FALL CHINOOK SALMON SURVIVAL AND SUPPLEMENTATION STUDIES IN THE SNAKE RIVER AND LOWER SNAKE RIVER RESERVOIRS, 1996

Annual Report 1996

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EXECUTIVE SUMMARY

Snake River fall chinook salmon (*Oncorhynchus tshawytscha*) are listed as threatened under the Endangered Species Act. At present, limited data exist on the migrational characteristics of Snake River subyearling fall chinook salmon, particularly concerning the proportion of migrants that survive passage through the Snake River dams and reservoirs, the effects of flows and temperatures on survival, and the percentage of subyearlings that are guided away from turbines into collection facilities and transported. As a result, operational strategies to maximize survival have been largely based on data from studies of subyearling chinook salmon that pass through lower Columbia River dams.

In 1996, the National Marine Fisheries Service, the Nez Perce Tribe, and the U.S. Fish and Wildlife Service completed the second year of research to investigate migrational characteristics of subyearling fall chinook salmon in the Snake River Basin. The primary study objectives were to: 1) describe the early life history characteristics of natural subyearling fall chinook salmon produced upstream from Lower Granite Dam (Part One), 2) estimate detection and passage survival probabilities for natural subyearling fall chinook salmon emigrating from the Snake River to the tailrace of Lower Granite Dam (Part One), 3) estimate detection and passage survival probabilities of hatchery subyearling fall chinook salmon released in the Snake and Clearwater Rivers (Part Two), and 4) investigate relationships between detection and passage survival probabilities and travel time of subyearling fall chinook salmon and environmental influences such as flow volume, water temperature, and turbidity (Parts One and Two).

In spring and early summer 1996, we captured natural subyearling fall chinook salmon by beach seine, PIT tagged them, and released them in two reaches of the Snake River (as defined in the text). Lyons Ferry Hatchery subyearling fall chinook salmon were also PIT tagged and released weekly at Pittsburg Landing on the Snake River and Big Canyon Creek on the Clearwater River to collect data on survival, detection probabilities, and travel time.

Survival and travel-time estimates to downstream dams are reported for both natural and hatchery subyearling fall chinook salmon. For natural fish, survival from release in the upstream and downstream reaches of the Snake River to the tailrace of Lower Granite Dam was approximately 66 and 46%, respectively. For hatchery fish released in the same general vicinity, survival ranged from 56% for the earliest release to 5% for the last release with an overall mean survival of 32%. Median travel time from release in the free-flowing Snake River to Lower Granite Dam for natural fish was approximately 42 days. Median travel time from release at Pittsburg Landing or Big Canyon Creek to Lower Granite Dam for hatchery fish was 49 days from both release sites. A small proportion of hatchery and natural subyearling fall chinook salmon residualized and migrated early in spring 1997; however, as with the 1995 releases, the number that overwintered and migrated seaward as yearlings in spring was small and had minimal effect on survival estimates. A number of comparisons of characteristics of natural and wild fish were made. Results generally support the use of hatchery fall chinook salmon as surrogates for natural fall chinook salmon in survival research.

Determining the relationship between survival, flow, and water temperature for subyearling fall chinook salmon is difficult because of their protracted migration. Combining the two years of data for hatchery fish, significant correlations were found between survival and all three environmental variables examined (flow, water temperature, and turbidity) from release to the tailrace of Lower Granite Dam with survival decreasing as flows and turbidity decreased and water temperatures increased. No significant relationships were found between travel time and survival or travel time and the environmental variables in reaches downstream from Lower Granite Dam except for the relationship between water temperature and travel time. Replicate data sets collected over a period of several years will be required to accurately define the relationships among fall chinook salmon survival, flow, and water temperature.

Natural subyearling fall chinook salmon in the upstream reach of the Snake River emerged earlier in the spring, arrived at Lower Granite Dam earlier in the summer, and had higher survival than fish from the lower Snake River reach. Because natural fish in the upstream reach of the Snake River migrated earlier in the summer, they experienced higher flows and lower water temperatures during their migration to Lower Granite Dam.

Survival rates for both natural and hatchery subyearling fall chinook salmon were lower in 1996 than in 1995, possibly due to the reliance on Snake River water from upstream of Hells Canyon Complex early in the summer, which is warmer than the water from Dworshak Reservoir used in 1995, to meet flow augmentation goals. Fishery managers are presented with a complex problem when planning and implementing summer flow augmentation.

PART ONE

Early Life History and Survival of Snake River Natural Subyearling Fall Chinook Salmon in 1996

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CONTENTS PART ONE

INTRODUCTION

Snake River fall chinook salmon (*Oncorhynchus tshawytscha*) have declined in abundance the last three decades and were listed as threatened under the Endangered Species Act (USFWS 1988) in 1992 (NMFS 1992). Fishery managers are attempting to aid recovery of the Snake River fall chinook salmon population through the interim recovery measures of summer flow augmentation and supplementation (NMFS 1995). The goal of summer flow augmentation and supplementation is to increase the number of fall chinook salmon produced naturally. Prior to our cooperative research with the National Marine Fisheries Service (Connor et al. 1997, Smith et al. 1997), there were no estimates of survival for natural subyearling fall chinook salmon emigrating from the Snake River. The objectives of this report are to 1) describe the early life history characteristics of natural subyearling fall chinook salmon in the Snake River in 1996, 2) estimate survival for natural subyearling fall chinook salmon emigrating from the Snake River to the tailrace of Lower Granite Dam in 1996, 3) compare natural subyearling fall chinook salmon detection and survival probability estimates in 1996 and 1995, and 4) compare the timing of flow augmentation to passage of natural fall chinook salmon at Lower Granite Dam in 1996 and 1995.

Study Area

The Snake River originates in Yellowstone National Park, Wyoming and drains about 240,300 km^2. Completion of the Hells Canyon Complex (Fig.1) [Brownlee Dam (1955, River Kilometer 456), Oxbow Dam (1961, RK 439) and Hells Canyon Dam (1967, RK 397)] blocked passage to the core area of historic Snake River fall chinook salmon spawning. The

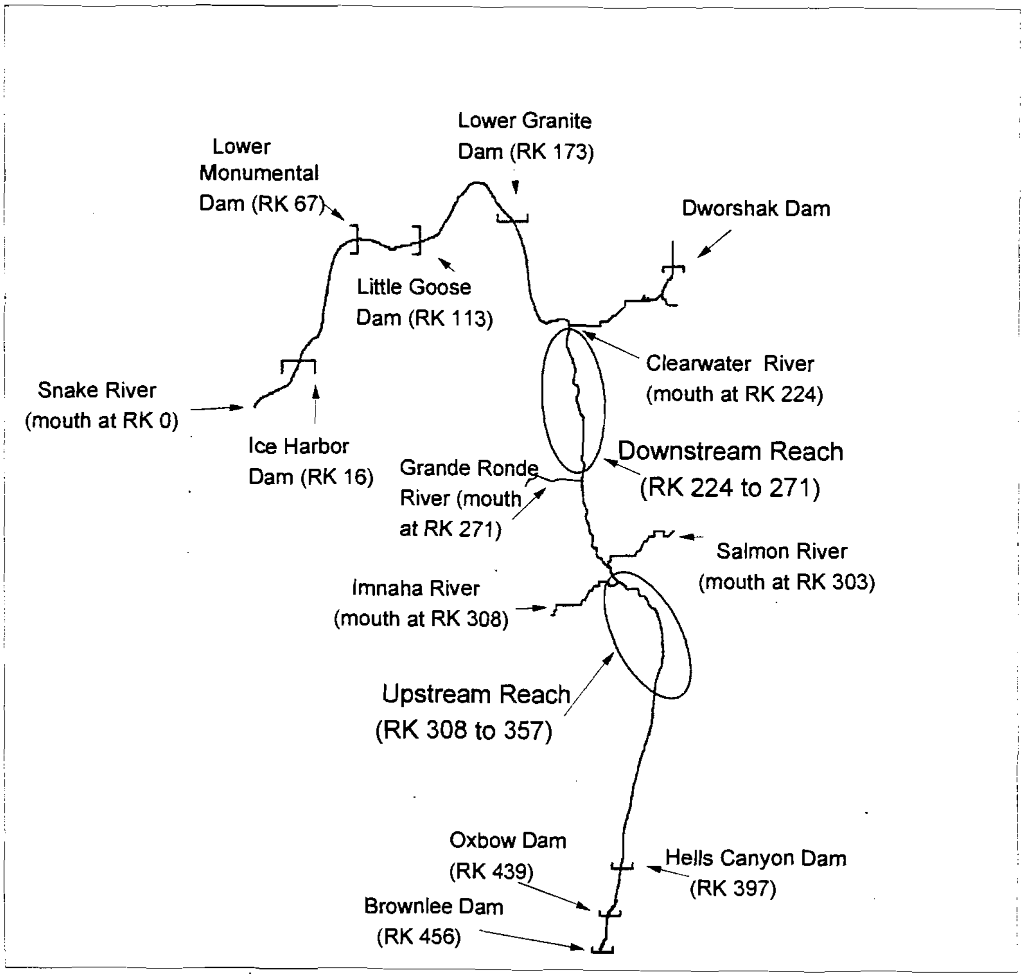

Figure 1. Snake River study area in 1996, including locations of upstream and downstream reaches, major tributaries, and dams.

