 1) operated from early April to early December.

Starting in 1999, non-fin clipped hatchery subyearling fall chinook salmon were released into the Snake River by personnel of the Nez Perce Tribe to supplement wild production. Field personnel subjectively identified these fish in the beach seine catch based on body morphology. Hatchery fish were more slender and appeared to have larger eyes than wild fish. Fish judged to be of hatchery-origin were released back to the river and were not included in analyses.

Accuracy of origin classification.—To assess how well field personnel distinguished between hatchery and wild fall chinook salmon juveniles, every fish was examined for wounds and scars after removing it from the seine. The origin of each recaptured PIT-tagged fish was judged, and then the fish was scanned for its unique tag code. The actual origin was traced using the unique tag code. Within-origin (hatchery and wild, separately) and across-origin (hatchery and wild, combined) classification accuracy were calculated. Within-origin classification accuracy was the number of correct classifications divided by the number of recaptured hatchery or wild fish. Across-origin classification accuracy was calculated as the weighted average of the within-run classification accuracy estimates.

Early life history and growth.—Capture dates of wild fall chinook salmon smaller than 45-mm fork length were used to describe time of presence for newly emergent fry (hereafter emergence timing). Capture dates for fish 45-mm fork length and longer to describe time of presence for fall chinook salmon parr (hereafter, rearing timing). All capture dates were adjusted to Sunday’s date the week of sampling to account for differences in day of sampling between the upper and lower reaches of the Snake

River. For example, a capture date of 2 May, 1993 (Sunday) was reported for fry and parr collected from 4 May to 6 May (Tuesday to Thursday).

Absolute growth rate (mm/d) during shoreline rearing was calculated using length data from PIT-tagged parr recaptured by beach seine after initial capture and tagging (e.g., Connor and Burge 2003). Absolute growth rate was calculated as: fork length at recapture minus fork length at initial capture divided by the number of days between initial capture and recapture.

The PIT-tag detection data collect at Lower Granite Dam were used to represent the onset of active seaward migration (e.g., Connor et al. 2003a) by subyearling smolts.

Passage forecasting.—See Connor et al. (2000) for a description of the original forecasting method developed by using data collected during 1993-1998. As foreseen by Connor et al. (2000), only two of the forecasts made during 1999-2002 were accurate (i.e., observed and forecasted passage were similar) and precise (i.e., observed passage was within the 90% forecast intervals). In this report, several changes in the original forecasting method were made to increase forecast accuracy and precision.

A new survival model was developed. This model was a discriminant function fit from data collected in 1994, 1995, and 1999. These years were selected because survival ranged widely from a low of approximately 25% (1994) to a high of 71% in 1999 (Connor et al. 1998, 2003b). In contrast to the original method that selected the final discriminant function based on accuracy predicting detected PIT-tagged fish, the final discriminant function in the revised analysis was based on how well the function predicted the number of survivors. For 1994 and 1995, the number of survivors was estimated as the number of fish tagged multiplied by detection rate first divided by an assumed value of fish guidance efficiency. In 1999, the number of survivors was estimated as the number of fish tagged multiplied by survival probability (Cormack 1964; Skalski et al. 1998). Accuracy was calculated on an annual basis by taking the absolute difference between the number of survivors predicted by the discriminant analysis function and the estimated number of survivors and then dividing this difference by the estimated number of survivors. The annual values of accuracy for 1994, 1995, and 1999 were averaged. The final discriminant function had the highest average value of accuracy.

A rate of seaward movement model was developed. This model was a multiple regression equation fit from the 1994, 1995, and 1999 data to predict rate of seaward movement measured from release in the Snake River to passage at Lower Granite Dam. These years were selected because rate of seaward movement ranged widely (1994 median, 1.5 km/d; 1999 median 3.3 km/d). The rate of seaward movement model replaced the passage date model used in the original forecasting method of Connor et al. (2000). The fourth change in the forecasting method was to eliminate the use of the adjustment factor (see Connor et al. 2000).

The original and revised forecast methods were applied to data collected in 1997 and during 2000-2002. These years were selected because they were not used to fit survival or passage date models by Connor et al. (2000), or to fit the survival or rate of seaward models in the revised method. Forecast performance was assessed in two ways. First, the absolute difference between observed and forecasted daily cumulative (%) passage during 1 July-31 August was calculated. The average of these daily differences was named the mean daily error rate. Mean daily error rates calculated for July and August were used to assess forecast accuracy. The number of days the forecast and its 90% intervals failed to contain observed passage during July and August was used to assess precision.

Survival.—See Connor et al. (2003b) for details on survival analyses. The annual samples of PIT-tagged fall chinook salmon were divided into four sequential within-year release groups referred to as “cohorts.” The single release-recapture model (Cormack 1964; Skalski et al. 1998) was used to estimate survival probability to the tailrace of Lower Granite Dam for each cohort.

The efficacy of flow augmentation.-The first step in this analysis was to fit an ordinary-least squares multiple regression model for predicting cohort survival to the tailrace of Lower Granite Dam. The survival probabilities for the 1998-2002 cohorts (N = 20) provided values for the dependent variable. The predictor variables were the median day of year of release, mean fork length (mm) at release, a flow (m^3/s) exposure index calculated as the mean flow measured at Lower Granite Dam during the period when the majority of smolts passed the dam, and a water temperature ($^{\circ}C$) exposure index calculated as the mean temperature measured in the tailrace of Lower Granite Dam during the period when the majority of smolts passed the dam. See Connor et al. (2003b) for exposure index calculations.

The regression model fitting procedure was similar to that of Connor et al. (2003b). The final model selected for predicting survival had a Mallow’s Cp score most similar to the number of model parameters (e.g., B_o, B_1, B_3 = 3), the lowest AIC value, and a high R^2 value. The final model was also selected to avoid collinear variables. Each variable was regressed individually against survival to calculate a bivariate regression coefficient ($\pm$SE). The bivariate regression coefficient and SE were then compared to one calculated for the variable when entered into a multiple regression equation. Sign changes in the regression coefficients and marked inflation of the SEs were indicative of problematic multicollinearity. Models with problematic collinearity were not selected as the final model. In contrast to Connor et al. (2003b), regression coefficients were not formally tested against a value of zero. The *P* values from t-tests on the regression coefficients were interpreted in terms of the probability of the coefficient not being different from zero.

The second step in the analysis was to devise five flow augmentation scenarios for survival modeling. The first scenario is called the baseline scenario, this scenario represented conditions at Lower Granite Dam had no flow augmentation from either Dworshak or USBR projects been implemented. The second scenario is called the Dworshak Scenario. In the Dworshak scenario, the observed volume of water (including flow augmentation water) was released from Dworshak Reservoir from 9 July to 10 September but no flow augmentation water was released from USBR projects. The third scenario is called the USBR scenario. In the USBR scenario, flow augmentation water was released from USBR projects from 1 July to 31 August, but no flow augmentation water was released from Dworshak Reservoir. The fourth scenario is called the September scenario and it was actually observed in 2002. In the September Scenario, flow augmentation from Dworshak Reservoir began on 9 July and ended on 10 September and flow augmentation water was released from USBR projects from 1 July to 31 August. The fifth scenario is called the July-August scenario. In this scenario, the majority of the 1.2 million acre-feet of stored water in Dworshak Reservoir was assumed to be released in July and August.

Putting the scenarios together required estimating the flow volumes that were actually released for summer flow augmentation each day between 1 July and 10 September, 2002 from Dworshak Reservoir and USBR projects. This step was completed in cooperation with David Benner of the Fish Passage Center. Water released from Dworshak Reservoir for summer flow augmentation during 1 July-10 September was equal to the difference between actual daily outflows and natural inflows to Dworshak Reservoir over the same period. Because natural inflows to Dworshak Reservoir were not readily available, reservoir elevations at the start and end of each day were used along with the reservoir storage table to calculate the volume of water stored or released every day. This method relied on the relationship of outflows minus inflows being equivalent to a change in storage; if the change in storage and outflows were known, inflows could be calculated. For example, if 57 m^3/s of stored water (converted from a volume) were drafted from Dworshak Reservoir in one day, then this water would be subtracted from the recorded outflows at Dworshak Dam to produce an estimation of the reservoir inflows. Natural inflows to Dworshak were assumed to be equivalent to the discharge at Dworshak under a no-flow augmentation scenario, in a few cases some draft was allowed so outflows at Dworshak were equal to the minimum output. Flow augmentation volumes from USBR reservoirs (287,000 acre feet) were obtained from the USBR. This volume was divided equally throughout the 62 days between 1 July and 31 August 2002 and the resulting daily volumes were converted to daily discharge.

Daily mean flows in Lower Granite Reservoir under the Baseline, Dworshak, USBR, and September scenarios were approximated as follows. The baseline scenario was approximated by subtracting the estimated daily volumes of flow augmentation water released from both Dworshak Reservoir (assuming that outflow never fell below minimum operating requirements of 42 m^3/s) and USBR reservoirs from the daily mean flows observed in the tailrace of Lower Granite Dam. The Dworshak scenario was approximated by subtracting the estimated daily flow augmentation volumes of water released from USBR reservoirs from the daily mean flows observed in the tailrace of Lower Granite Dam. The USBR scenario was approximated by subtracting the estimated daily volumes of flow augmentation water released from Dworshak Reservoir from the daily mean flows observed in the tailrace of Lower Granite Dam. The September scenario included the actual daily mean flows recorded in the tailrace of Lower Granite Dam by personnel of the U.S. Army Corps of Engineers.

Daily mean flow in Lower Granite Reservoir under the July-August scenario was approximated as follows. Beginning on 2 July, a daily discharge of 397 m^3/s (maximum allowable within dissolved gas standards) was assumed to be released from Dworshak Reservoir. This assumed volume was sustained throughout August resulting in a draft of 1.16 million-acre feet of Dworshak Reservoir water. The Dworshak Reservoir daily outflows observed during July and August were then subtracted from 397 m^3/s. This provided 61 daily differences that were added to the corresponding values of daily outflows observed in the tailrace of Lower Granite Dam. The remaining 0.04 million acre-feet of stored water in Dworshak Reservoir was assumed to be released the first five days of September after which inflow was released. The assumed release volumes were lower than observed at Dworshak Dam, which resulted in a decrease in Lower Granite Reservoir flow during the first 10 days of September.

Daily mean water temperatures for the tailrace of Lower Granite Dam were simulated under the Baseline, Dworshak, USBR, and July-August scenarios based on the approximated daily flow conditions described previously for each scenario. Water temperatures were simulated by John Yearsley of the U.S. Environmental Protection Agency using a one-dimensional heat budget model developed for the Snake River (Yearsley et al. 2001). Past model validation showed that daily mean water temperatures simulated for July and August were within an average of 0.7^{o}C of those observed (Yearsley et al. 2001).

The flow and temperature exposure indices for each cohort were recalculated with the approximated flows and simulated temperatures under the Baseline, Dworshak, USBR, and July-August scenarios. Survival ($\pm$ 95% C.I.) of each of the four cohorts in 2002 was then predicted from these recalculated indices, and the observed flow and temperature indices for the September scenario, by use of the final multiple regression model. The predicted levels of survival for the September, Dworshak, USBR, and July-August scenarios were then compared to survival predicted under the Baseline scenario to assess the efficacy of each scenario.

Results and Discussion

Accuracy of Origin Classification

In 2002, we recaptured 596 previously PIT-tagged fish. Within-origin classification accuracy was 98.6% for hatchery fall chinook salmon and 100% for wild fall chinook salmon, which equates to an across-origin classification accuracy of 99.7% (Table 1).

Table 1.—Within- and across-origin classification accuracy (%) for distinguishing between wild and hatchery subyearling fall chinook salmon in 2002. Classification of origin (hatchery vs. wild) was based on a subjective assessment of body morphology, and then verified based on PIT tags.

Actual origin	*n*	Number classified into each origin		Classification accuracy	
		Hatchery	Wild	Within	Across
Hatchery	142	140	2	98.6	99.7
Wild	454	0	454	100.0	

Early Life History and Growth

In 2002, a total of 9,881 wild fall chinook salmon was captured by beach seine (including marked fish captured more than once). Of these, 3,249 were fry. Fry emergence during 2002 occurred earlier in the upper reach than in the lower reach of the Snake River based on time of fry presence (Table 2). Fry emergence in 2002 in the upper and lower reaches was similar to other years except emergence timing was more protracted (Table 2).

Table 2.—Emergence timing (given as Sunday’s date for each week) of wild fall chinook salmon fry in the upper and lower reaches of the Snake River, 1992 to 2002. The range of dates is

given in parentheses.

Year	*N*	Median dates of presence
		Snake River upper reach
1995	117	23 Apr (02 Apr to 21 May)
1996	14	28 Apr (14 Apr to 05 May)
1997	1	20 Apr (N/A)
1998	101	19 Apr (12 Apr to 10 May)
1999	97	02 May (04 Apr to 23 May)
2000	683	09 Apr (02 Apr to 14 May)
2001[a]	552	29 Apr (01 Apr to 20 May)
2002[a]	2,289	21 Apr (31 Mar to 02 Jun)
		Snake River lower reach
1992	355	26 Apr (29 Mar to 24 May)
1993	199	16 May (04 Apr to 20 Jun)
1994	440	15 May (03 Apr to 05 Jun)
1995	257	30 Apr (02 Apr to 04 Jun)
1996	268	05 May (14 Apr to 23 Jun)
1997	114	04 May (20 Apr to 29 Jun)
1998	322	26 Apr (12 Apr to 14 Jun)
1999	278	02 May (04 Apr to 27 Jun)
2000	415	09 Apr (02 Apr to 04 Jun)
2001	1,268	06 May (01 Apr to 03 Jun)
2002	960	05 May (01 Apr to 16 Jun)

[a]adjusted by removing fish collected at a non-typical site.

A total of 6,632 of the wild fall chinook salmon captured in 2002 were parr. Shoreline rearing by parr during 2002 occurred earlier in the upper reach than in the lower reach of the Snake River (Table 3). Rearing timing in the upper and lower reaches of the Snake River in 2002 was a little earlier than during other years and was more protracted.

Table 3.—Rearing timing (given as Sunday’s date for each week) of wild fall chinook salmon parr in the upper and lower reaches of the Snake River, 1992 to 2002. The range of dates is given

in parentheses.

Year	*N*	Median dates of presence
Snake River upper reach		
1995	985	28 May (09 Apr to 18 Jun)
1996	118	12 May (14 Apr to 16 Jun)
1997	119	25 May (20 Apr to 15 Jun)
1998	1,078	17 May (12 Apr to 05 Jul)
1999	1,493	23 May (11 Apr to 27 Jun)
2000	1,064	23 Apr (02 Apr to 11 Jun)
2001[a]	793	29 Apr (01 Apr to 10 Jun)
2002[a]	3,013	29 Apr (07 Apr to 30 Jun)
Snake River lower reach		
1992	1,765	17 May (29 Mar to 07 Jun)
1993	2,215	06 Jun (11 Apr to 18 Jul)
1994	4,346	29 May (03 Apr to 10 Jul)
1995	1,408	04 Jun (02 Apr to 02 Jul)
1996	756	26 May (14 Apr to 14 Jul)
1997	938	08 Jun (20 Apr to 13 Jul)
1998	2,512	31 May (12 Apr to 05 Jul)
1999	1,647	06 Jun (04 Apr to 11 Jul)
2000	1,578	14 May (02 Apr to 25 Jun)
2001	3,078	20 May (01 Apr to 17 Jun)
2002	3,619	26 May (01 Apr to 07 Jul)

[a]adjusted by removing fish collected at a non-typical site.