167-km free-flowing reach presently used for spawning and rearing starts below Hells Canyon Dam (Fig. 1). Dworshak Dam, completed in 1971, is located on the North Fork Clearwater River about 3.1 km upstream from its confluence with the Clearwater River (Fig. 1; Clearwater RK 65).

Since 1991, water has been released from Dworshak Dam, U.S. Bureau of Reclamation projects upstream from Brownlee Reservoir, and the Hells Canyon Complex (RK 397) to augment summer flows and to cool the water in Lower Granite Reservoir, thereby increasing subyearling fall chinook salmon survival during seaward migration. Dworshak Dam has multilevel selector gates for temperature regulation of water released from Dworshak Reservoir into the Clearwater River. Water released from the U.S. Bureau of Reclamation projects was ultimately passed through Brownlee Reservoir and through the Hells Canyon Complex (Fig. 1). Hells Canyon Complex regulates Snake River reservoir flows and water temperatures in the Snake River, but the temperature of water released cannot be selected as at Dworshak Dam. Hells Canyon complex is referred to hereafter as being the source of flow augmentation from Snake River reservoirs.

Seaward migrating subyearling chinook salmon pass through Lower Granite Reservoir (Fig. 1). Lower Granite Reservoir is approximately 51 km long and has a surface area of 3,602 ha, a mean depth of 17 m, and a maximum depth of 42.1 m (Chipps et al. 1997). Lower Granite Dam, at RK 173 on the Snake River (Fig. 1), has six turbine intakes and eight spillways. Between 21 June and 30 August there was little spill so nearly all fish were routed to the powerhouse where a portion of fish were collected by submersible traveling screens. Detailed figures and descriptions of submersible traveling screens and juvenile fish bypass facilities at selected Columbia River Basin dams are given by Gessel et al. (1991). In 1995, experimental extended length (12 m) screens were installed in one turbine intake and the remaining five turbine intakes were fitted with extended screens by 1996. Collected fish were routed through the fish bypass system where they were electronically scanned for Passive Integrated Transponder (PIT) tags (Prentice et al. 1990).

METHODS

Data Collection

Natural subyearling fall chinook salmon were collected with a beach seine for PIT-tagging and survival studies in the Snake River (Connor et al. 1997). Seining sites were located in two reaches of the Snake River termed upstream (RK 308 to 357) and downstream (RK 224 to 271; Fig. 1). Seining was done weekly in both reaches starting in April and continued until water temperatures reached 20°C or the catch neared zero. Natural chinook salmon were aged at capture based on fork length and PIT tagged if greater than or equal to 60 mm (Connor et al. 1996).

A subsample of PIT-tagged natural salmon was recaptured at Little Goose Dam (Fig. 1) in 1996 using a separation-by-code hardware and software system (S. Downing et al. unpublished protocol, National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA 98112-2097). Recaptured salmon were weighed and measured. A scale was taken for aging and the fish was frozen for subsequent race identification.

Water temperature was monitored by University of Idaho personnel in Lower Granite Reservoir at RK 178. Water temperature profiles in Lower Granite Reservoir indicate that data collected at RK 178 largely provide representative water temperatures for at least the lower two thirds of the reservoir (Bennett et al. 1997). Cooler water from the Clearwater River mixes with the warmer Snake River water in the upper 10 to 15 km of the reservoir. A thermograph was positioned vertically on a rope 20 m below the water surface at RK 178. A thermograph was also placed downstream of Hells Canyon Dam (Fig. 1) to measure water temperature exiting Hells Canyon Complex. All thermographs recorded water temperature hourly. Daily average water temperature and flow data for Dworshak Dam, and daily average flow data for Lower Granite Dam, were provided by the U.S. Army Corps of Engineers. Daily average flow data for the Hells Canyon Complex, gaged at Hells Canyon Dam, were supplied by the U.S. Geological Survey.

Data Analysis

Race determination of each natural chinook salmon recaptured at Little Goose Dam was made by Washington Department of Fish and Wildlife (WDFW) personnel using tissue extracts, horizontal starch-gel electrophoresis (Aebersold et al. 1987), and maximum likelihood estimation (A. Marshall, unpublished protocol, WDFW, P.O. Box 43135, Olympia, Washington 98504-3135). The race determination for each fish was used to calculate the percentage of fall and spring/summer race chinook salmon in our sample. This percentage was tabulated by river reach. The age of each PIT-tagged natural chinook salmon recaptured at Little Goose Dam was tabulated with the race determinations.

Emergence dates were estimated (Connor et al. 1997) for natural subyearling fall chinook salmon fry to compare timing of emergence in upstream and downstream reaches of the Snake River. Box plots were used to characterize the tagging period and timing of dam passage by natural subyearling chinook salmon from the upstream and downstream reaches of the Snake River. The percentage of PIT-tagged natural subyearling fall chinook tagged in 1996 that were detected at or downstream from Lower Granite Dam in 1997 was tabulated. Survival of PIT-tagged natural subyearling fall chinook salmon was estimated to the tailrace of Lower Granite Dam using the single release version of the Cormack/Jolly-Seber survival probability model (Muir et al. 1998, Part Two in this report).

Mean daily flows for Lower Granite Reservoir were calculated using Lower Granite Dam flow data collected daily between 21 June and 31 August. Hourly water temperature data, recorded by the thermograph 20 m below the surface of Lower Granite Reservoir, were used to calculate daily mean water temperatures for 21 June to 31 August. We selected the 20-m depth because subyearling chinook salmon must sound to at least 20 m to pass Lower Granite Dam and fish could descend to this depth to avoid warm surface water. The daily mean maximum water temperature for each year was selected as an index of summer water temperature in Lower Granite Reservoir.

Mean daily flows and water temperatures in Lower Granite Reservoir were plotted to describe effects of flow augmentation. Fish passage indices (FPC 1996) were plotted to compare timing of flow augmentation to passage at Lower Granite Dam by natural subyearling chinook salmon. Fish passage indices were expanded fish collection counts at the dam adjusted for the proportion of water going through the powerhouse vs. the spillway. Since there is usually little spill during the summer emigration season the collection counts are equal to the total number passing the dam multiplied by fish guidance efficiency.

RESULTS

Subyearling fall chinook salmon dominated the racial composition of PIT-tagged natural fish recaptured at Little Goose Dam in 1996 (Table 1). Recaptured fish from the upstream reach of the Snake River were 100% subyearling fall chinook salmon. Recaptured fish from the downstream reach were 86% subyearlings and 72% fall chinook salmon. All yearling fish were spring/summer chinook salmon. Seven of 10 spring/summer chinook salmon were classified correctly, based on morphology at tagging, as spring/summer chinook salmon. No fall chinook salmon were misclassified as spring chinook salmon when tagged. We omitted spring/summer chinook salmon, and fish classified during tagging as spring/summer chinook salmon, from subsequent analyses. All fish referred to hereafter are assumed to be natural subyearling fall chinook salmon.

Fall chinook salmon fry emerged earlier in the upstream reach of the Snake River (n = 107; median date = 25 April) than in the downstream reach of the Snake River (n = 695; median date = 8 May) (Fig. 2). We PIT tagged 51 and 293 fall chinook salmon in the upstream and downstream reaches (Table 2). Fall chinook salmon tagged in the upstream reach averaged 5 mm shorter (69 mm) than fish in the downstream reach (74 mm) (Table 2). Mean water temperature during tagging was 0.9°C cooler in the upstream reach than in the downstream reach (Table 2). Tagging occurred over a shorter time period and earlier in the upstream reach (49 days; median date = 16 May) than in the downstream reach (91 days; median date = 11 June) (Fig. 3). Fall chinook salmon tagged in the upstream reach were detected earlier (n = 19; median date = 4 July) at Lower Granite Dam than fish

Table 1. Number of PIT-tagged natural subyearling chinook salmon detected and recaptured at Little Goose Dam in 1996. The percentage of subyearlings (0) and yearlings (1) determined by aging, and the percentage of fall chinook salmon vs. spring/summer chinook salmon determined by genetic analyses, are also given.

			Age (%)		Race (%)	
Reach	Number detected	Number recaptured	0	1	Fall	Spring/ summer
Upstream	9	9	100	0	100	0
Downstream	45	42	86	14	72	28

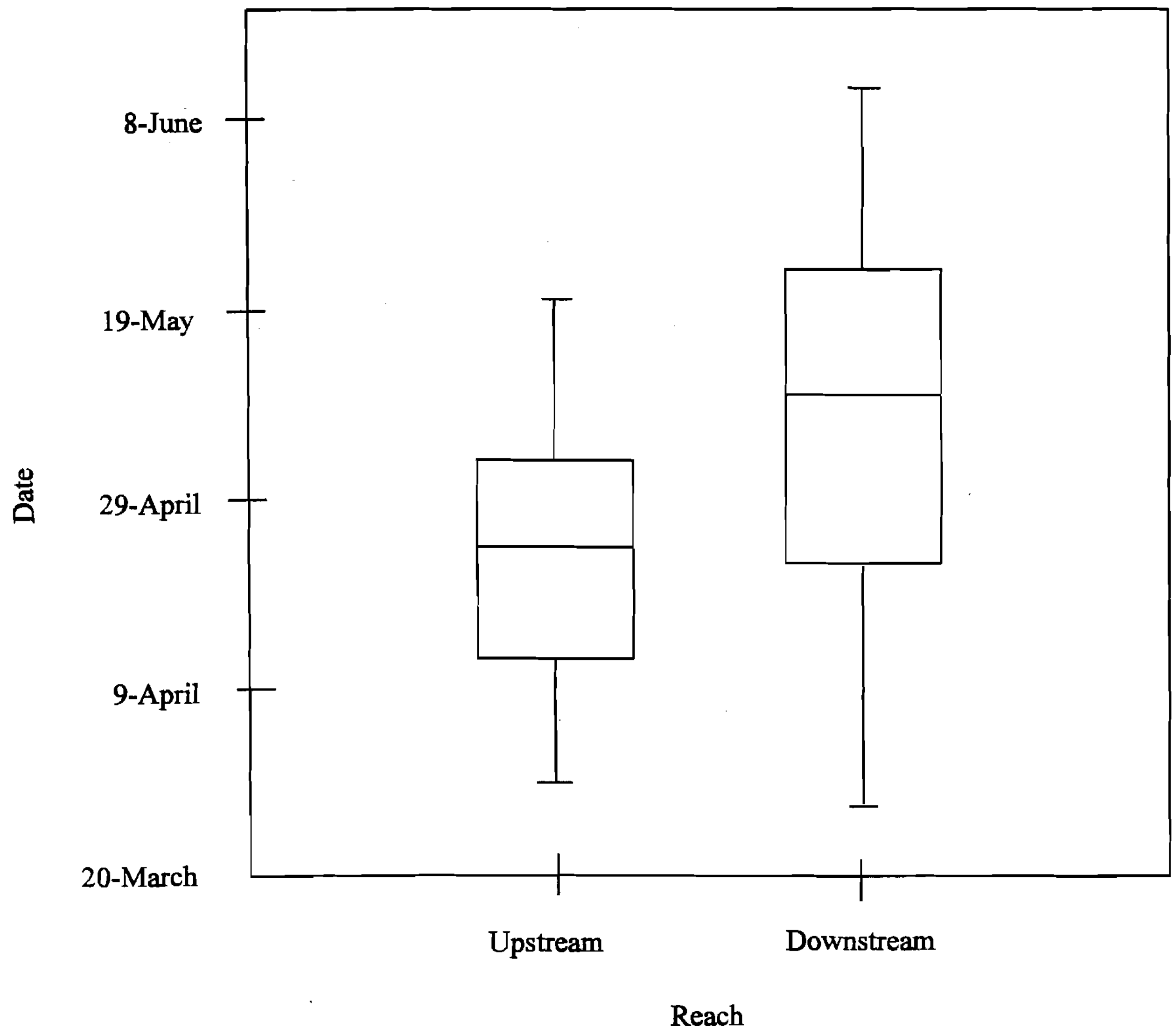

Figure 2. Dates of fry emergence for natural subyearling fall chinook salmon PIT tagged in the upstream and downstream reaches of the Snake River, 1996. The bottom and top of each box are the 25th and 75th percentiles, respectively, and the horizontal line within the box is the median. Vertical lines represent the range.

Table 2. Number of natural subyearling fall chinook salmon released in the Snake River in upstream and downstream reaches and the mean fork length (mm) and mean water temperature at tagging (°C). Standard deviations are in parentheses.

Reach	Number released	Mean fork length (mm)	Mean water temperature (°C)
Upstream	51	69 (7.7)	12.8 (1.43)
Downstream	293	74 (12.3)	13.7 (2.40)