A total of 2,377 of the wild fall chinook salmon parr was PIT tagged in 2002. Of these, 356 were recaptured during beach seining. Mean growth rate was higher for parr in the upper reach than in the lower reach of the Snake River (Table 4). Growth rates in 2002 within a reach were similar to other years (Table 4).

Table 4.—Mean growth rates (mm/d±SD) for wild fall chinook salmon parr collected in the upper and lower reaches of the Snake River, 1992 to 2001. Sample sizes are given in parentheses.

Year	Growth rate by reach	
	Upper reach	Lower reach
1992		0.9±0.1 (66)
1993		0.7±0.4 (202)
1994		1.1±0.4 (341)
1995	1.2±0.3 (148)	1.0±0.4 (78)
1996	1.1±0.3 (19)	0.9±0.4 (49)
1997	1.3±0.3 (20)	0.8±0.3 (80)
1998	1.1±0.3 (112)	0.9±0.3 (129)
1999	1.3±0.3 (171)	1.1±0.3 (92)
2000	1.3±0.2 (90)	1.0±0.3 (40)
2001[a]	1.2±0.1 (12)	0.9±0.2 (123)
2002[a]	1.1±0.2 (170)	0.9±0.2 (186)

[a]adjusted by removing fish collected at a non-typical site.

A total of 95 of the 720 parr PIT tagged in the upper reach of the Snake River was detected as smolts as they passed Lower Granite Dam. Passage of smolts from the upper reach was slightly earlier than normal (Table 5). Of the 1,657 parr PIT tagged in the lower reach, a total of 395 fish was detected as they passed Lower Granite Dam. The median date of passage for fish from the lower reach was slightly earlier than normal.

Table 5.—Smolt migration timing at Lower Granite Dam for wild fall chinook salmon that were initially captured, PIT tagged, and released in the upper and lower reaches of the Snake River, 1992–2002. The range of dates is given in parentheses.

Year	*N*	Median dates of detection
		Snake River upper reach
1995	203	18 Jul (04 Jun to 24 Oct)
1996	19	04 Jul (20 May to 25 Jul)
1997	22	27 Jun (04 Jun to 13 Aug)
1998	173	07 Jul (19 May to 21 Aug)
1999	319	03 Jul (02 Jun to 28 Aug)
2000	72	27 Jun (06 May to 18 Jul)
2001[a]	10	12 Jul (24 Jun to 17 Oct)
2002[a]	95	01 Jul (30 May to 27 Jul)
		Snake River lower reach
1992	39	20 Jun (04 May to 21 Jul)
1993	234	21 Jul (31 May to 25 Oct)
1994	193	17 Jul (23 May to 01 Nov)
1995	238	01 Aug (02 Jun to 26 Oct)
1996	126	22 Jul (17 May to 31 Oct)
1997	97	16 Jul (14 Jun to 13 Oct)
1998	380	11 Jul (29 May to 19 Oct)
1999	241	25 Jul (01 Jun to 30 Aug)
2000	257	02 Jul (18 May to 28 Oct)
2001	185	07 Jul (16 May to 26 Oct)
2002	395	06 Jul (06 Jun to 30 Sep)

[a]adjusted by removing fish collected at a non-typical site.

Passage Forecasts

The revised forecast method performed better than the original forecast method (Table 6). Mean daily error in July was lower for the revised forecast method in all years (Table 6). Mean daily error was lower for the original forecast method in three of four years (Table 6). The revised method provided forecasts that were within the 90% forecast interval all of the time, whereas forecasts made by use of the original forecast method were often lower or higher than observed passage (Table 6). The actual forecast provided to managers in 2002 made using the original method, and a 2002 forecast made using the revised method are compared in Figure 2.

Table 6.-Mean daily error (% ± SD) during July and August for the original (Connor et al. 2000) and revised methods for forecasting cumulative (%) passage at Lower Granite Dam for PIT-tagged wild subyearling fall chinook salmon, and the number of days during July and August that forecasted passage was lower or higher than the 90% forecast intervals. Abbreviations: July, mean daily error in July; August, mean daily error in August; Days, number of days forecasted passage was lower or higher than the 90% forecast interval.

	Original method			Revised method		
Year	July	August	Days	July	August	Days
1997	7.2±3.1	1.8±1.7	0	5.1±2.4	7.1±2.9	0
2000	12.9±8.4	4.7±1.1	7	8.3±3.9	9.4±1.2	0
2001	23.0±10.7	3.8±2.9	21	8.7±4.6	6.5±3.7	0
2002	27.4±11.6	8.1±4.8	23	5.8±6.3	1.7±0.5	0

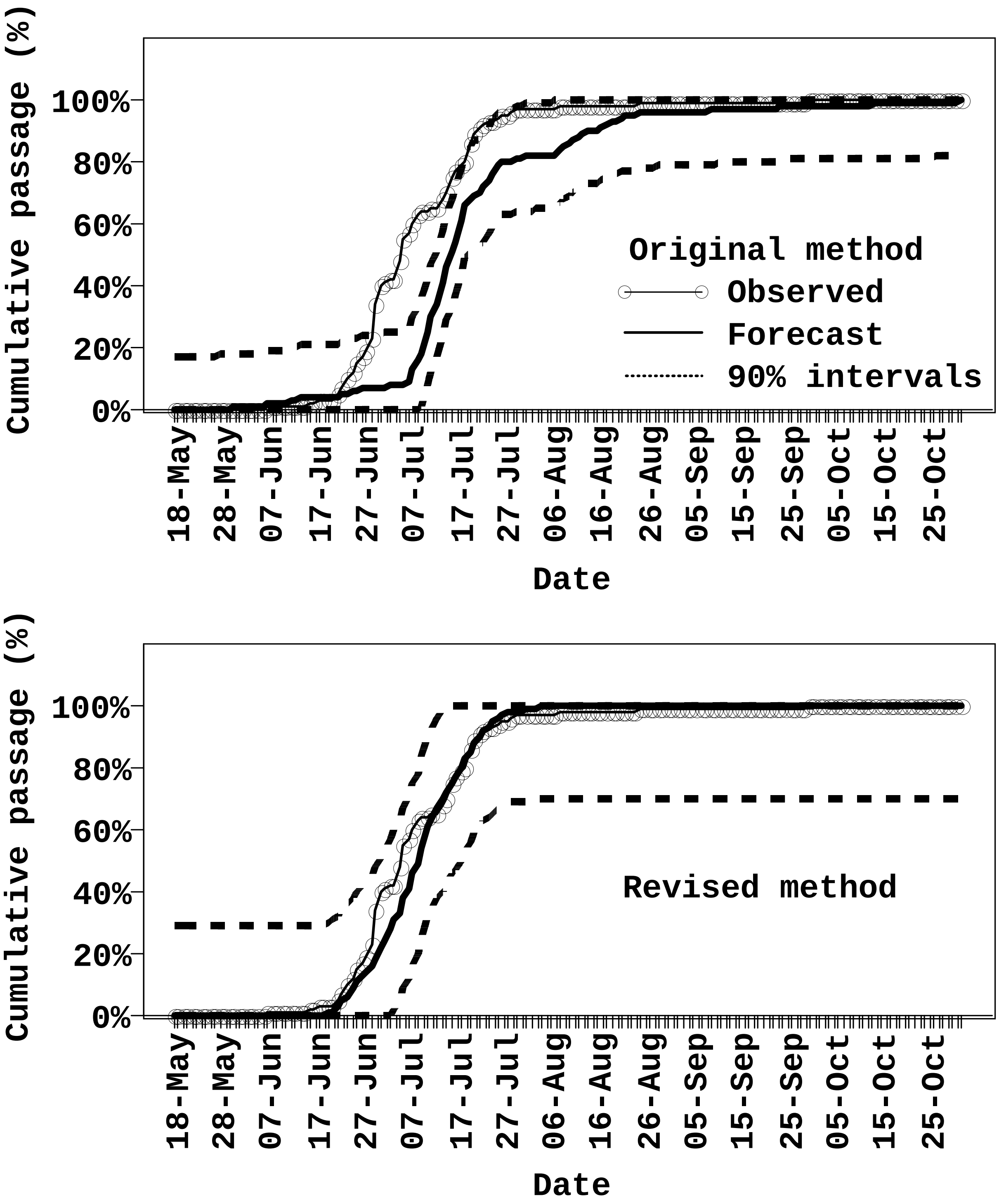

Figure 2.-Forecasts of passage at Lower Granite Dam for wild subyearling fall chinook salmon PIT tagged in the Snake River in 2002. The top panel is the forecast made by use of the original method of Connor et al. (2000). The bottom panel is the forecast made by use of a revised method.

Survival

Mean survival to the tailrace of Lower Granite Dam for the four cohorts in 2002 was 40.7% (Table 7). This was low compared to 1998, 1999, and 2000, but higher than that observed in 2001 (Table 7).

Table 7.—Estimates of survival probability (%±SE) to the tailrace of Lower Granite Dam for cohorts of wild subyearling fall chinook salmon, 1998 to 2002.

	Survival by year					
Cohort	1998	1999	2000	2001[a]	2002[a]	Cohort means
1	70.8±2.9	87.7±4.6	57.1±4.1	41.3±3.2	55.7±3.0	62.5
2	66.1±3.3	77.0±3.8	53.4±4.2	20.4±2.6	48.4±3.0	53.1
3	52.8±3.1	81.2±5.8	44.4±3.6	16.5±2.9	40.5±3.1	47.1
4	35.6±2.9	36.4±3.5	35.7±4.3	5.6±2.6	18.3±2.0	26.3
Annual means	56.3	70.6	47.7	21.0	40.7	

[a]adjusted by removing fish collected at a non-typical site.

The Efficacy of Flow Augmentation

The starting multiple regression model included all four predictor variables (Table 8) and it was the third best model according Cp scores, AIC values, and R^2 values (Table 9). The sign of the regression coefficient for tagging date changed from being negative in a bivariate regression against survival (B = -0.555±0.52 SE) to positive in the multiple regression model (Table 9). The positive regression coefficient is not biologically sound because it contrasts with two other studies that reported an inverse relation between survival of subyearling fall chinook salmon and tagging date (Connor et al. 2000; Smith et al. in press). There was also a 72% chance that the regression coefficient for tagging date did not differ from zero (Ho: *B* = 0; *P* = 0.721; Table 9). This model was removed from consideration for predicting survival.

The next best model according Cp scores, AIC values, and R^2 values was fit from fork length and flow (Tables 8 and 9). Though these two variables were significantly correlated (*r* = 0.63; *P* = 0.0029) there was no evidence for problematic multicollinearity. The bivariate regression coefficients for fork length (*B* = 0.395$\pm$0.81 SE) and flow (*B* = 0.037$\pm$0.004) were positive, as observed in the multiple regression model (Table 9). There was no evidence for inflation of the regression coefficient SEs (Table 9).

The multiple regression model including the variables fork length, flow, and temperature (Table 8) was the best predictor of survival according to the combination of Cp scores, AIC values, and R^2 values (Table 9). The Cp score was only 0.9 points less than the number of parameters compared to the date-fork length-flow-degrees and flow-fork length models that had a Cp scores 1.0 and 1.5 points higher than the number of parameters (Table 9). The R^2 value was second highest and the AIC score was lowest (Table 9). Fork length, flow, and temperature were correlated (fork length versus flow, *r* = 0.63; *P* = 0.0029; fork length versus temperature, *r* = -0.51, *P* = 0.0233; flow versus degrees, *r* = -0.59, *P* = 0.0066). The signs of the bivariate regression coefficients were negative (fork length *B* = 0.395$\pm$0.81 SE; flow *B* = 0.037$\pm$0.004; temperature *B* = -15.277$\pm$3.78 SE) as observed in the multiple regression equation (Table 9). There was an 8% probability (Ho: *B* = 0; *P* = 0.080; Table 9) that the regression coefficient for temperature did not differ from zero suggesting some inflation of the SE of the coefficient (Table 9). This was likely caused by temperature-fork length and temperature-flow correlation. Nonetheless, the resulting model was biologically sound because the signs of the regression coefficients showed that survival generally increased as fork length and flow increased, and decreased as temperature increased, which is consistent with other studies (Connor et al. 1998, 2000, 2003a). The model: Cohort survival = -13.87892 + 1.33613 fork length + 0.02625 flow -4.12232 temperature was selected for predicting survival of wild subyearling fall chinook salmon to the tailrace of Lower Granite Dam in 2002 under the five scenarios.

Table 8.—Predictor variables entered into a multiple regression model for predicting survival of wild subyearling chinook salmon to the tailrace of Lower Granite Dam, 1998–2002. Abbreviations: Date = median day of year of release; Fl = mean fork length (mm) at release; Flow = a flow (m^3/s) exposure index calculated as the mean flow measured at Lower Granite Dam during the period when the majority of smolts passed the dam; and, Degrees = a water temperature (°C) exposure index calculated as the mean temperature measured in the tailrace of Lower Granite Dam during the period when the majority of smolts passed the dam. See Connor et al. (2003a) for exposure index calculations.

Year	Cohort	*N*	Date	Fl	Flow	Degrees
1998	1	515	140	80	2,344	17.6
	2	515	141	75	2,021	18.7
	3	515	153	73	1,898	19.0
	4	515	167	70	1,299	19.8
1999	1	441	147	80	2,378	16.3
	2	440	153	77	1,963	17.1
	3	440	152	70	2,116	16.7
	4	440	167	68	1,353	18.3
2000	1	303	130	77	1,510	16.7
	2	302	144	77	1,296	17.6
	3	302	146	77	1,274	17.8
	4	302	158	71	859	18.5
2001[a]	1	340	136	74	761	18.5
	2	340	142	69	743	18.9
	3	340	143	68	753	19.2
	4	341	151	66	745	18.7
2002[a]	1	594	141	74	1,712	16.7
	2	594	143	71	1,620	16.8
	3	594	149	68	1,352	17.4
	4	595	163	69	946	18.7

[a]adjusted by removing fish collected at a non-typical site.