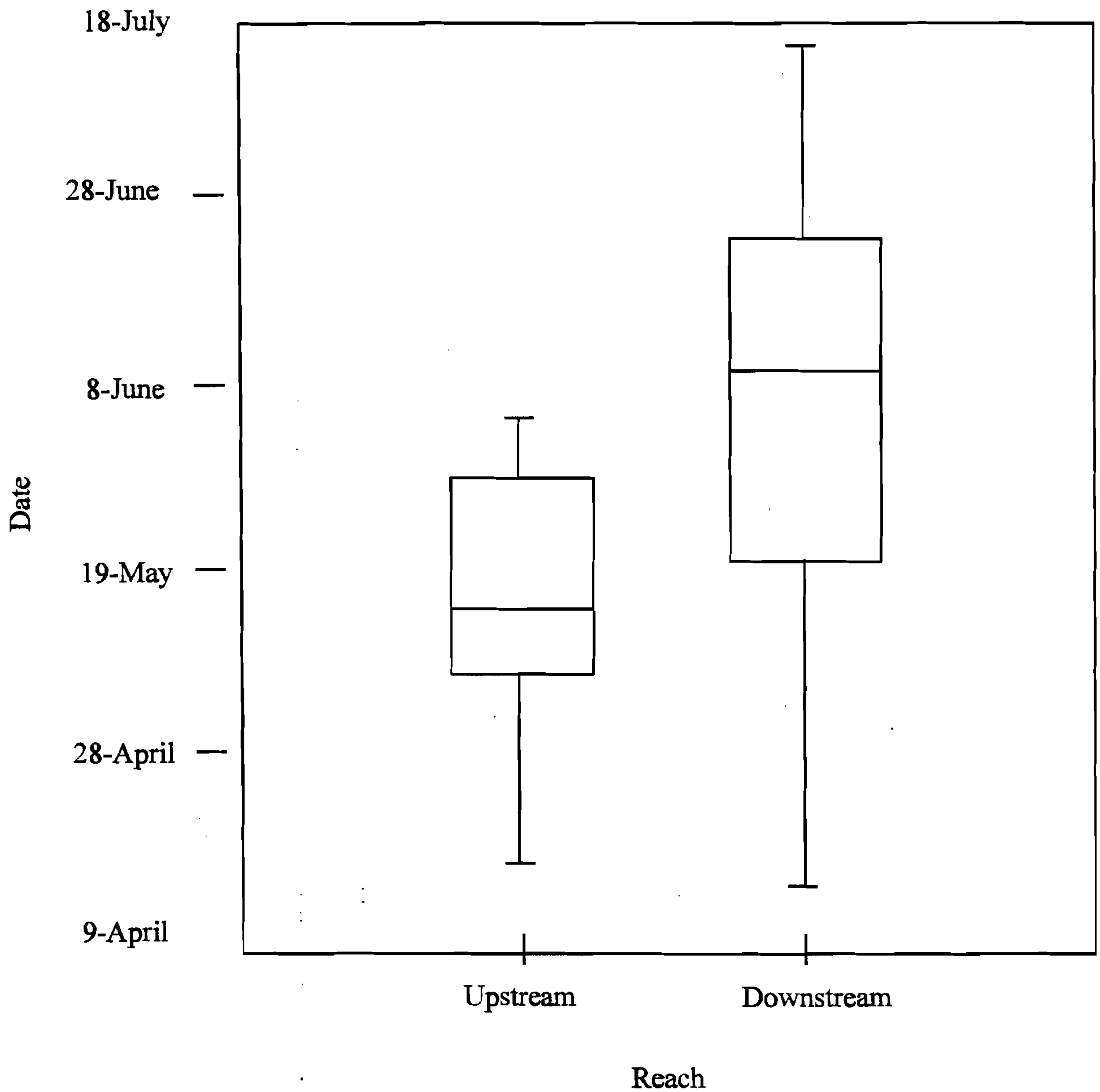

Figure 3. Dates of PIT tagging for natural subyearling fall chinook salmon in the upstream and downstream reaches of the Snake River, 1996. The bottom and top of each box are the 25th and 75th percentiles, respectively, and the horizontal line within the box is the median. Vertical lines represent the range.

from the downstream reach (99; median date = 23 July) (Fig. 4). Only 1 (2.0%) and 5 (1.7%) fall chinook salmon PIT tagged in the upstream and downstream reaches in 1996 residualized in Snake River or Columbia River reservoirs and survived to be detected migrating seaward as yearlings in 1997 (Table 3).

Detection and survival probability estimates for fall chinook salmon tagged in the upstream reach of the Snake River lacked precision. Nevertheless, differences between estimates for the fish from the upstream and downstream reaches were evident (Table 4). Detection probability at Lower Granite Dam estimated by pooling releases of fish from upstream and downstream reaches was markedly higher in 1996 than in 1995 (Table 5). Survival probability to the tailrace of Lower Granite Dam estimated by pooling releases of fish was lower in 1996 than in 1995 (Table 5). Flows during the 21 June to 31 August summer flow augmentation period were lower in 1996 than in 1995, and mean daily and maximum summer water temperatures were higher in 1996 than in 1995 (Table 5).

Implementation of summer flow augmentation in 1995 began on about 16 July using 10°C water from Dworshak Reservoir, and ended on about 31 August (Fig. 5). Augmentation from Hells Canyon Complex began and ended on about 25 July and 12 August. Effects of augmentation on flow in 1995 was masked by natural runoff, but augmentation dampened the rate of descent of the hydrograph and maintained water temperatures in Lower Granite Reservoir below 20°C throughout the summer flow augmentation period (Table 5). Timing of flow augmentation in 1995 coincided with fall chinook salmon passage at Lower Granite Dam as measured by the subyearling passage index (Fig. 5).

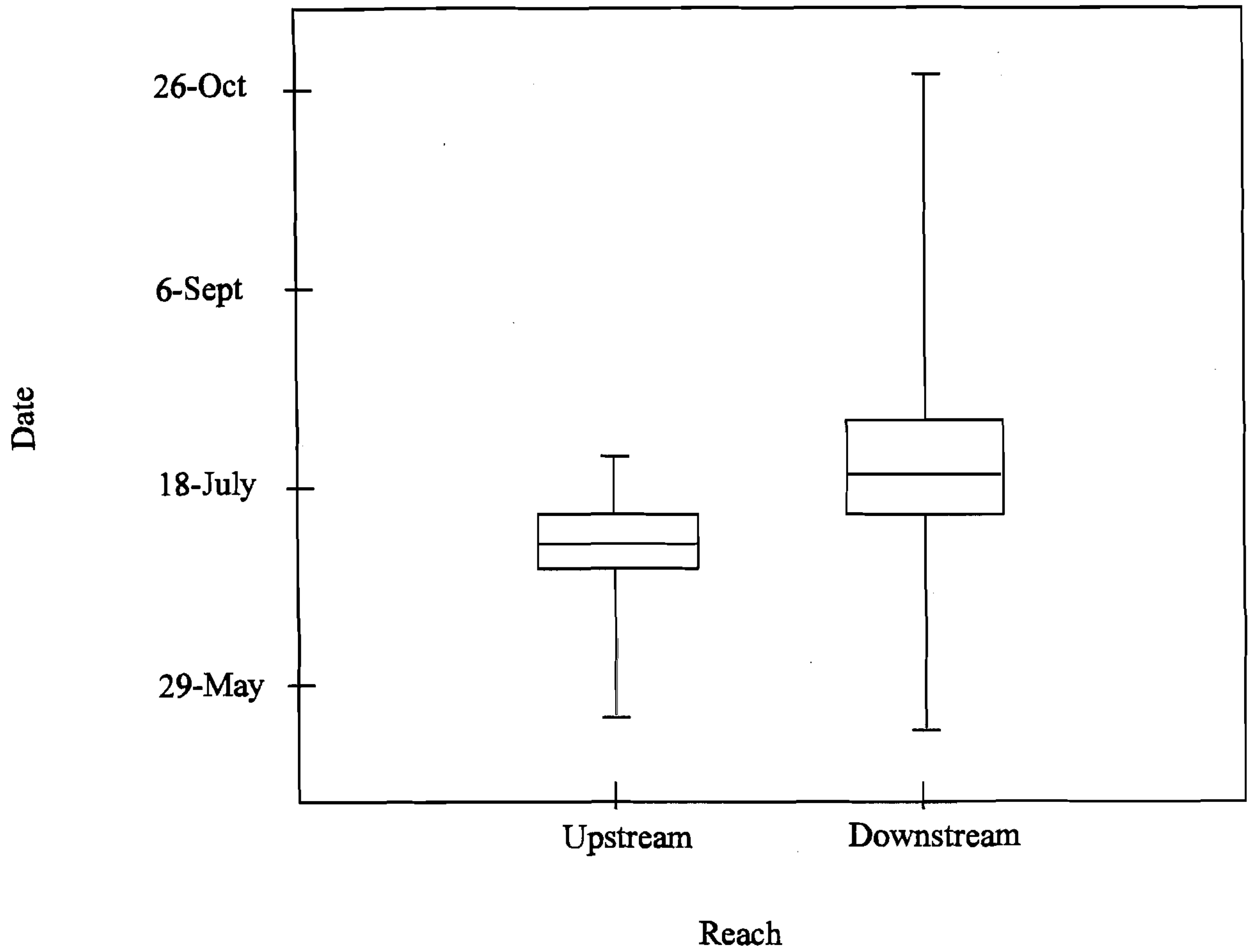

Figure 4. Passage dates at Lower Granite Dam for natural subyearling fall chinook salmon PIT tagged in the upstream and downstream reaches of the Snake River, 1996. The bottom and top of each box are the 25th and 75th percentiles, respectively, and the horizontal line within the box is the median. Vertical lines represent the range.

Table 3. First detections by dam of natural fall chinook salmon PIT tagged in the Snake River as subyearlings in 1996 that were detected in 1997 as yearlings after over-wintering in Snake or Columbia River reservoirs.

Reach	First detection by dam									
	Lower Granite		Little Goose		Lower Monumental		McNary		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Upstream	0	0.0	0	0.0	0	0.0	1	2.0	1	2.0
Downstream	0	0.0	3	1.0	1	0.3	1	0.3	5	1.7

Table 4. Detection and survival probability estimates at Lower Granite Dam for PIT-tagged natural subyearling fall chinook salmon released in the upstream and downstream reaches of the Snake River in 1996. Standard errors are in parentheses. Detection probability is a measure of fish guidance efficiency at Lower Granite Dam and survival probabilities are estimates of survival from release to the tailrace of the dam.

	Probability estimates	
Reach	Detection at LGR	Survival release to LGR
Upstream	0.474 (0.115)	0.662 (0.127)
Downstream	0.729 (0.053)	0.459 (0.039)

Table 5. Detection and survival probability estimates from release to the tailrace of Lower Granite Dam for PIT-tagged natural subyearling fall chinook pooled from the upstream and downstream reaches of the Snake River in 1995 and 1996. Mean daily flow (KCFS), mean daily water temperature (°C), and mean daily maximum water temperature (Max °C) in Lower Granite Reservoir for the 21 June to 31 August summer flow augmentation period are also given.

		Lower Granite Reservoir			Probability estimates	
Year	Reach	KCFS	°C	Max °C	Detection (s.e.)	Survival (s.e.)
1996	Pooled	52.7	18.3	21.1	0.675 (0.050)	0.491 (0.039)
1995	Pooled	55.4	17.9	19.9	0.468 (0.035)	0.678 (0.046)

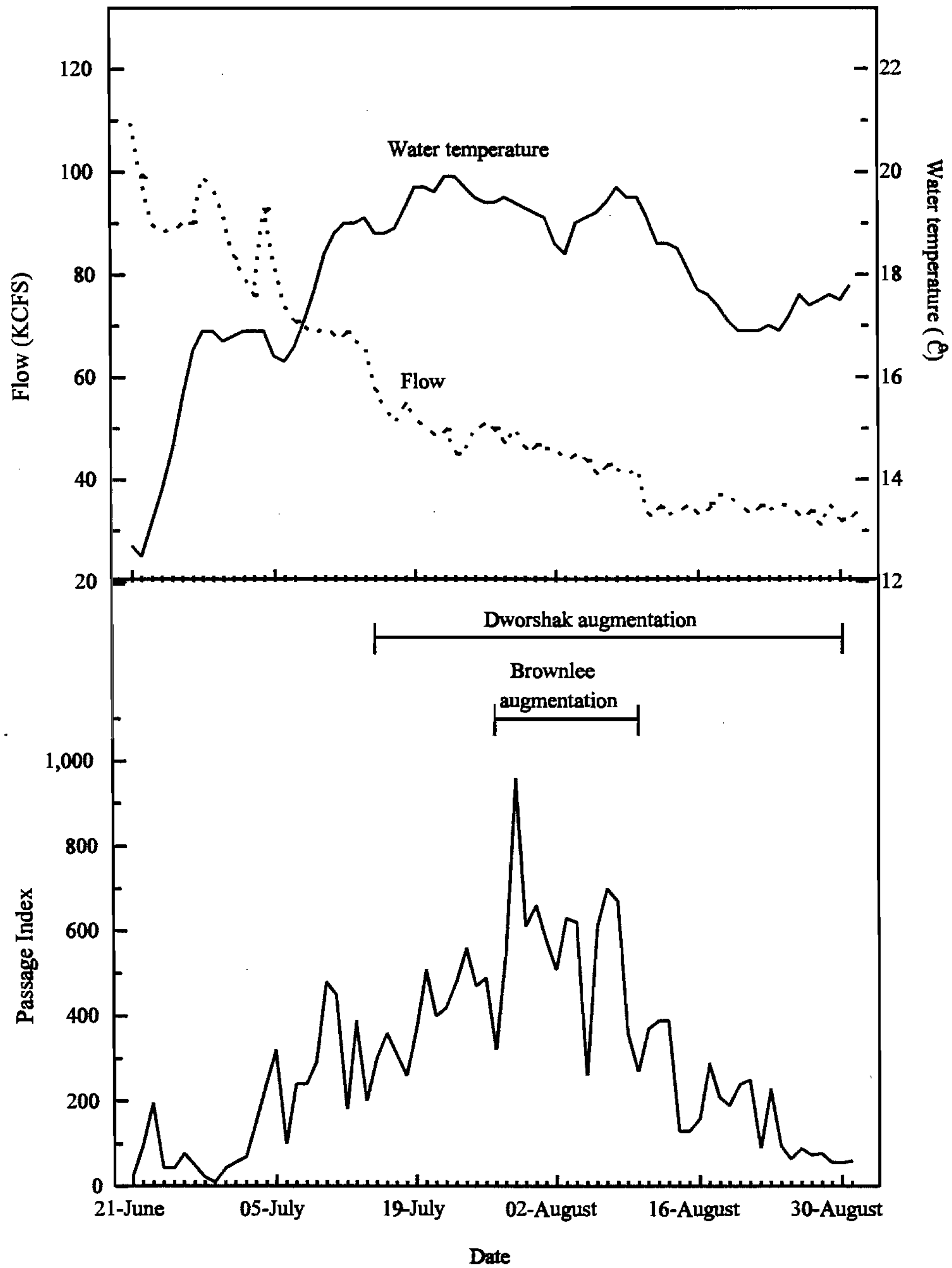

Figure 5. Pattern of Lower Granite Reservoir flow and water temperature during the 21 June to 31 August summer flow augmentation period, time of augmentation from Brownlee and Dworshak Reservoirs, and the subyearling passage index at Lower Granite Dam in 1995.

In 1996, 20°C water from Hells Canyon Complex was released for summer flow augmentation before drafting of Dworshak Reservoir began. Augmentation from Hells Canyon Complex began about 15 July and continued to about 15 August (Fig. 6). Augmentation from Dworshak Reservoir began as augmentation from Hells Canyon Complex ended. The effect of augmentation on flows at Lower Granite Dam in 1996 and 1995 was to dampen the rate of descent in the hydrograph. The effect of augmentation on water temperature in Lower Granite Reservoir differed between years. In 1996, water temperature continued to rise after augmentation began and eventually reached 21.1°C (Table 5; Figs. 5 and 6). The passage index for subyearling chinook salmon in 1996 was skewed and dropped off markedly as augmentation from Hells Canyon Complex began (Fig. 6). Most natural subyearling fall chinook salmon passed Lower Granite Dam before any water from Dworshak Reservoir was released in 1996 (Fig. 6).

DISCUSSION

Differences in timing of early life history events for Snake River fall chinook salmon may be important to survival and are caused by water temperature. In 1996, Snake River water was warmer in the upstream reach than in the downstream reach. Fall chinook salmon juveniles developed faster in the upstream reach and emerged, reared, and began seaward migration earlier in the summer than in the downstream reach. Fall chinook salmon PIT tagged in the upstream reach passed through Lower Granite Reservoir earlier when flows were relatively high and water temperatures were relatively low. Seaward migrating natural and hatchery fall chinook salmon which passed through Lower Granite Reservoir early in