Table 9.—Diagnostics including Mallow's Cp scores, Akaikes information criteria (AIC) and coefficients of determination (R^2)used to compare the fit of multiple regression models for predicting survival of cohorts of wild subyearling fall chinook salmon from release in the Snake River to the tailrace of Lower Granite Dam, 1998 to 2002. Abbreviations: Date = median day of year of release; Fl = mean fork length (mm) at release; Flow = a flow (m^3/s) exposure index calculated as the mean flow measured at Lower Granite Dam during the period when the majority of smolts passed the dam; and, Degrees = a water temperature (°C) exposure index calculated as the mean temperature measured in the tailrace of Lower Granite Dam during the period when the majority of smolts passed the dam.

Predictor Variables	Coeffi -cients	SE	t-value (*B* = 0)	Prob (*B* = 0)	Cp	AIC	R^2	*P*
Intercept	-27.832	74.06	-0.38	0.712	5.0	86.91	0.902	<0.0001
Date	0.084	0.23	0.36	0.721				
Fl	1.449	0.64	2.27	0.038				
Flow	0.026	0.01	5.03	<0.001				
Degrees	-4.439	2.43	-1.83	0.087				
Intercept	-108.653	37.60	-2.89	0.010	4.5	87.05	0.879	<0.0001
Fl	1.554	0.57	2.74	0.014				
Flow	0.030	0.01	6.65	<0.001				
Intercept	-13.880	61.62	-0.23	0.825	3.1	85.09	0.901	<0.0001
Fl	1.336	0.54	2.46	0.026				
Flow	0.026	0.01	5.78	<0.001				
Degrees	-4.122	2.20	-1.87	0.080				

Prior to discussing the final results of this analysis on the efficacy of summer flow augmentation, it is important for the reader to recognize its limitations. Post-tagging mortality of cohorts released later in the summer would bias the analyses. Though Prentice et al. (1990a) found that delayed mortality of subyearling fall chinook salmon was low (range, 1–5%) 135–139 d after PIT tagging, their tests were not conducted at temperatures above 14.4°C. Research should be conducted on delayed mortality of PIT-tagged fall chinook salmon at temperatures above 14.4°C. It is not known where PIT-tagged fall chinook salmon died en route to Lower Granite Dam. This assessment of summer flow augmentation would be weakened if the majority of tagged fish died in the free-flowing Snake River before flow was augmented. The analysis relies on simple approximations of the flow volumes released for summer flow augmentation to simulate temperatures in Lower Granite Reservoir, and to predict survival of young fall chinook salmon had the summer flow augmentation not been implemented. This is especially true in the case of the USBR scenario where the total known volume of water set aside for summer flow augmentation was averaged across 1 July-31 August because it is not possible to determine when the water was actually released. This is an important limitation because if the water was released as a large volume over a short period of time its influence on cohort survival would be different than reported in this chapter. Finally, the analysis focused on two races of wild subyearling fall chinook salmon tagged in the Snake River (i.e., the upper reach and lower reach races), whereas the population of wild Snake River fall chinook salmon includes the lower Clearwater River race that migrates from July through September (Connor et al. 2002). The effect of the five scenarios on subyearling fall chinook salmon in the lower Clearwater River was not assessed because few of these fish pass Lower Granite Dam as subyearlings (Connor et al. 2002).

Acknowledging the above limitations, releases of Dworshak Reservoir water had a larger effect on Lower Granite Reservoir flows than releases of water from USBR reservoirs (Figure 3) because more stored water was made available from Dworshak Reservoir. The September scenario showed releasing water from both Dworshak and USBR reservoirs resulted in a marked increase in Lower Granite Reservoir flows (Figure 3). These results support the conclusion that summer flow augmentation in 2002 increased flow in Lower Granite Reservoir consistent with analyses on data from 1993-2000 (Connor et al. 1998; Connor et al. 2003b).

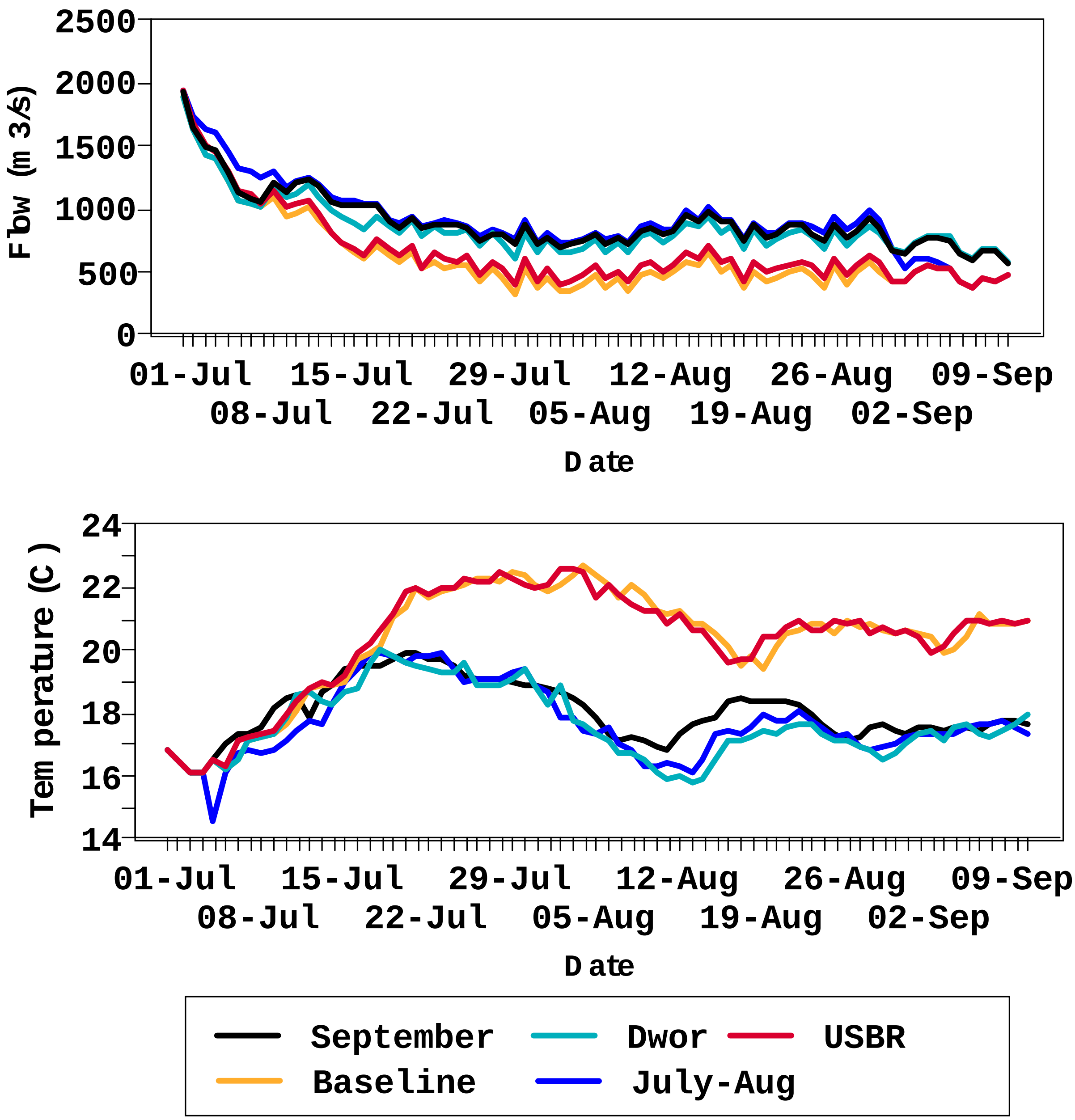

Figure 3.- Daily mean flows (m^3/s; top panel) in Lower Granite Reservoir approximated under the September, Dworshak (Dwor), USBR, baseline, and July-August scenarios of summer flow augmentation in 2002. Daily mean temperatures (^oC; bottom panel) were simulated (Yearsley et al. 2001) for the tailrace of Lower Granite Dam based on the approximated flows.

Simulated temperatures in Lower Granite Reservoir were cooler under the Dworshak scenario than under the USBR scenario (Table 10; Figure 3). This indicates that releasing water from Dworshak Reservoir decreases temperature in Lower Granite Reservoir, whereas water from the USBR reservoirs after being routed through Brownlee, Oxbow, and Hells Canyon reservoirs (Figure 1) increases temperature. However, under the September scenario that actually occurred, the net result of releasing water from both Dworshak and USBR reservoirs was a decrease in Lower Granite Reservoir temperatures (Table 10; Figure 3). These results support the conclusion that summer flow augmentation in 2002 decreased temperature in Lower Granite Reservoir consistent with analyses on data from 1993-1995 and 1998-2000 (Connor et al. 1998; Connor et al. 2003b).

Under the Dworshak, USBR, and September scenarios, the mean increase in predicted survival resulting from flow augmentation increased from cohort 1 to cohort 4 and was consistent with 1998-2000 results (Connor et al. 2003b). The mean increase in predicted survival over the baseline scenario was higher under the Dworshak scenario than under the USBR scenario (Table 10) because of the aforementioned differences in temperature and flow effects between the scenarios (Figure 3). The September scenario showed the greatest increase in predicted survival over the Baseline scenario when compared to the Dworshak and USBR scenarios (Table 10). These results demonstrate the incremental benefits obtained by releasing water from both Dworshak Reservoir and USBR reservoirs. These results also show that summer flow augmentation increased survival of wild subyearling fall chinook salmon passing downstream in Lower Granite Reservoir during 2002 as was observed during 1993-2000 for wild and hatchery subyearling fall chinook salmon (Connor et al. 1998; Connor et al. 2003b; Smith et al. in press)

Approximated flows under the September scenario were lower during the period when wild subyearling fall chinook salmon of Snake River origin were in Lower Granite Reservoir than under the July-August scenario (Tables 5,10; Figure 3). There was little difference in flows between the two scenarios during the first 10 d of September (Figure 3).

Simulated temperatures under the September scenario were slightly higher during the period when wild subyearling fall chinook salmon of Snake River origin were in Lower Granite Reservoir than under the July-August scenario (Tables 5, 10; Figure 3). There was little difference in temperature between the two scenarios during the first 10 d of September (Figure 3).

Table 10.-Predicted survival (± 95% C.I.) to the tailrace of Lower Granite Dam for cohorts of wild fall chinook salmon tagged in the Snake River in 2002. Predictions were made using the median fork lengths given in Table 8 for each cohort and flow (m^3/s) and temperature (^oC) exposure indices recalculated to approximate conditions under each scenario. Note that the flow and temperature exposure indices were not recalculated because they were actually observed (Table 8), and that the baseline scenario represents conditions approximated to have occurred without flow augmentation.

		Recalculated			
Scenario	Cohort	Flow	Temperature	Survival	Increase in survival over baseline scenario
Baseline	1	1,590	16.8	57.5 ± 5.9	
	2	1,477	17.2	48.8 ± 5.7	
	3	1,117	18.9	28.4 ± 5.9	
	4	655	20.4	11.4 ± 9.9	
Dworshak	1	1,669	16.5	60.8 ± 6.9	3.3
	2	1,578	16.6	54.0 ± 7.8	5.2
	3	1,283	17.2	39.7 ± 7.9	11.3
	4	875	18.4	25.4 ± 5.6	14.0
					Mean 8.5
USBR	1	1,619	16.9	57.8 ± 5.5	0.3
	2	1,509	17.3	49.3 ± 5.4	0.5
	3	1,161	19	29.1 ± 6.2	0.7
	4	709	20.5	12.4 ± 10.3	1.0
					Mean 0.6
September	1	1,712	16.7	61.1 ± 6.1	3.6
	2	1,620	16.8	54.3 ± 7.1	5.5
	3	1,336	17.4	40.3 ± 7.3	11.9
	4	946	18.7	26.1 ± 5.3	14.7
					Mean 8.9
July-Aug	1	1,743	16.4	63.1 ± 7.2	5.6
	2	1,648	16.5	56.2 ± 8.1	7.4
	3	1,361	17.1	42.2 ± 8.2	13.8
	4	977	18.3	28.5 ± 5.2	17.1
					Mean 11.0

Predicted survival of cohorts 1 and 2 was higher under the September and July-August scenarios than for baseline conditions (Table 10), but this difference was not significant (Figure 4). Predicted survival of cohorts 3 and 4 was significantly higher under the September and July-August scenarios than under the Baseline scenario (Figure 4). These results differ from those reported for cohorts 1 to 4 during 1998-2000 (Connor et al. 2003). During 1998-2002, predicted survival of all four cohorts was significantly higher than predicted survival for Baseline conditions (Connor et al. 2003b). The most plausible explanation for this finding is related to the availability of water from Snake River reservoirs. During 1998-2000, roughly 427,000 acre feet of USBR reservoir water was provided for flow augmentation, and the Bonneville Power Administration purchased an additional 237,000 acre feet from the Idaho Power Company though a settlement agreement. Drafting Brownlee Reservoir for flow augmentation provided this “settlement water”. During 1998-2000, fish and water managers had more control over when this Snake River reservoir water was released and they released it early when the water was cool to avoid warming Lower Granite Reservoir. It is likely that this water from Snake River reservoirs increased survival of the earlier migrating fish (i.e., cohorts 1 and 2) in 1998 and 1999, and in its absence after 1999, cohorts 1 and 2 did not accrue as large of a benefit from flow augmentation.

The increases in survival predicted for cohorts 3 and 4 in 2002 (Table 10) were also lower than observed during 1998 (19.2% and 19.0%) and 1999 (16.6% and 23.7%), but similar to 2000 (13.6% and 18.6%)(Connor et al. 2003). Notably, 2000 was the first year the State of Idaho declined a waiver for exceeding the 110% dissolved gas standard in the tailrace of Dworshak Dam. The lower levels of increase in predicted survival is likely a direct result of the gas cap. For example, in 1998 and 1999 up to 566 m^3/s of water was released from Dworshak Reservoir during late July or early August. Thus flow was increased and temperature was decreased in Lower Granite Reservoir when juveniles of cohorts 3 and 4 were present. Consequently, the increase in survival cohorts 3 and 4 associated with flow augmentation during 1998 and 1999 was higher than observed during 2000 and 2002.