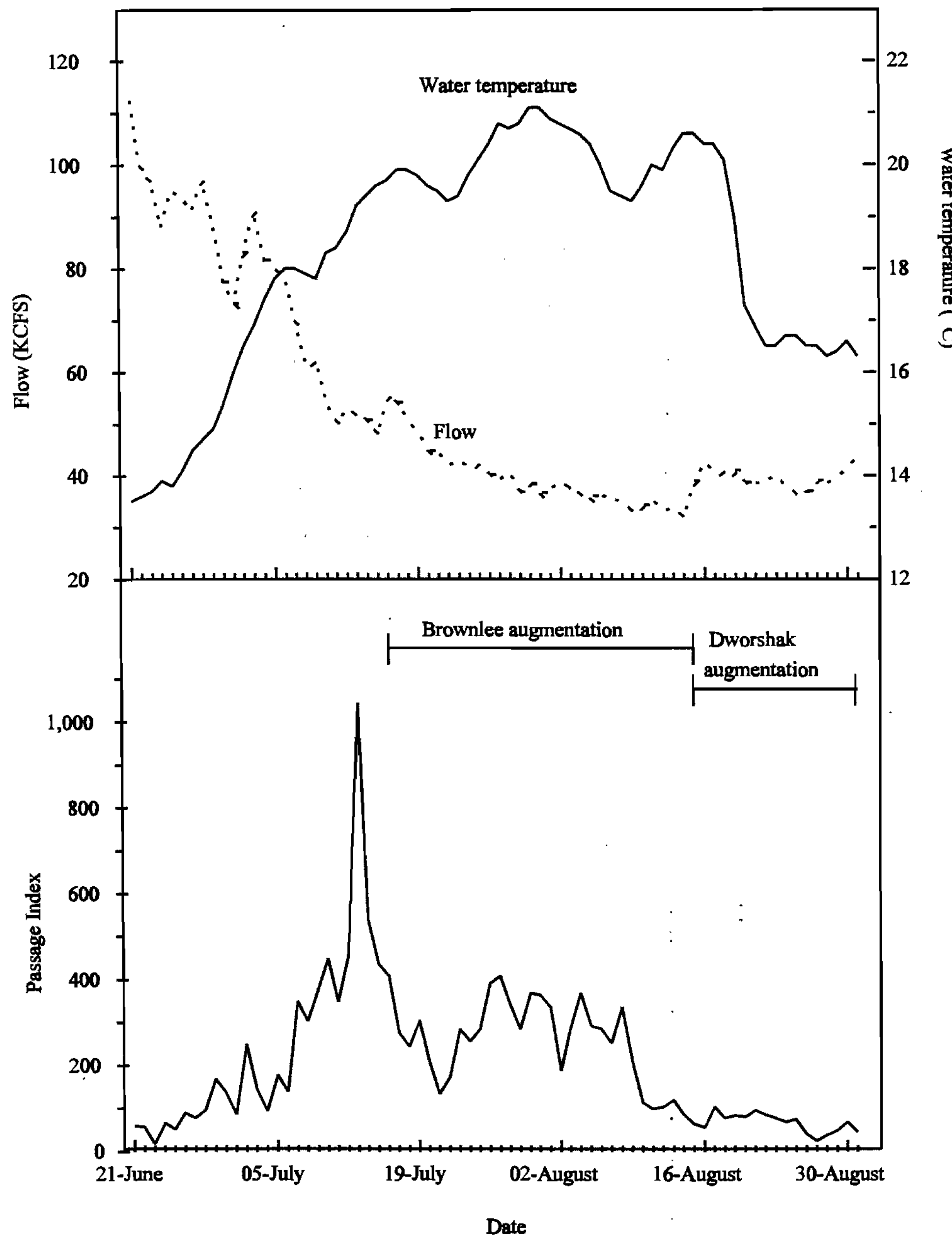

Figure 6. Pattern of Lower Granite Reservoir flow and water temperature during the 21 June to 31 August summer flow augmentation period, time of augmentation from Brownlee and Dworshak Reservoirs, and the subyearling passage index at Lower Granite Dam in 1996.

1995 survived better than those that passed later (Connor et al. 1997; Muir et al. 1998, Part Two in this report; Smith et al. 1997). Although the standard error on our survival probability estimate for PIT-tagged salmon from the upstream reach in 1996 was large, we suspect survival for fish produced in the upstream reach was higher than in the downstream reach.

Seaward migration by yearling fall chinook salmon could be meaningful to our efforts to estimate survival because survival probability estimates are made assuming that the yearling emigrants died upstream from Lower Granite Dam. If we count the yearlings as survivors to Lower Granite Dam in 1996, survival probability estimates for the upstream and downstream reaches increase by about 2 percentage points (upstream = 0.682 $\pm$ 0.126; downstream = 0.476 $\pm$ 0.039) consistent with the limited effects demonstrated with survival probability estimates for hatchery subyearling fall chinook (Smith et al. 1997; Muir et al. 1998, Part Two in this report). More conclusive assessments of yearling emigration by fall chinook salmon would only be possible if the fish bypass system at Lower Granite Dam was operated year round. For the present, it appears that the effects of yearling emigration on survival probability estimates are insubstantial.

The increase in detection probability between 1995 and 1996 was most likely caused by installation of extended length traveling screens in all six turbine intakes of Lower Granite Dam in 1996. Only one turbine intake was equipped with extended screens in 1995. Juvenile salmonids passing through turbines of Columbia River dams die at rates of about 11% (Schoeneman et al. 1961). Installation of extended traveling screens should have increased subyearling fall chinook salmon survival in 1996.

Despite the installation of extended traveling screens at Lower Granite Dam, we estimated lower survival from release to the tailrace of Lower Granite Dam in 1996 than in 1995. A relation is evident between natural and hatchery subyearling fall chinook salmon survival and Lower Granite Reservoir flow and water temperature (Connor et al., in press; Muir et al. 1998, Part Two in this report). Connor et al. (in press) concluded that summer flow augmentation, especially cool water releases from Dworshak Reservoir, can increase subyearling chinook salmon survival by limiting thermally induced mortality in dry years and reducing predation under all flow conditions. Reliance on flow augmentation from water upstream from Hells Canyon Complex in 1996 resulted in warmer water than in 1995 and possibly decreased survival of later emigrating fish.

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PART TWO

Passage Survival of Hatchery Subyearling Fall Chinook Salmon to Lower Granite, Little Goose, and Lower Monumental Dams, 1996

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CONTENTS PART TWO

INTRODUCTION

Snake River fall chinook salmon (*Oncorhynchus tshawytscha*) were listed as threatened under the Endangered Species Act in April 1992 (NMFS 1992). The status was changed to endangered by emergency action in 1994, then restored to threatened in 1995. Until recently, little was known about the migrational characteristics of Snake River subyearling fall chinook salmon, including the proportion that survive passage through the Snake River dams and reservoirs, how flow volume and water temperature affect their survival, and the percentage of migrants collected and transported at the dams. As a result, operational strategies to maximize survival of subyearling chinook salmon in the Snake River have been largely based on data from studies of subyearling chinook salmon in the lower Columbia River. Specific information on Snake River migrants is necessary to develop and assess the effects of possible restoration strategies such as supplementation, dam modification, flow augmentation, spill, or reservoir drawdown.

For Snake River fall chinook salmon, it has been difficult to collect enough fish to serve as experimental subjects. Although the number of natural subyearling fall chinook salmon collected by beach seine and PIT tagged upstream from Lower Granite Dam has increased in recent years (Connor et al. 1994a,b, 1997a,b), numbers are still too low to make sufficient releases within a single year to examine relationships among survival, travel time, and environmental conditions. Three options are available to increase the number of subyearling fall chinook salmon available for tagging: 1) collect more natural river migrants from the Snake River using available capture methods, 2) import fall chinook salmon collected in the Columbia River, where they are more abundant, or 3) use hatchery-reared subyearling fall chinook salmon of Snake River stock as surrogates of naturally produced migrants. The current population status of fall chinook salmon in the Snake River and concerns about inter-basin stock transfers limits the use of options 1 and 2.

Conclusions derived from studies of hatchery-reared fish (option 3) are applicable to natural fish only if the assumption of surrogacy is met. However, it is unlikely that fish taken directly from a hatchery, tagged, and released will behave similarly to natural migrants, at least initially (Steward and Bjornn 1990). Acclimation to ambient environmental conditions prior to release, releasing fish of appropriate size, and timing of releases to coincide with the migration of natural fish may, however, lessen differences between hatchery-reared and natural migrants. Additionally, survival information using hatchery fish can help guide future supplementation efforts with fall chinook salmon in the Snake River Basin.

Here we report the results of the second year of releases of PIT-tagged hatchery subyearling fall chinook salmon in the Snake River and the first year of releases in the Clearwater River to estimate survival and travel time. This study represents an extension of earlier studies (1993-1996) of juvenile salmon and steelhead survival in the Snake River conducted by the National Marine Fisheries Service and the University of Washington (Iwamoto et al. 1994; Muir et al. 1995, 1996). In these studies, researchers estimated passage survival and PIT-tag detection probabilities (an approximation of fish guidance efficiency (FGE) at the dams) for hatchery-reared and natural yearling spring/summer chinook salmon and hatchery-reared yearling steelhead (*O. mykiss*) using Single-Release (SR) and Paired-Release (PR) methodologies for survival estimation.

Study objectives were to: 1) estimate detection and passage survival probabilities of hatchery subyearling fall chinook salmon released in the Snake and Clearwater Rivers, and 2) investigate relationships between travel times and passage survival probabilities of subyearling fall chinook salmon and environmental influences such as flow volume, water temperature, and turbidity.

METHODS

Study Area

The study was conducted from Pittsburg Landing on the Snake River (Snake River Kilometer (RK) 346) and Big Canyon Creek on the Clearwater River (Clearwater RK 57) to McNary Dam on the Columbia River (Columbia RK 470) (Fig. 1). The area included a 111-km free-flowing reach of the Snake River, a 57-km free-flowing reach of the Clearwater River (confluence at Snake RK 224), and five dams and reservoirs: Lower Granite Dam (Snake RK 173), Little Goose Dam (Snake RK 113), Lower Monumental Dam (Snake RK 67), Ice Harbor Dam (Snake RK 16), and McNary Dam. The Snake River enters the Columbia River at RK 522.