The mean increase in predicted survival was 2.1 percentage points lower under the September scenario than under the July-August scenario (Table 10). This was to be expected because the final regression model coefficients show that survival will decrease as flow decreases and temperature increases, and the

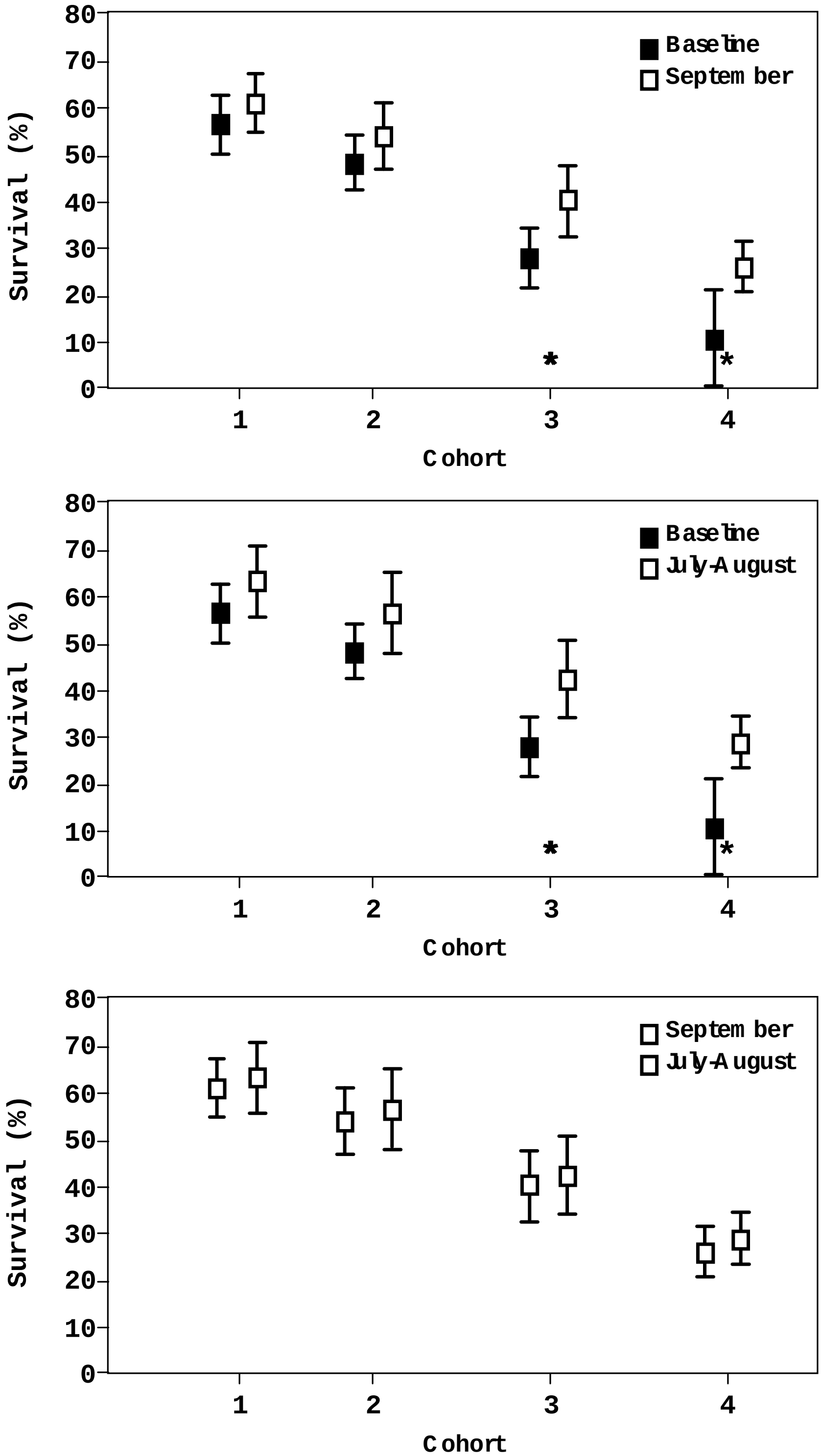

Figure 4.-Comparisons of predicted survival (±95% C.I.) to the tailrace of Lower Granite Dam for cohorts of wild subyearling fall chinook salmon under the Baseline, September, and July-August scenarios in 2002. An asterisk above the x-axis label for a cohort indicates a significant difference based a lack of overlap of 95% C.I.s and point estimates of survival.

September scenario exposed fish to lower flows and higher temperatures than would have occurred under the July-August scenario (Tables 5, 10; Figure 3). The difference in survival predicted for the September and July-August scenarios, however, cannot be viewed as statistically significant because of marked overlap in the 95% C.I.s of the two predictions (Figure 4). The implications of these results are dependent on the perspective of individual fish and water managers. This contrasts with, and rescinds, the conclusion the author provided to fish and water managers in 2003 (Connor 2003).

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CHAPTER TWO

Migratory behavior of subyearling fall Chinook salmon in relation to summer flow augmentation in the Snake River

by

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Abstract.—In 2002, we used a combination of radio telemetry, velocity measurement, and temperature monitoring to evaluate the effects of summer flow augmentation on subyearling fall Chinook salmon in the Snake River. Mean cross-sectional water velocity was measured at regular intervals from Lower Granite Dam to Heller Bar on the Snake River on two occasions using an acoustic Doppler current profiler. Water velocity was highest in the free-flowing Snake River and decreased with proximity to Lower Granite Dam. Water velocities also decreased later in the summer when flows were lower. Median travel rates of radio-tagged fall chinook salmon were strongly related to water velocity, and travel rates decreased the closer that fish got to Lower Granite Dam. Some of our radio-tagged fish made upstream excursions after initially reaching the downstream part of Lower Granite Reservoir. Some of these were extensive and may have negative consequences for subyearling fall chinook salmon. A small release of fish fitted with temperature-sensing radio transmitters produced limited information on temperature selection in the confluence area, but some fish did select cooler water as they passed downstream. Detection information from underwater antennas located at the Red Wolf Bridge about 2 miles below the Snake-Clearwater River confluence suggested that fish were traveling deep in the water column, presumably in cooler water, as they passed this site.

Introduction

The abundance of fall Chinook salmon in the Snake River has declined to the point that they are now listed as “threatened” under the Endangered Species Act (NMFS 1992). Fall Chinook salmon have an ocean-type life history in which fry emerge in the spring and migrate seaward in their first year of life as subyearlings. Because the outmigration of subyearling fall Chinook salmon in the Snake River occurs primarily during the summer, flows are low and water temperatures are high—sometimes near the upper incipient lethal maximum in surface waters (Tiffan et al. 2003). Consequently, the survival of cohorts of late migrants is often low (Connor 2003).

One of the measures currently implemented to improve summer migratory conditions and survival is the release of additional water from upstream storage reservoirs, which is referred to as flow augmentation. The underlying assumption of flow augmentation is that increasing flows will decrease fish travel time, thereby decreasing exposure to predators, disease, and unfavorable environmental conditions, which will subsequently increase survival. Additionally, water released from Dworshak Reservoir in Idaho has a cooling effect on Lower Granite Reservoir, the first reservoir encountered by fish during their seaward migration. Therefore, Dworshak releases are believed to increase survival by reducing exposure to high water temperatures. However, one of the unintended consequences of this may be to delay the migration of fish outmigrating from the Snake River that encounter cooler water at the confluence of the Clearwater River. The assumption that flow augmentation decreases fish travel time has not been conclusively established. This study attempted to quantify the differences in migratory behavior of subyearling fall Chinook salmon before and after summer flow augmentation, and also to identify the water temperatures selected by fish at the confluence of the Snake and Clearwater rivers.

Methods

Radio telemetry

Fish collection, tagging, and release.—Subyearling fall Chinook salmon were collected and fitted with radio transmitters at the Lower Granite Dam juvenile fish collection facility (river kilometer (Rkm) 173). Tagging took place between June 29-July 2 (Release 1), July 22-27 (Release 2), and August 5-9, 2002 (Release 3). During Releases 1 and 2, fish were surgically implanted with coded radio tags (Lotek Wireless, Inc., Newmarket, Ontario) following the methods of Adams et al. (1998). Tags measured 15 mm long, 4.5 mm in diameter, weighed 0.85 g in air, and had a life span of 8 d. During Release 3, fish were implanted with temperature-sensing tags (Advanced Telemetry Systems, Inc., Isanti, Minnesota). Temperature-sensing transmitters were 17 mm long, 6 mm in diameter, weighed 1.7 g in air, and had a life span of 8 to 10 d. Tag accuracy was ±0.5°C. The transmitters operated on unique frequencies and had pulse intervals (in milliseconds) that decreased with increased temperature. Of the fish we tagged, the ratio of tag weight to fish weight did not exceed 5%.

Groups of 6-21 fish were tagged each day for 5 d during each release period. Tagged fish were held for 24 h after tagging to monitor short-term delayed mortality and then were transported to release sites in the Snake and Clearwater rivers. Fish were transported in 125-L insulated containers in groups of three fish per container. On each release day, half the fish were released at Heller Bar (Rkm 271; Release 1) or Rkm 267.5 (Release 2 and 3) in the Snake River, and half the fish were released in the Clearwater River near Potlatch (Rkm 6.5; Release 1) or at Lenore, Idaho (Rkm 43; Release 2 and 3). Some fish were also released at Asotin, Washington (Rkm 235).

Fixed-site monitoring.—The movement of radio-tagged fish was monitored by arrays of antennas and receivers located at various fixed sites between release locations and Lower Granite Dam (Figure 1). Arrays were established at Lower Granite Dam (Rkm 173.0), the forebay of Lower Granite Dam (Rkm 174.5), Granite Point (Rkm 183.0), Water Canyon (Rkm 188.2), Steptoe Canyon (Rkm 206.0), Red Wolf Bridge (Rkm 221.2), the Highway 12 bridge (Blue Bridge) between Clarkston, WA and Lewiston, ID (Rkm 224.5), Couse Creek on the Snake River (Rkm 254.0), and the mouth of the Clearwater River. We refer to the areas between detection sites as reaches. Four- or nine-element Yagi antennas were used at each site in conjunction with a Lotek SRX receiver. Antennas were also placed on barges located in the forebay of Lower Granite Dam, at Water Canyon, and at Steptoe Canyon to increase detection efficiency. In addition, an array of underwater antennas was deployed at the Red Wolf Bridge to increase detection of fish traveling deeper in the water column. A series of dipole antennas were deployed along the riverbed perpendicular to the river flow and spaced at 10-m intervals. A total of 27 underwater antennas were deployed to obtain detection coverage for about 80% of the river's width, which excluded the shallowest areas on the south side of the river.

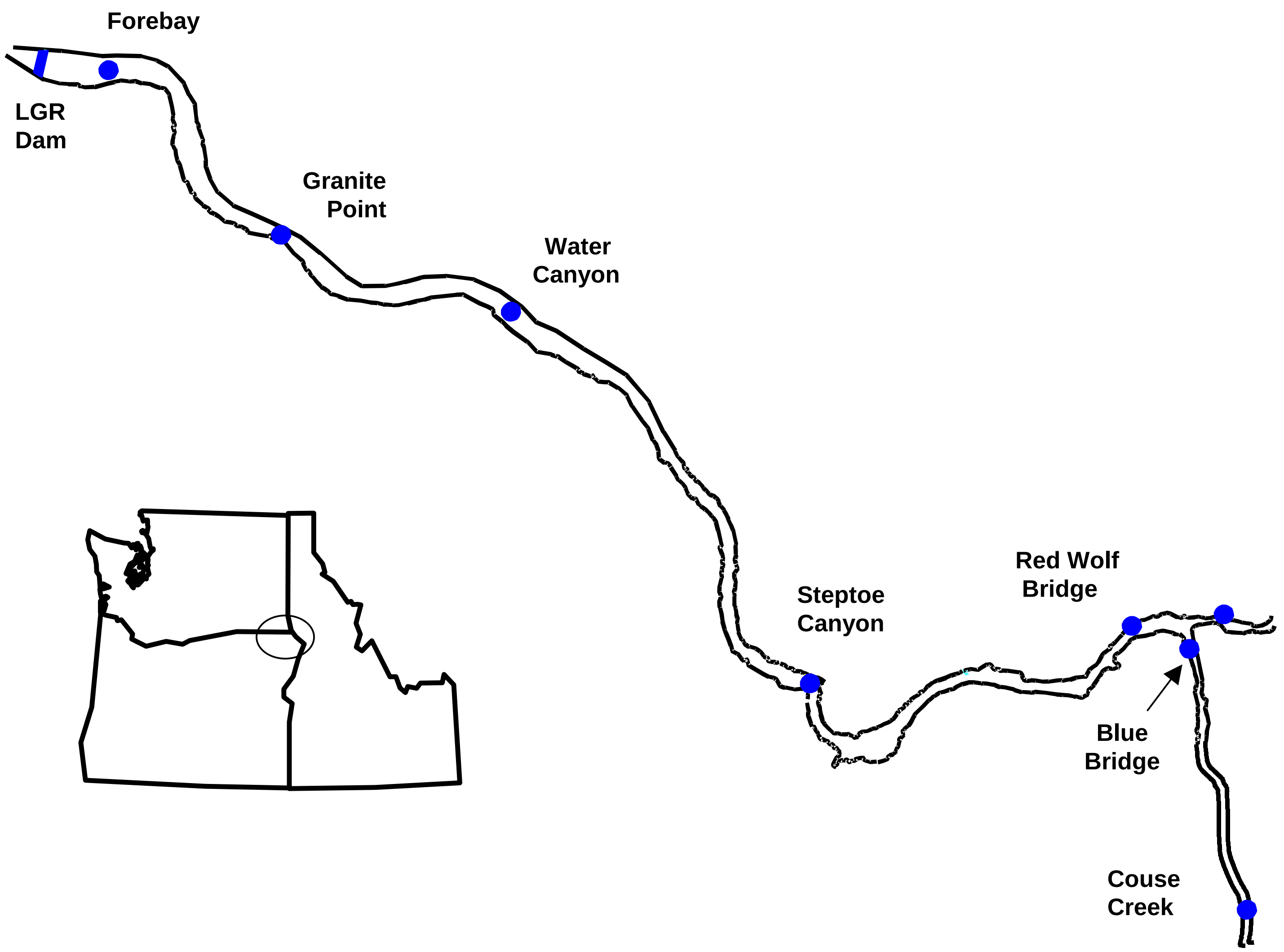

Figure 1.-Locations of radio telemetry detection sites in the Snake River in 2002. See text for river kilometer locations.

Mobile tracking.-Boat mobile tracking was the primary method used to obtain data on fish tagged with temperature-sensing transmitters during Release 3. A separate day and nighttime shift together provided up to 20 h of tracking effort each day. Hourly fish locations were recorded with a GPS for as many fish as possible. Between hourly locations, temperature information was collected and logged by a receiver on as many fish as possible.

Water velocity

Water velocities were measured in Lower Granite Reservoir and the Snake River to relate fish travel rates to velocities. An acoustic Doppler current profiler (ADCP) was used to measure water velocities in bins that were 5-m long x 0.5-m deep along cross sections established every 3 km from Lower Granite Dam upstream to Heller Bar. Bin velocities were averaged to determine the mean cross-sectional water velocity for each transect. Cross-sectional water velocities were also averaged within each reach defined by radio telemetry detection sites. ADCP data collection coincided with the first and second releases of radio-tagged fish.

Temperature monitoring

Thermograph strings were used to monitor the vertical distribution of water temperatures in the Snake and Clearwater rivers. Five to eight data-logging thermographs (HOBO Water Temp Pro loggers (model H20-001), Onset Corporation) were deployed at different depths from the surface to the bottom of the river at the Blue Bridge, railroad bridge in Lewiston, ID, Red Wolf Bridge, Steptoe Canyon barge, Water Canyon barge, and the barge in the forebay of Lower Granite Dam (Table 1). Thermographs were deployed in early July and were retrieved in late August. Temperatures were recorded every 15 min.