Primary Release Groups

All subyearling fall chinook salmon used in our study in 1996 were from Lyons Ferry Hatchery (Snake RK 95) (Washington Department of Fish and Wildlife). Our goal was to release experimental fish of approximately the same size as natural fall chinook salmon

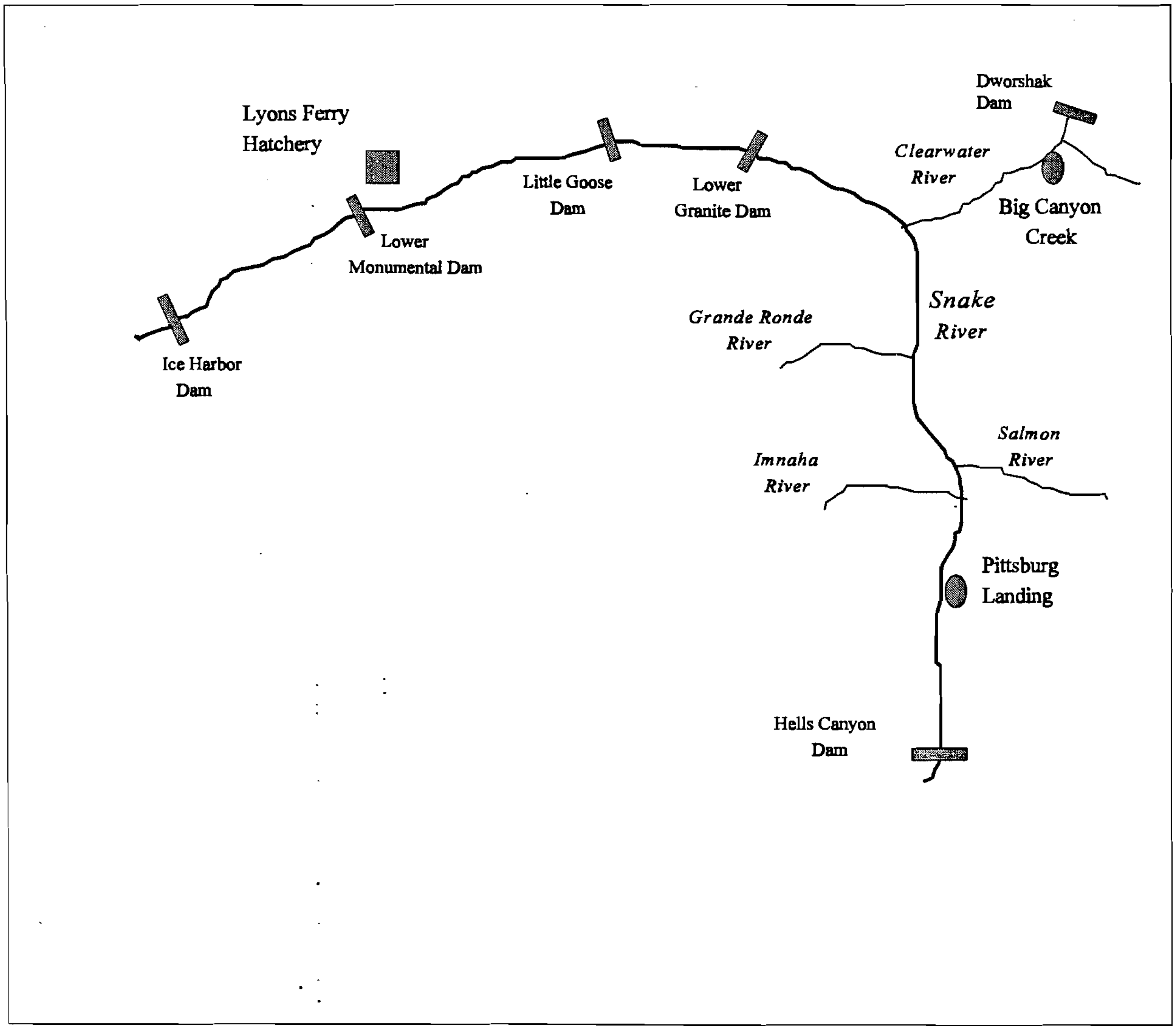

Figure 1. Study area showing location of Lyons Ferry Hatchery and release sites (Pittsburg Landing and Big Canyon Creek), 1996.

present in the Snake River at the time of release. On a given date, natural fall chinook salmon in the Clearwater River tend to be smaller than those in the Snake River (Arnsberg et al. 1992). Target length for fish in primary release groups was 75 mm in fork length.

Primary releases were made in the Snake River at Pittsburg Landing and in the Clearwater River at Big Canyon Creek. Fish for primary release groups were PIT-tagged weekly at Lyons Ferry Hatchery, using established techniques (Iwamoto et al. 1994). Tagging was done weekly from 4 June to 8 July. At the hatchery, well water was supplied during PIT tagging and loading for transportation at a near constant temperature averaging 11.5°C. Fork lengths were measured on all fish tagged, and about 20% of the fish were weighed. Fish were not coded-wire-tagged in 1996.

Immediately after tagging, we transported tagged fish in truck-mounted aerated tanks to Pittsburg Landing (1,045-L fiberglass tank) and Big Canyon Creek (1,080-L aluminum tank). Elapsed time from departure from the hatchery to release into floating net-pens was standardized at 8 hours for both release sites. Actual transport to Pittsburg Landing and Big Canyon Creek release sites took about 6 and 3 hours, respectively. Immediately after arrival at Pittsburg Landing, fish were acclimated to ambient river temperature using a gasoline powered water pump that slowly replaced the hatchery water in the tank with river water. Upon arrival at Big Canyon Creek, trucks were parked for about 3 hours before beginning in-tank acclimation to river temperature. After 8 hours had elapsed since departure from the hatchery, at both release sites fish were released into 2 x 1 x 1-m floating net-pens for approximately 48 hours of additional acclimation. Holding densities in the transport vehicles and in the net pens were kept below 8 kg fish/m^3 of water.

Secondary Release Groups

Secondary releases to estimate post-detection bypass survival consisted of a pair of release groups; the treatment group released into the terminus of the juvenile bypass system at Lower Granite Dam, and the reference group released into the tailrace (Iwamoto et al. 1994). We PIT tagged hatchery subyearling fall chinook salmon on 13 and 20 June at Lyons Ferry Hatchery for eventual use as secondary releases at Lower Granite Dam. The tagging and transport procedures were the same as those used for the primary release groups, while acclimation procedures differed. Fish for secondary release groups were transported to Pittsburg Landing immediately after tagging, and allowed to recover from tagging during the transport and river acclimation process. After several hours of holding in the transport tank to acclimate to ambient river temperature, fish were released directly into the Snake River. Fish for secondary releases were not held in net-pens for additional acclimation.

The fish from these release groups were subsequently recovered at Lower Granite Dam for use in secondary releases. Their PIT-tag codes were entered into the separation-by-code system at Lower Granite Dam at the time of their release, so that we could collect them when they were detected as they passed through the juvenile collection facility. The purpose of secondary releases at Lower Granite Dam is to assess mortality that may have occurred to fish in primary release groups between the point of detection at Lower Granite Dam and the point of remixing with nondetected fish in the tailrace. Because the fish for our secondary releases were initially released at Pittsburg Landing and then recaptured at Lower Granite Dam, they were more representative of the fish from our primary release groups as they passed Lower Granite Dam.

We released secondary groups daily during the period (18 July to 11 August) that most PIT-tagged fish from the primary release groups were passing Lower Granite Dam. Each day, fish collected from the secondary group in the separation-by-code system were randomly divided into two release groups and loaded into 1.8 x 1.8 x 0.9-m (3,000-L) aluminum tanks mounted on trucks. Fish were anesthetized, PIT-tag codes were scanned, and lengths and weights measured before loading. Holding densities were low, not exceeding 100 fish per tank. Both groups were held in fresh water at least 24 hours before release. Tanks were aerated and supplied with at least 2 L/min of water per tank during holding. Mortalities were recorded and loose tags recovered and recorded just before live fish were released. Treatment groups were released directly from the truck-mounted tank into a PVC pipe that ran parallel to the pipe used to return PIT-tagged fish diverted by the slide-gate to the river. Reference groups were transferred to similar-sized containers on board a vessel, transported to the tailrace release site, and released water-to-water. Fish were released midday (between 12:00 and 3:00 PM).