A bathythermograph (BT) was used to collect vertical water temperature profiles in the area of the Snake and Clearwater confluence. Cross-sectional transects were established every 200 m from just above the Blue Bridge on the Snake River (Rkm 226) and from Potlatch (Clearwater Rkm 6.5) downstream to the Port of Wilma (Rkm 216). BT profiles were collected at five points spaced evenly along each transect. The BT recorded time, depth, and temperature every 0.3 s, and was lowered and raised to the surface at a rate of 0.5 m/s with an electric winch. The location of each BT profile was recorded with a GPS. Water temperature data were collected to show changes in the

Table 1.-Locations and depths of thermograph strings deployed in the Snake and Clearwater rivers in 2002.

Thermograph string location	Depths of individual thermographs (m)
Blue Bridge	0.5, 1.5, 3, 5, 7, 9
Railroad Bridge	0.5, 1.5, 3, 5, 7, 9
Red Wolf Bridge	0.5, 1.5, 3, 5, 7
Steptoe Barge	0.5, 1.5, 3, 7, 14
Water Canyon Barge	0.5, 1.5, 3, 5, 10, 15, 20, 26
Forebay Barge	0.5, 1.5, 3, 5, 10, 15, 21

distribution of temperatures from the confluence of the Snake and Clearwater rivers downstream to Red Wolf Bridge.

Data analysis

Data downloaded from radio telemetry receivers were incorporated into a SAS (Statistical Analysis Software, SAS 2000) database and automatically proofed to remove erroneous data records. Data were also manually proofed to ensure data accuracy and confirm the integrity questionable data records. Fish detection records were analyzed to examine travel times, migration rates, and upstream excursions. Fish travel times were calculated as the elapsed time between release and first detection at a detection site, or between last detection at a site and the first detection at the next downstream detection site. Migration rates were calculated as the length of the reach divided by fish travel time in the reach. The incidence of upstream excursions was determined by plotting the detections of each fish over time to determine if a fish detected at a downstream site was later detected at an upstream site.

We used least-squares regression to examine the relationship between water velocity and subyearling migratory behavior. Fish travel times and migration rates were pooled by release group (1 and 2 only), and medians were calculated because the data were not normally distributed. Median travel rates within reaches were then regressed against the average cross-sectional water velocity for each reach.

Results

River conditions and flow augmentation

During the summer of 2002, flows at Lower Granite Dam declined from 137 kcfs on June 1 to 24 kcfs on September 1 (Figure 2). Snake River flows at Anatone, Washington declined from 83 to 13 kcfs during this same period. Dworshak Dam outflows, typically <5 kcfs in June, reached a high of 19.6 kcfs in late June and declined to 7.4 kcfs during our first release. Dworshak outflows were less than 13 kcfs for only 8 d during our study. Flow augmentation began on July 9 with the release of 13.7 kcfs from Dworshak Dam, which was maintained through late August. Snake River flows, as measured at Lower Granite Dam, declined from 80 to 40 kcfs during Release 1, from 31 to 25 kcfs during Release 2, and averaged about 26 kcfs during Release 3. Water temperatures measured at Lower Granite Dam (scroll case) increased to a peak of 20.6°C in late July then declined or remained relatively stable (Figure 2).

Radio telemetry

Tagging.-We tagged 50 and 107 subyearling Chinook salmon with coded radio tags during Releases 1 and 2, respectively (Table 2). Mean fork lengths ranged from 120 to 135 mm during Release 1 and mean weights ranged from 20.0 to 29.8 g. During Release 2, mean fork lengths ranged from 118 to 127 mm and mean weights ranged from 19.8 to 24.2 g. A total of 27 fish were tagged with temperature-sensing radio tags in early August (Release 3), which averaged 134 mm fork length and 28.9 g (Table 3). There was no tagging mortality in 2002.

Detection efficiency.- We detected 77% (121 of 157) of subyearling Chinook salmon marked with coded radio tags in 2002 (Table 4). Detection efficiency was generally higher during Release 1 than in Release 2. During Release 1, detection efficiency ranged from 100% in the Clearwater River to 34% at Couse Creek in the free-flowing Snake River. During Release 2, detection efficiency ranged from 77% in the Clearwater River to 0% at Lower Granite Dam. Below the confluence of the Snake and Clearwater rivers, detection efficiency decreased as fish moved downstream (Table 4). Few fish were detected downstream of Steptoe Canyon during the second release in late July.

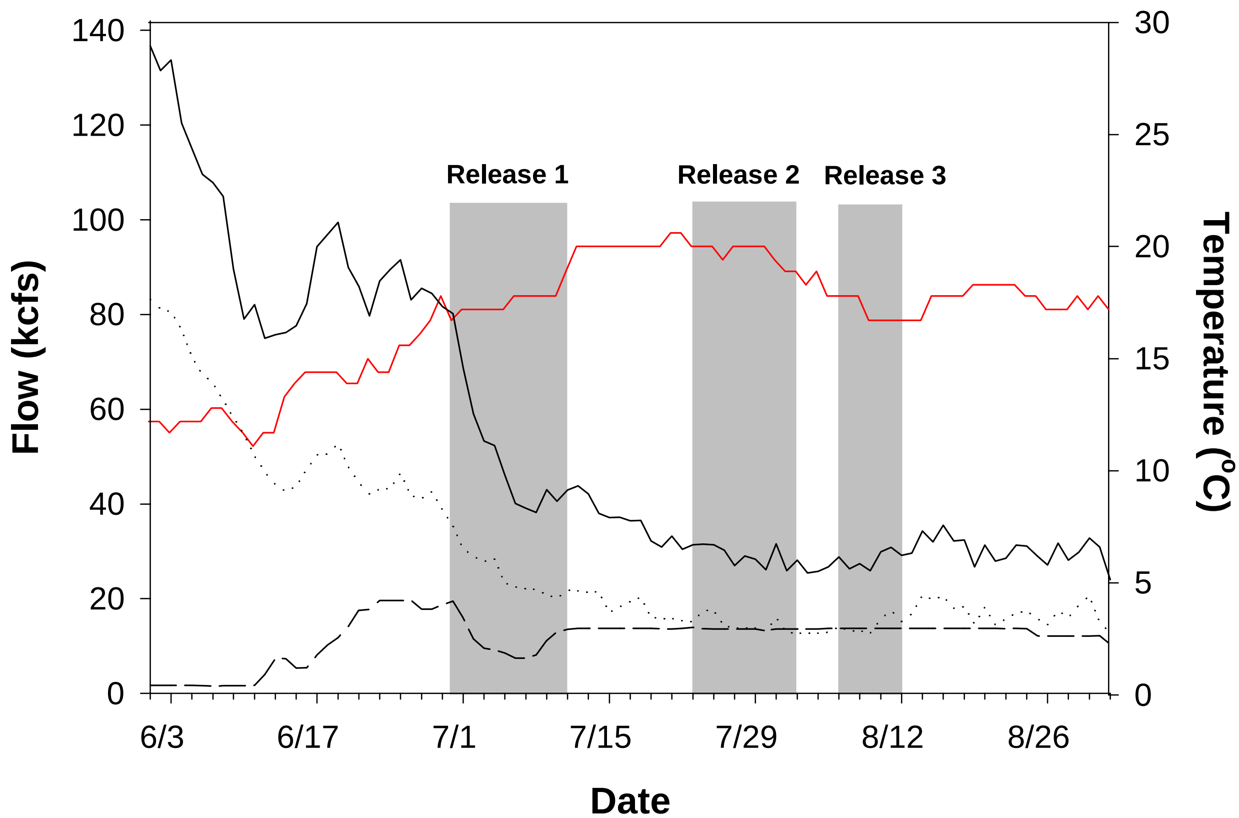

Figure 2.-Snake River flows at Lower Granite Dam (solid line), Anatone, Washington (dotted line), and Clearwater River outflow from Dworshak Dam (dashed line) during summer, 2002. Water temperatures measured at the scroll case of Lower Granite Dam are shown in red. Also shown are the periods when radio-tagged subyearling Chinook salmon were at large in the Snake and Clearwater rivers.

Table 2.-Release date, number, site, fork length, and weight of subyearling fall Chinook salmon tagged with coded radio tags and released into the Snake and Clearwater rivers in 2002.

Release Date	No. of Fish	Release Site	Mean Fork Length (range mm)	Mean Weight (range g)
06/30/02	3	Clearwater	123(115-134)	22.3(17.5-29.9)
06/30/02	3	Asotin	132(120-143)	27.5(18.6-36.2)
06/30/02	3	Heller Bar	128(119-139)	25.3(19.7-36.4)
07/01/02	6	Clearwater	133(128-147)	25.8(22.3-35.4)
07/01/02	5	Asotin	124(117-138)	21.4(17.3-30.9)
07/01/02	3	Heller Bar	135(125-156)	26.8(19.7-39.9)
07/02/02	6	Clearwater	132(120-146)	26.9(20.0-34.9)
07/02/02	6	Asotin	135(119-143)	29.2(21.0-37.2)
07/02/02	6	Heller Bar	130(115-148)	26.1(17.7-38.8)
07/03/02	3	Clearwater	135(123-152)	29.8(21.7-43.0)
07/03/02	3	Asotin	125(118-130)	22.3(18.9-24.6)
07/03/02	3	Heller Bar	120(119-121)	20.0(19.3-20.5)
07/23/02	8	Clearwater	121(115-128)	20.6(18.8-25.6)
07/23/02	9	Heller Bar	118(113-129)	19.8(17.8-24.3)
07/24/02	9	Clearwater	123(117-132)	21.9(18.4-26.0)
07/24/02	9	Heller Bar	122(116-133)	21.0(17.6-25.4)
07/25/02	6	Clearwater	125(121-127)	23.5(21.0-25.4)
07/25/02	6	Heller Bar	128(122-134)	24.2(20.3-29.2)
07/26/02	12	Clearwater	124(116-136)	22.6(19.3-29.3)
07/26/02	9	Heller Bar	123(119-130)	20.5(18.1-23.4)
07/27/02	9	Clearwater	123(120-127)	22.0(20.9-24.0)
07/27/02	9	Heller Bar	126(120-132)	24.2(22.0-28.3)
07/28/02	12	Clearwater	123(118-127)	22.3(19.4-24.5)
07/28/02	9	Heller Bar	126(119-135)	24.0(20.1-29.4)
Totals	157		127(113-156)	23.7(17.3-43.0)

Table 3.-Release date, number released, fork length, and weight of subyearling fall Chinook salmon tagged with temperature-sensing tags released in the Snake and Clearwater rivers, 2002.

Release Date	No. of Fish	Release Site	Fork length (range mm)	Weight (range g)
08/06/02	3	Clearwater	135(131-143)	31.3(27.6-35.1)
08/06/02	3	Heller Bar	127(123-132)	26.1(24.4-29.6)
08/07/02	3	Clearwater	133(129-139)	27.9(24.5-32.6)
08/07/02	3	Heller Bar	133(132-134)	27.1(24.1-29.7)
08/08/02	3	Clearwater	134(128-135)	29.5(26.9-31.4)
08/08/02	3	Heller Bar	132(127-135)	29.4(26.1-31.6)
08/09/02	3	Clearwater	135(134-137)	31.8(28.5-35.3)
08/09/02	3	Heller Bar	136(134-138)	30.8(29.8-31.7)
08/10/02	2	Clearwater	139(138-140)	33.9(33.5-34.3)
08/10/02	1	Heller Bar	134	28.9
Totals	27		134(127-143)	29.7(24.1-35.3)

Table 4.-Release location, number released, and percent detection efficiencies by release period of radio-tagged subyearling fall Chinook salmon at receiver banks in the Snake and Clearwater Rivers in 2002. Numbers in parenthesis denote number of fish detected.

	Release 1 (Jun 30-Jul 3)		Release 2 (Jul 23-28)	
Release location	Clearwater	Snake	Clearwater	Snake
Number released	18	32	56	51
Couse Creek		34% (11)		65% (33)
Blue Bridge		34% (11)		45% (23)
Clearwater	100% (18)		77% (43)	
Red Wolf Bridge	80% (40)		69% (64)	
Steptoe Canyon	80% (40)		50% (53)	
Water Canyon	72% (36)		17% (19)	
Granite Point	68% (34)		12% (13)	
LGR Forebay	56% (28)		7% (7)	
LGR Dam	44% (22)		0%	

Water velocity and migration rate

Mean cross-sectional water velocity in the Snake River increased in an upstream direction, and strong relationships existed between water velocity and distance from Lower Granite Dam for Release 1 and Release 2 in Lower Granite Reservoir (Figure 3). We only used velocity data from Lower Granite Reservoir in regression analyses because we were primarily interested in velocity differences in the reservoir. The equation that best fit the data from Release 1 was:

Velocity = 2.9156 + 0.5622 Distance from Lower Granite Dam

where velocity is measured in cm/s and distance is measured in kilometers. The r^2 for this relationship was 0.85. The equation that best fit the data from Release 2 was:

Velocity = 4.6632 + 0.3233 Distance from Lower Granite Dam

where velocity is measured in cm/s and distance is measured in kilometers. The r^2 for this relationship was 0.83. Mean cross-sectional velocity increased slowly and linearly from Lower Granite Dam to just above the confluence and then increased more rapidly upstream, particularly in the free-flowing river.

Subyearling Chinook salmon travel rates were also related to distance from Lower Granite Dam and water velocity. Travel rates decreased with decreasing distance to Lower Granite Dam, and travel rates were substantially higher in the free-flowing Snake River than in Lower Granite Reservoir (Figure 4). Strong relationships existed between travel rate and distance to Lower Granite Dam for Release 1 (r^2=0.89, P=0.0005) and Release 2 (r^2=0.86, P=0.0025) with travel rates decreasing as fish got closer to the dam. Similarly, strong relationships existed between subyearling travel rate and mean reach water velocity for Release 1 (r^2=0.98, P=0.0001) and Release 2 (r^2=0.99, P=0.0001; Figure 5). The regression equation that best fit the data for Release 1 is defined as:

Median travel rate = 4.5087 + 0.8716 Mean velocity

where both median travel rate and mean velocity are measured in km/d. The regression equation that best fit the data for Release 2 is defined as:

Median travel rate = -0.2343 + 0.8448 Mean velocity

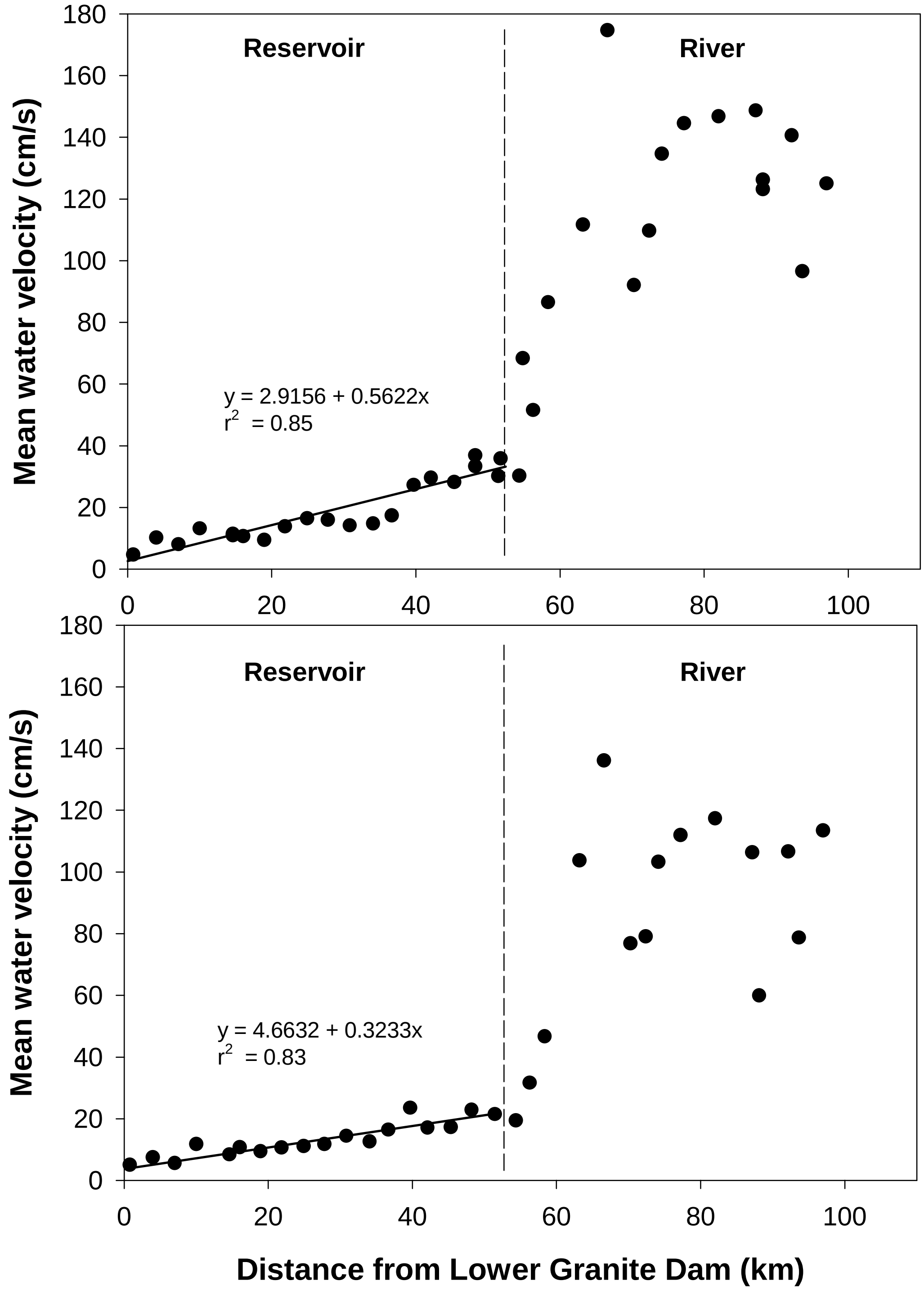

Figure 3.- Relationship between mean water velocities as measured with an ADCP and the distance from Lower Granite Dam, 2002. Velocities were measured on July 5-6 at flows from 40-46 kcfs (top) and on July 29-31 at flows from 28-32 kcfs (bottom). Regression lines are shown as well.

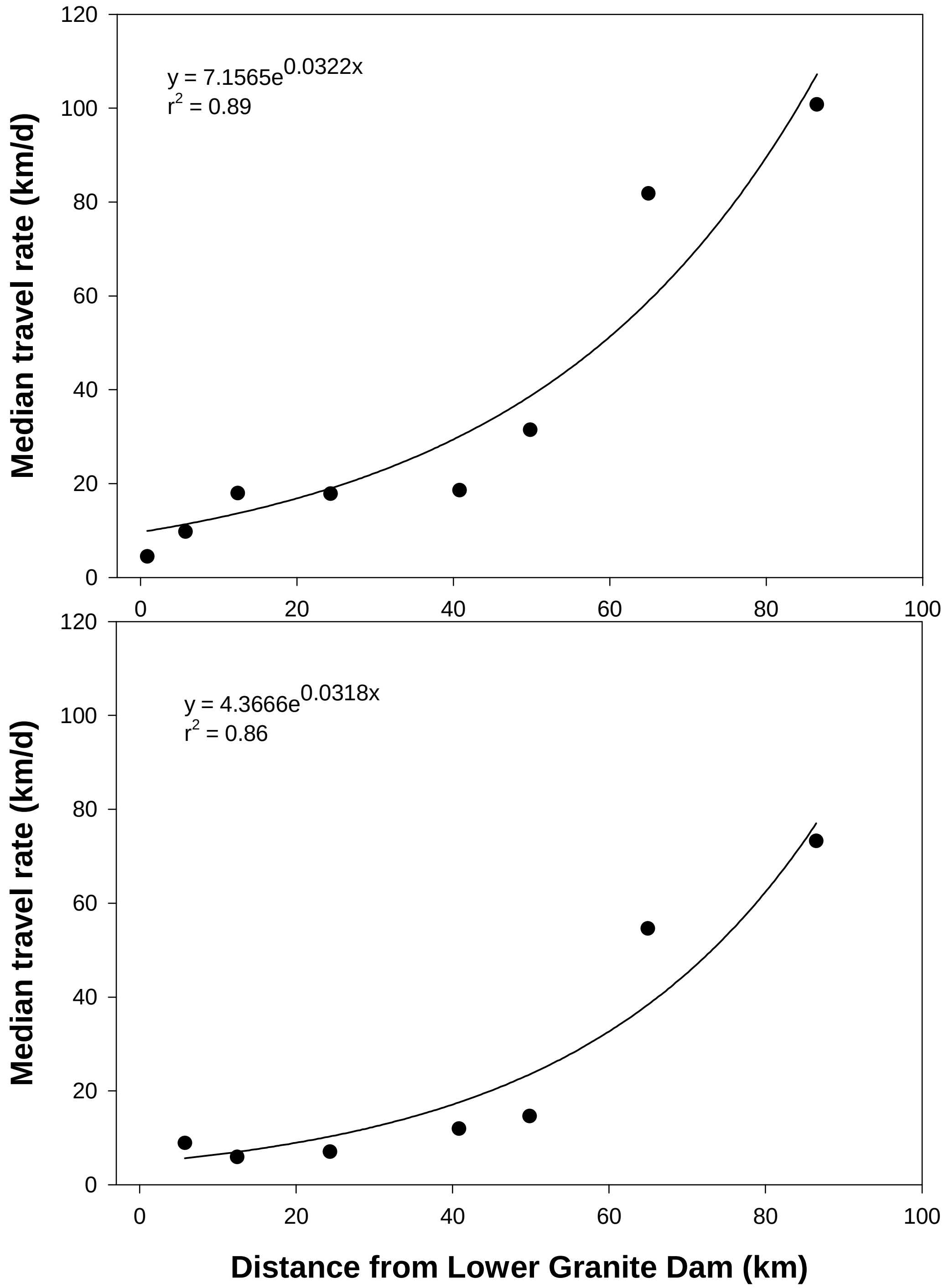

Figure 4.-Relationship between median travel rate and distance from Lower Granite Dam for subyearling Chinook salmon released in the Snake River from Jun 30-July 3 (top panel) and from July 23-28, 2002 (bottom panel). Regression lines are shown as well.

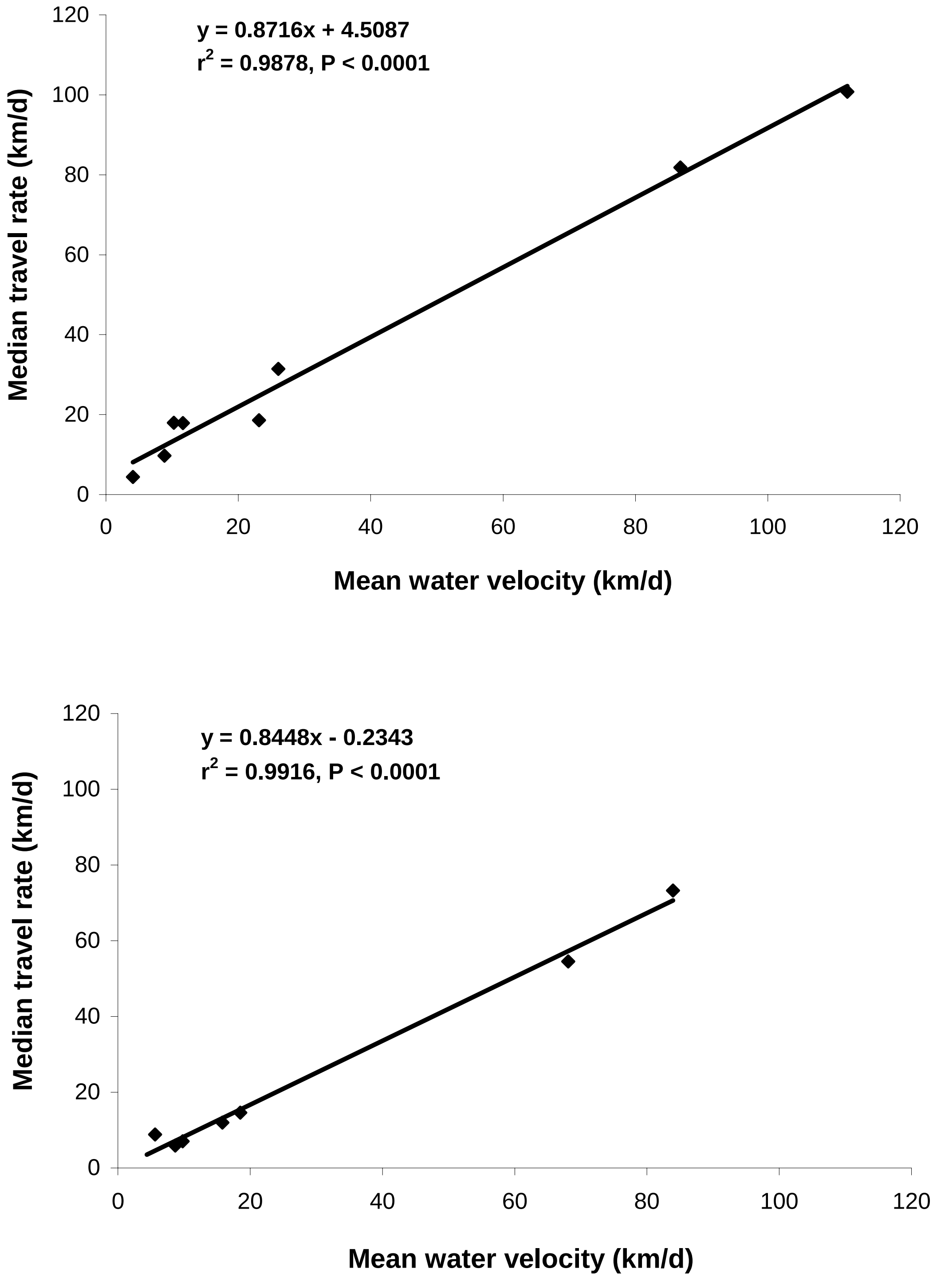

Figure 5.-Relationship between median travel rate and water velocity for subyearling Chinook salmon released in the Snake River from June 30-July 3 (top) and from July 22-28, 2002 (bottom) in the Snake River. Least-squares regression lines and equations are shown as well.

where both median travel rate and mean velocity are measured in km/d. Fish traveled significantly faster at the higher velocities in the free-flowing river than in the reservoir. The slopes of the travel rate-velocity regressions indicate that fish traveled slightly slower than the mean water velocity. Both travel rates and water velocities were lower during Release 2, which corresponded to lower flows (25-31 kcfs).

Upstream excursions

Of the 121 subyearling Chinook salmon tagged with coded radio transmitters and detected in our arrays, 10 (8%) fish made 14 upstream excursions (at least from one detection site to the next upstream detection site; Table 5). All upstream excursions were initiated from Granite Point or the Lower Granite Dam forebay. Nine of these fish were from Release 1 and one fish was from Release 2. Of the nine fish from Release 1, seven fish initiated upstream excursions after arrival at Granite Point and the other two fish initiated upstream excursions after arrival in the Lower Granite forebay. The upstream excursion distances ranged from 5.63 km to 32.98 km and upstream excursion times ranged from 3 h 9 min to 92 h 12 min.

Water temperature

Water temperatures recorded by thermograph strings indicated that on average the Snake River above the confluence is over 8°C warmer than that of the Clearwater River (Table 6). Vertical water temperatures measured at both the Blue Bridge on the Snake River and the Railroad Bridge on the Clearwater River indicate that water temperatures in both the Snake and Clearwater rivers are generally homothermic above their confluence (Figure 6). At Red Wolf Bridge (3 km downstream of the confluence), temperatures were about 3°C cooler at a depth of 7 m compared to those near the surface due to the cooler Clearwater River water traveling along the bottom of the river channel (Figure 7). Thermograph strings at Steptoe Canyon, Water Canyon, and in the forebay of Lower Granite Dam all showed decreasing temperatures with increasing depth (Figures 7-8). Temperatures at the greatest depths were generally about 3-5°C cooler than surface temperatures. There was also less variability in temperatures at greater depths. Finally, surface water temperatures in the lower portion of the reservoir were high and occasionally exceeded 27°C in the forebay of Lower Granite Dam.

Table 5.-Summary of upstream excursions in Lower Granite Reservoir made by subyearling Chinook salmon tagged with coded radio transmitters in 2002. Times of initial and last detection are shown for fish at each site as well as arrows to show direction of travel.

		Detection site				
Fish ID	Date	Steptoe Canyon	Water Canyon	Granite Point	Forebay	Exit
20171	7-4-02		11:56 ←	02:17		
	7-4-02		12:24 →	14:54		
	7-5-02		14:27 ←	10:20		
	7-5-02		15:20			
	7-7-02	04:19 ↙				
	7-8-02	07:13 →	20:24			
	7-8-02		22:43 ↘			
	7-9-02			06:23		
	7-9-02			07:32 →		15:10
21171	7-3-02		19:57 ←	05:14		
	7-3-02		21:07 ↘			
	7-4-02			01:46		
	7-4-02			04:52 →	08:41	
	7-5-02				21:27	
	7-6-02			11:05 ↙		
	7-6-02			11:41 →	17:03	
20176	7-3-02		05:31 ←	01:45		
	7-3-02		05:46 →	08:30		
21173	7-6-02		19:50 ←	15:52		
	7-6-02		21:24			
22143	7-5-02			15:34		
	7-6-02		05:06 ↙			
	7-7-02		17:10 →	22:25		
	7-7-02			23:05		
	7-8-02		03:56 ↙			
	7-10-02		06:08			
20178	7-6-02		11:31 ←	08:05		
	7-7-02		12:01 ↘			
	7-8-02				10:49	
20181	7-6-02		19:27 ←	10:58		
	7-8-02		07:14			
21179	7-6-02				20:33	
	7-7-02			15:11 ↙		
	7-8-02			06:28 →	13:12	
21181	7-8-02				21:07	
	7-9-02			06:25 ↙		
	7-9-02		11:06 ←	7:27		
	7-9-02		12:20			
20188	7-29-02				23:37	
	7-30-02			20:37 ↙		
	7-30-02			21:32		

Table 6.-Means and ranges of temperatures measured by thermograph strings deployed in the Snake and Clearwater rivers, July-August 2002.

Location	Depth (m)	Mean Temp (^{o}C)	Temp Range (min-max)
Blue Bridge	0.5	21.80	18.60-23.81
	1.5	21.75	18.60-23.59
	3	21.65	18.53-23.52
	5	21.72	18.60-23.64
	7	21.79	18.72-23.74
	9	21.58	13.33-23.76
Rail Road Bridge	0.5	13.64	10.66-16.39
	1.5	13.64	10.66-16.42
	3	13.61	10.59-16.39
	5	13.68	10.61-16.46
	7	13.51	10.44-16.30
	9	13.49	10.42-16.30
Red Wolf Bridge	0.5	20.70	16.82-23.66
	1.5	20.32	16.77-22.92
	3	19.58	16.01-22.63
	5	18.52	13.95-21.91
	7	17.12	12.82-21.17
Steptoe Canyon Barge	0.5	19.81	17.25-22.30
	1.5	19.60	16.77-22.13
	3	19.36	16.27-21.94
	7	18.34	14.98-20.94
	14	16.99	14.31-20.91
Water Canyon Barge	0.5	21.64	18.72-25.26
	1.5	21.45	18.70-24.10
	3	21.12	18.44-23.35
	5	20.70	18.25-23.09
	10	19.96	18.06-22.27
	15	18.97	16.89-21.29
	20	18.00	15.37-19.60
	26	17.35	15.10-19.32
Forebay Barge	0.5	21.92	19.75-27.95
	1.5	21.63	19.29-25.23
	3	21.31	18.77-24.97
	5	20.96	18.58-24.36
	10	19.87	18.01-21.80
	15	19.12	17.13-21.13
	21	18.17	15.70-20.29

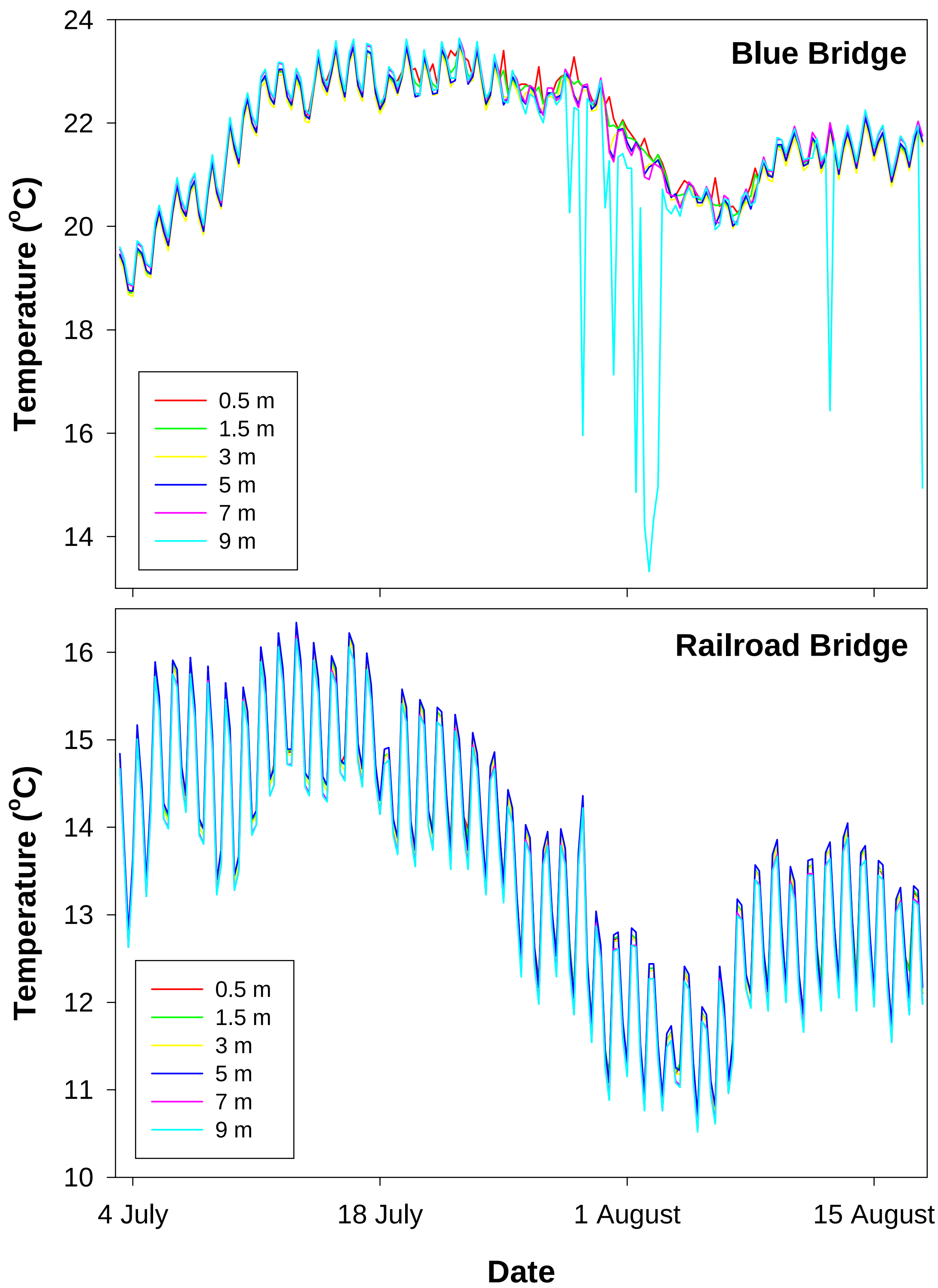

Figure 6.-Temperatures recorded by thermographs deployed at various depths at the Blue Bridge on the Snake River and the Railroad Bridge on the Clearwater River in 2002. Overlap in temperatures between thermographs may obscure some trend lines.

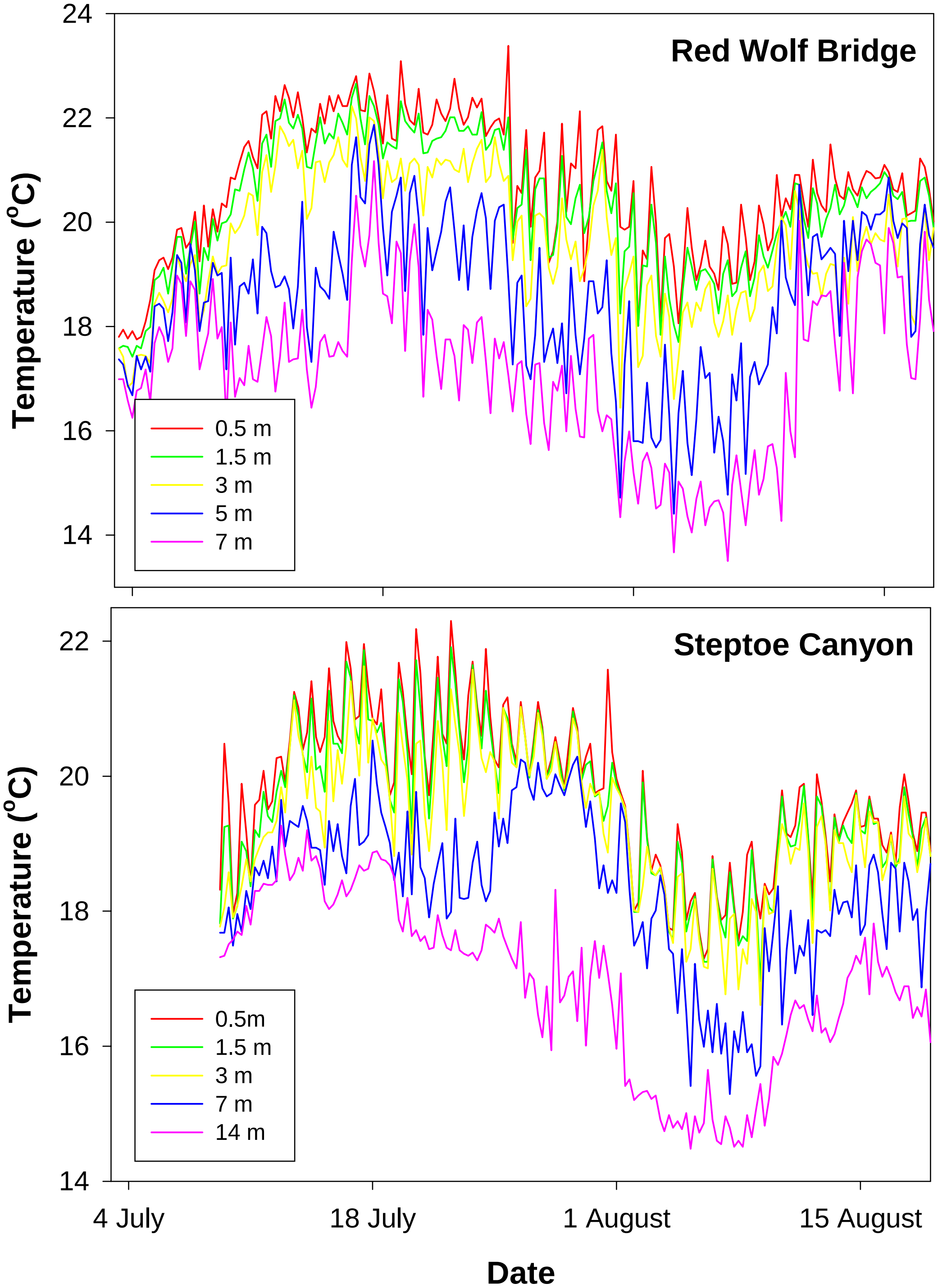

Figure 7.-Temperatures recorded by thermographs deployed at various depths at the Red Wolf Bridge and at Steptoe Canyon on the Snake River in 2002. Overlap in temperatures between thermographs may obscure some trend lines.

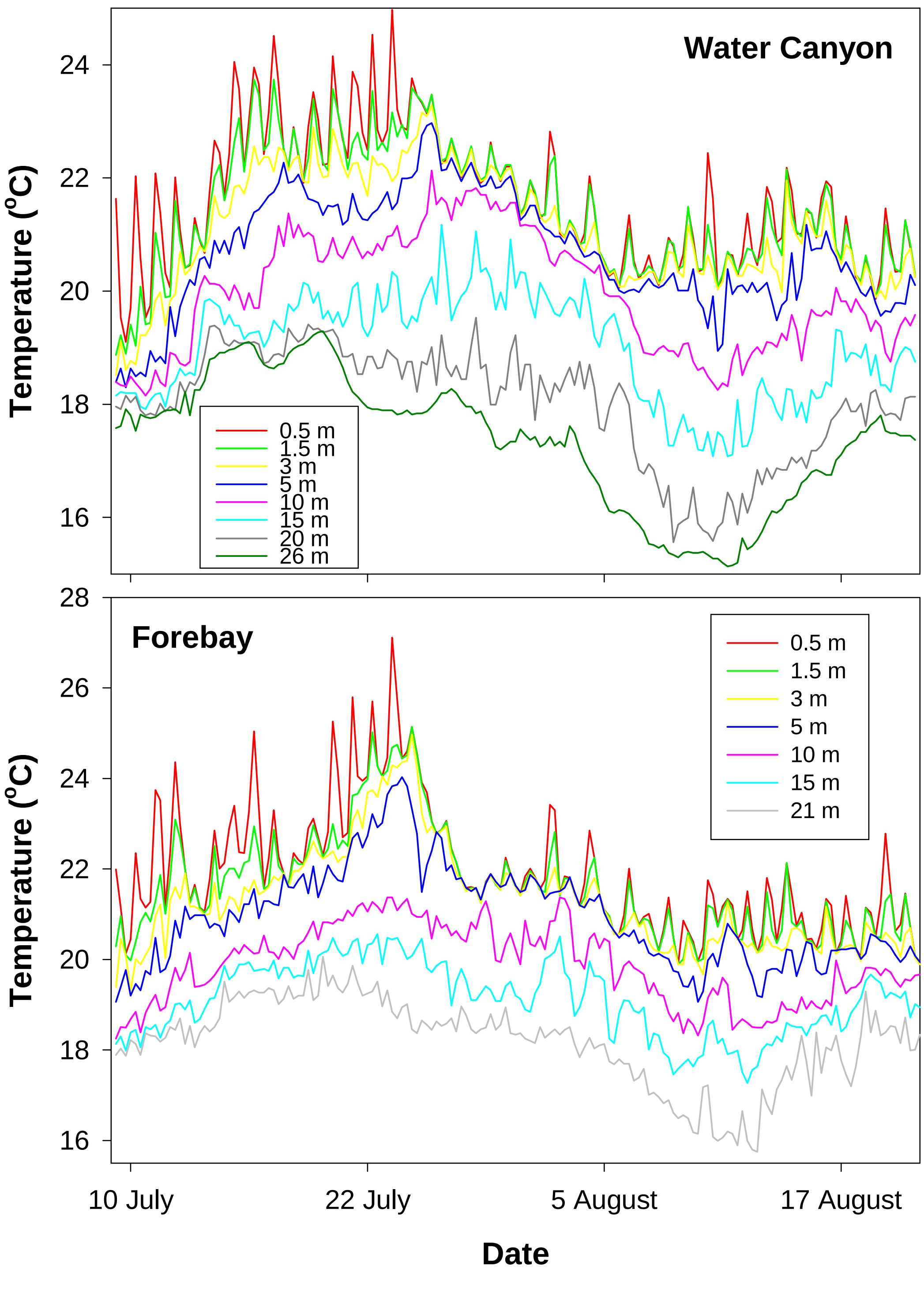

Figure 8.-Temperatures recorded by thermographs deployed at various depths at Water Canyon and in the forebay of Lower Granite Dam on the Snake River in 2002. Overlap in temperatures between thermographs may obscure some trend lines.

Plots of temperature data collected with a bathythermograph in the confluence area of the Snake and Clearwater rivers show how water of different temperatures mix and move downstream to the Red Wolf Bridge (Figures 9-10). Cooler water from the Clearwater River initially flows along the bottom and left side of the channel then gradually becomes warmer further downstream. Warmer water from the Snake River remains near the top of the water column and initially flows along the right (north) shore until it becomes more evenly distributed at the Red Wolf Bridge.

Twenty-seven subyearling Chinook salmon were fitted with temperature-sensing radio transmitters and released in early August in the Snake and Clearwater rivers to investigate temperature-related behavior in the confluence area. Of the 27 fish released, only four were detected from releases in the Snake River and eight were detected from releases in the Clearwater River. The eight fish detected in the Clearwater River were located near the river's mouth above the confluence with the Snake River. Seven of the fish remained in the Clearwater River or were not detected at any sites downstream of the confluence. Temperatures experienced by fish exhibited little variation and ranged from 13 to 15°C.

We detected only one fish from the Clearwater River that traveled through the confluence and was detected at Red Wolf Bridge. After leaving the 12-13°C temperatures in the Clearwater River, it was detected in 16-17°C water at the Red Wolf Bridge. These temperatures were only available at the greatest depths (>7 m) in the channel. Surface water temperatures at Red Wolf Bridge when this fish was detected exceeded 20°C. Similarly, we only detected one fish released in the Snake River that was subsequently detected in the confluence area. This fish was detected at the Blue Bridge in 22.2°C water and then 1 h later at the Red Wolf Bridge in 15.9°C water indicating that it was also seeking the coolest water available.

Most of the fish released in the Clearwater River delayed their migration above the confluence with the Snake River. Fish generally traveled the 43 km from the release site at Lenore, Idaho to the lower Clearwater River in about 1 d. They then lingered above the confluence for 2-8 d until their time of last detection. We observed one fish, released in the Snake River, travel into the Clearwater River and stay for 2 d before returning to the Snake River to be detected one last time.

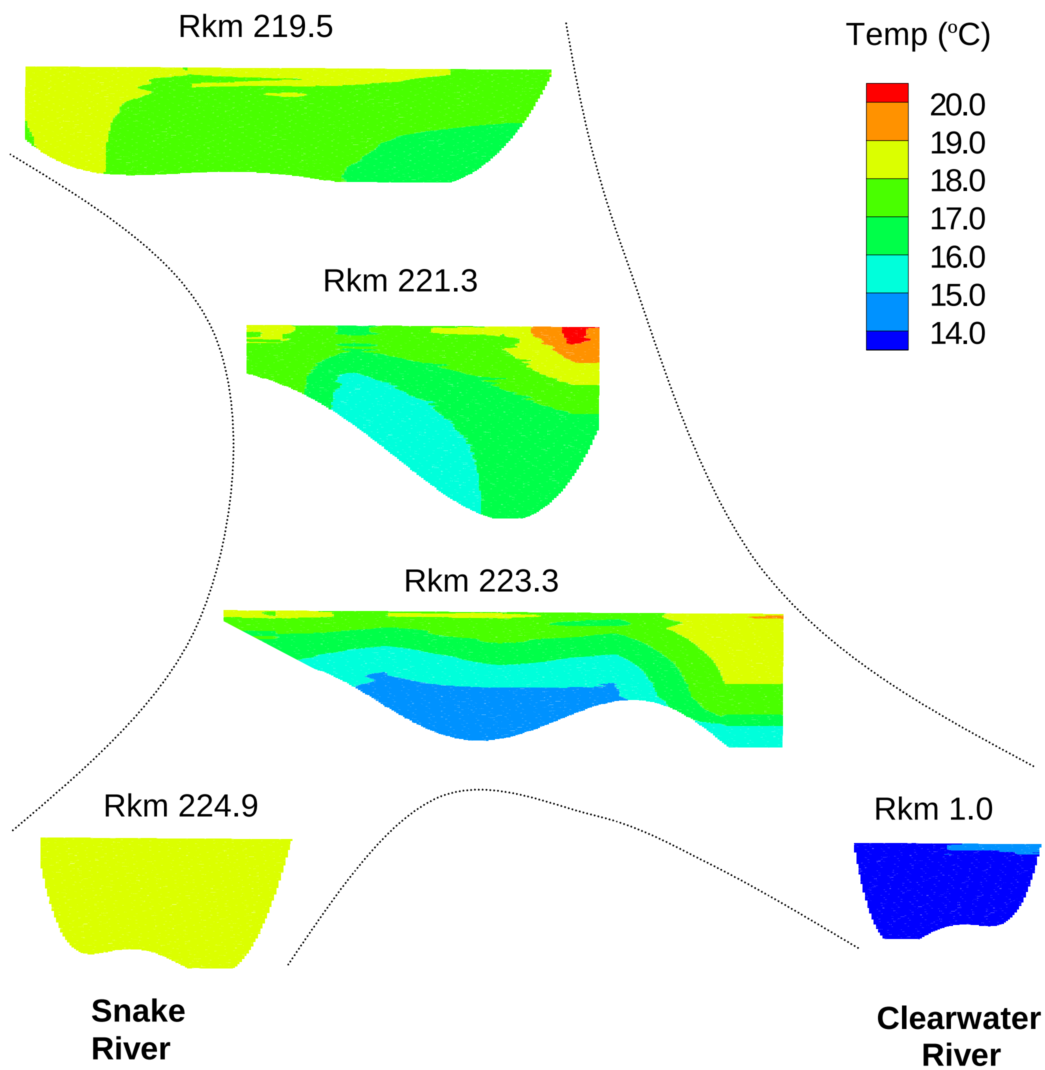

Figure 9.-Graphic representation of temperatures at cross sections in the confluence of the Snake and Clearwater rivers on July 3-7, 2002. Vertical temperature profiles were collected with a bathythermograph at points at each cross section. Temperature data were interpolated where data were lacking.

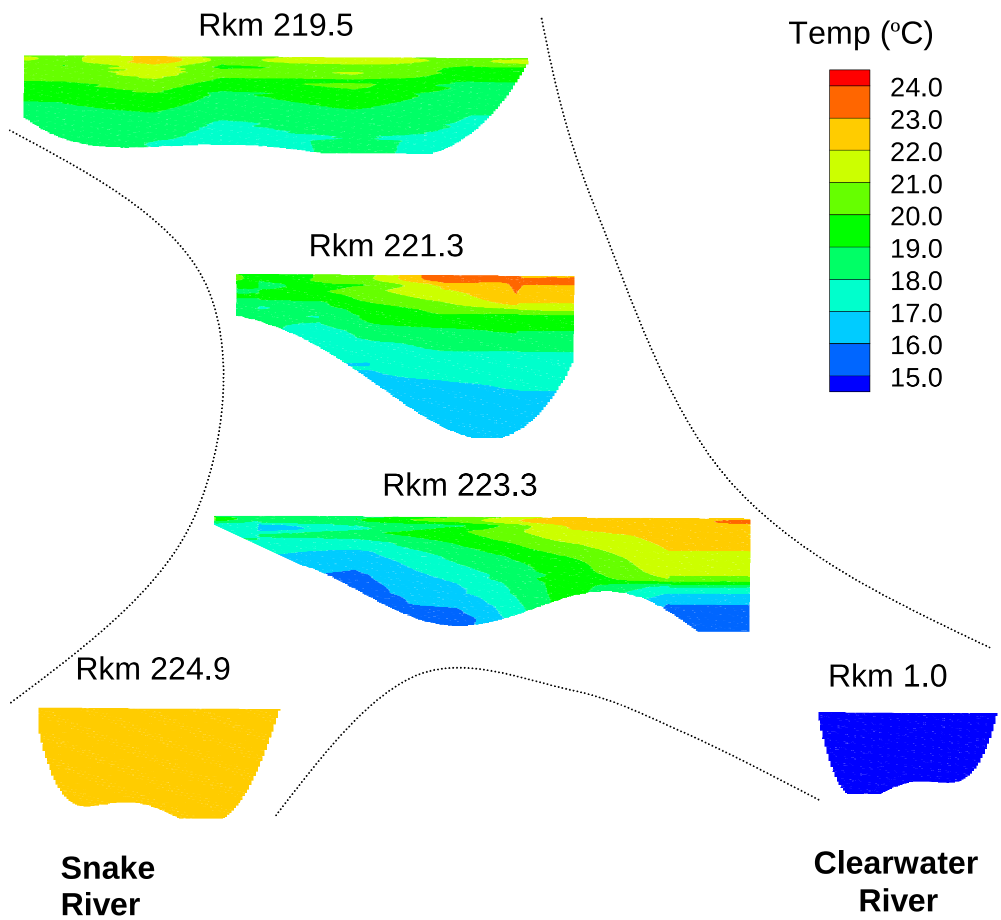

Figure 10.-Graphic representation of temperatures at cross sections in the confluence of the Snake and Clearwater rivers on July 15-18, 2002. Vertical temperature profiles were collected with a bathythermograph at points at each cross section. Temperature data were interpolated where data were lacking.

Discussion

Flows from the Clearwater River were higher than normal in June in 2002 and did not represent typical pre-flow augmentation conditions. In an average year, discharge from Dworshak Reservoir is about 1.5 kcfs until flow augmentation begins in early July. In 2002, Dworshak discharge exceeded 19 kcfs during our first release of radio-tagged fish but declined to 7.4 kcfs before flow augmentation began. The intent of the first two radio tag releases was to compare subyearling fall Chinook salmon migratory behavior before and after the onset of flow augmentation. However, flow conditions in 2002 precluded a comparison of a pre-augmentation low-flow (1.5 kcfs) condition to a post-augmentation higher-flow (14 kcfs) condition from Dworshak Reservoir. Nonetheless, we were able to obtain valuable fish behavior information under two different discharge scenarios.

The detection efficiency of radio-tagged fish generally declined both seasonally and with increasing proximity to Lower Granite Dam. It is likely that survival was lower later in the season as flows declined and temperatures increased as shown by Connor et al. (2003). Alternatively, fish may have sought greater depths and cooler water temperatures later in the season as they traveled through the reservoir. At greater depths (>10 m), radio-tagged fish are not detectable (Kelly and Adams 1996). It is also possible that as fish traveled slower during lower flows in late July that their radio tags expired before they could be detected at downstream arrays.

Most detection sites functioned adequately, but power supply problems occurred for the detection array on the Blue and Red Wolf bridges during Release 1. Consequently, efficiency was reduced at those sites during Release 1. The deployment of underwater antennas along the riverbed at the Red Wolf Bridge proved to be very successful in detecting a high number of tagged fish. The Red Wolf Bridge site detected the most fish of any site below the Snake-Clearwater River confluence, and most fish were detected by underwater antennas at this site. Of the three underwater antenna arrays at this site, most fish were detected on antennas located in the deepest part of the channel. This fact coupled with a detection range of only about 5 m for underwater antennas indicates that fish were traveling close to the bottom as they passed the Red Wolf Bridge.

Subyearling fall Chinook salmon travel rate was strongly related to water velocity in 2002. Although flow is the variable commonly used in analyses and management decisions (see reviews in Giorgi et al. 2002 and ISAB 2003), water velocity is the functional variable that likely influences fish migratory behavior. We demonstrated that water velocity at various locations in Lower Granite Reservoir and in the free-flowing Snake River change along this continuum despite flow remaining relatively constant. Consequently, fish travel times were strongly related to water velocity being significantly higher in the free-flowing river than in the reservoir. Travel times were also slightly higher in the reservoir during Release 1 when both flows and water velocities were higher than during Release 2. The slopes of the regressions between fish travel time and velocity for Releases 1 and 2 reveals that fish moved about 15% slower than that of the mean cross-sectional water velocity. This indicates that increasing water velocity in Lower Granite Reservoir should increase the travel rate of subyearling fall Chinook salmon.

We only fit a linear regression model to the reservoir portion of our water velocity dataset because flow augmentation is aimed primarily at improving migratory conditions in reservoir habitats. This approach allowed us to examine the change in water velocity at two different flows, which showed that water velocities were lower at lower river flows in late July. The increase in water velocity in the free-flowing Snake River above Lower Granite Reservoir was accompanied by a high degree of variability, which was due to the variation in the river morphology, complexity, and location of sampling transects. It should be noted that water velocities will reach a maximum in a free-flowing river as a function of the channel gradient. Any function fit to all the data we collected would have to account for this and would likely be represented by a sigmoidal function wherein velocities would reach a plateau as distance from Lower Granite Dam increased.

If water velocity is indeed a cue for downstream migration in subyearling fall Chinook salmon, then loss of this cue may result in altered migration behavior. The upstream excursions that we observed for some fish may be evidence of this. All upstream excursions were initiated from Granite Point or the forebay, locations characterized by the lowest water velocities in Lower Granite Reservoir. Venditti et al. (2000) observed the same upstream excursion behavior for radio-tagged fall Chinook salmon in Little Goose Reservoir. They speculated that migrating fish may lose velocity cues in low-velocity areas, such as in dam forebays, and may move back upstream to relocate the main current. This behavior may contribute to migrational delay that might make fish more susceptible to disease, predation, and exposure to high water temperatures.

One of the main benefits of using cool water from Dworshak Reservoir for flow augmentation is moderating high summer water temperatures in the lower Snake River. Our temperature sampling showed that cooler Clearwater River water entering the Snake River remains deeper in the water column and along the bottom underneath warmer Snake River water. Although surface temperatures in the Snake River can exceed the upper incipient lethal maximum for subyearling Chinook salmon, there remains cool-water refugia for fish deeper in the water column. It is likely that this condition only exists in Lower Granite Reservoir. Tiffan et al. (2003) found no cool-water refugia in Little Goose Reservoir during periods of summer flow augmentation, but flow augmentation did have the effect of reducing Little Goose Reservoir temperatures overall.

We met with limited success in characterizing the thermal selection of subyearling fall Chinook salmon in the confluence area. Detection of fish tagged with temperature-sensing tags was low (12 out of 27). Seven of the eight fish detected in the Clearwater River were not detected moving into the Snake River. These fish traveled the 45 km to the confluence rapidly and then stopped their downstream movement just above the confluence. It is possible that these fish did enter the Snake River and then reentered the Clearwater River where they remained. Because the Clearwater River was fairly homothermic, these fish displayed no temperature selection.

Two fish, one from the Clearwater River and one from the Snake River, did move downstream past the Red Wolf Bridge. Both fish selected the coolest water available in the vicinity of the bridge indicating that subyearling salmon are capable of detecting and using the cool water provided by flow augmentation. Similarly, the high number of fish from Releases 1 and 2 detected on the underwater antennas at the Red Wolf Bridge suggests that fish were traveling deep in the water column in cooler water. However, many fish from these releases were also detected by aerial antennas at downstream sites indicating that they were traveling in the upper 10 m of the water column in temperatures often exceeding 20°C.

This report summarizes the results from the first year of a three-year study of flow augmentation in the Snake River. It should be considered that the fish tagged for the first release in late June and early July represent the largest fish in the outmigrant population. On average, only 36% of the daily sample of fish collected at Lower Granite Dam during Release 1 were large enough for tagging. However, during Release 2 in late July, 87% of fish collected at Lower Granite Dam were large enough to be tagged. Consequently, smaller migrants and premigrants still rearing in Lower Granite Reservoir in late June and early July might have exhibited different responses to water temperature and velocity. However, we believe the fish we tagged adequately represented general population in late July and our results are generally applicable to active migrants for both releases.

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