Operation of PIT-Tag Interrogation and Slide-Gate Systems

Most detected PIT-tagged fish from this and other studies were automatically diverted back to the river by slide gates (details of their operation in Muir et al. 1995) at Lower Granite, Little Goose, and Lower Monumental Dams beginning on 14 June. Prior to these dates, some PIT-tagged fish were anesthetized and handled as part of the fish sampling procedure of the Smolt Monitoring Program before their return to the Snake River. However, this had little effect on this study because few fish from our releases arrived at the dams prior to 14 June. PIT-tag interrogation was terminated in 1996 on 31 October at Lower Granite Dam, on 28 October at Little Goose and Lower Monumental Dams, and on 14 December at McNary Dam. In 1997, operations resumed on 26 March at Lower Granite Dam, on 1 April at Little Goose and Lower Monumental Dams, and on 5 April at McNary Dam. To study growth, we recaptured a subsample of each release group using the separation-by-code system at Little Goose Dam.

Data Analyses

We used the methods described by Iwamoto et al. (1994) and Muir et al. (1995, 1996) for data collection and retrieval from the PIT Tag Information System (PTAGIS), database quality assurance/control, construction of capture histories, tests of assumptions, estimation of survival and detection probabilities, and travel time. The statistical models used to estimate survival from PIT-tag data were the Single-Release (SR) and Paired-Release (PR) Models. Background information and statistical theory underlying these models were described by Iwamoto et al. (1994).

Residualization and Interpretation of Model Parameters

The tendency of subyearling fall chinook salmon to residualize (some subyearling fish overwinter in the Snake River, then resume migration as yearlings the following spring) violates assumptions of the Single-Release Model (Smith et al. 1997). Fish released in the Snake and Clearwater Rivers that immediately migrated downstream would be expected to have higher survival probabilities than would fish released at the same time that residualized and spent the winter in the reservoir prior to migrating the following spring.

Because of the effects of residualization on survival estimates, we first based our survival analyses solely on PIT-tag detections that occurred during the summer and fall following release, and ignored detections that occurred the following spring. This approach changed the interpretation of survival probabilities in the Single-Release Model. For example, the parameter previously defined as the probability of survival within a particular reach (Iwamoto et al. 1994; Muir et al. 1995, 1996), became the combined probability of migrating through the reach as a subyearling and the probability of surviving the reach for subyearling migrants (i.e., the product of the two probabilities). The detection probability at each dam was the probability for individuals that migrated as subyearlings, not for the entire group.

We then estimated the proportion of fish tagged in 1996 that residualized, based on the proportion detected in the spring of 1997 and detection probabilities of PIT-tagged hatchery fall chinook salmon released as yearlings in the spring of 1997. The probability of detecting in 1997 a fish that residualized and migrated as a yearling could not be estimated reliably from the residualized fish themselves because too few of them were detected in 1997.

Validity of Secondary Releases

We assessed the validity of our secondary releases by comparing detection rates and travel times downstream from Lower Granite Dam for fish from secondary release groups with those for fish from primary release groups. We also compared mean fork lengths of fish from secondary release groups at the time of release at Lower Granite Dam, with fork lengths of fish from primary release groups measured when they were recaptured at Little Goose Dam.

Detection Probability vs. Fish Guidance Efficiency

Fish guidance efficiency (FGE) is the proportion of those fish entering the powerhouse that are successfully guided away from turbine intakes and into juvenile bypass facilities. The FGE at a particular dam can be expressed as:

$$FGE = \frac{A}{A + B} \times 100\% \qquad (1)$$

where: A = number of fish diverted into the bypass system; and

B = number of fish that passed through turbines.

The probability of detecting a PIT-tagged fish (P) estimated by the Single-Release Model is similar, but not equivalent to FGE:

$$P = \frac{C}{C + D} \qquad (2)$$

where: C = number of fish detected at the dam; and

D = number of fish that survived to the tailrace of the dam but were not detected as they passed.

The values A and C are nearly identical: a difference could be caused by a small amount of mortality that may occur in the bypass system between entry into the powerhouse and the point of detection and the negligible number of fish that pass through the bypass without being detected. The value B includes only fish that entered the powerhouse, while D also includes fish that passed via the spillway. However, even under conditions of no spill at the dam, the values of B and D differ, because B includes all fish that enter the turbines and D includes only those that survive turbine passage. Thus, when there is no spill, P is a larger value than FGE (and the estimate $\hat{P}$ generally overestimates FGE) because the numerators for FGE (Equation 1) and P (Equation 2) are essentially the same, but the denominator for FGE is larger than the denominator for P. The extent to which $\hat{P}$ overestimates FGE depends on the probability of surviving turbine passage (S_T) for the fraction of fish that pass through turbines. Assuming that A and C are equal, an estimate of FGE can be derived from

$$\hat{FGE} = \frac{(\hat{P} \cdot S_T)}{\hat{P} \cdot S_T + (1 - \hat{P})} \times 100\%. \qquad (3)$$

Effects of Acclimation on Travel Time and Survival

On 13 and 20 June, two distinct groups of PIT-tagged subyearling chinook salmon were released at Pittsburg Landing. A primary group was released after 48-hour acclimation in floating net pens and a secondary group was released directly from a truck-mounted tank into the Snake River (after acclimation to river temperature while still in the tank). To evaluate the physiological effects of 48-hour acclimation, levels of gill Na^+-K^+ ATPase were measured at the hatchery during tagging and from both groups of fish at release. Gill samples were collected for Na^+-K^+ ATPase assay and processed using the method of Schrock et al. (1994) and mean activity levels compared using ANOVA and Tukey's Multiple Comparison Test. To evaluate the effects of 48-hour acclimation on fish performance after release, travel time and survival to Lower Granite Dam and survival to Lower Monumental Dam were compared between the two groups.

Comparison of Natural and Hatchery Subyearling Chinook Salmon

To evaluate the efficacy of using hatchery fish as surrogates for natural fish, several measures of fish performance were evaluated, including comparisons of size at release and at time of recapture at Lower Granite and Little Goose Dams, Gill Na^+-K^+ ATPase activity at release, passage distributions and travel times to Lower Granite Dam, percent that residualized, and survival rates to downstream dams. The natural fish used for comparison were those captured by beach seine, PIT tagged, and released in the free-flowing Snake River (Connor et al. 1998, Part One in this report).

Survival, Travel Time, and Environmental Variables

Subyearling fall chinook salmon migrate over prolonged periods of time, during which environmental conditions can change dramatically. Thus, measures of environmental conditions relevant to migration performance must be chosen carefully. This is especially true for subyearlings taken directly from hatcheries and released into rivers, because both timing of onset of migration and migration rates can vary widely among individuals. Smith et al. (1998) investigated relationships of environmental factors to survival of actively migrating yearling chinook salmon. Indices of exposure to factors at each dam for each group of PIT-tagged fish were defined as the average value of the factor during the period between the group's 25th and 75th percentiles of passage at the dam. However, indices defined over this "middle-of-passage" period were not appropriate to relate to survival to Lower Granite Dam tailrace for subyearling fall chinook salmon released in free-flowing river sections above Lower Granite Dam, because mortality was relatively high, and much of the mortality probably occurred prior to the date of the 25th percentile of passage at Lower Granite Dam, which was as much as 44 days after the date of release (many fish in the release group never experienced the conditions present at the 25th percentile of passage; they were already dead).

We defined the relevant indices of exposure to flow, water temperature, and turbidity for release groups in free-flowing reaches above Lower Granite Dam as the average daily value measured at Lower Granite Dam between the date of release and the date of the 5th percentile as passage at Lower Granite Dam. Using an index defined in the period immediately after release, we characterized conditions experienced by all the fish after release and before initiation of migration. Relationships between exposure indices and survival and travel time from release to Lower Granite Dam tailrace were examined with linear regression using data for individual release groups from the Snake and Clearwater Rivers in 1995 and 1996.

For relationships between environmental factors and survival and travel time in reaches below Lower Granite Dam, we redefined groups of PIT-tagged fish based on the date of passage at Lower Granite Dam, rather than based on the date and location of initial release. Using this approach, we identified groups of fish that actively migrated, and that had passed Lower Granite Dam within the same 24-hour period. The "post-Lower Granite" capture histories of all fish released to the tailrace of Lower Granite Dam on a particular day were grouped, and the Single-Release Model was applied to estimate survival and travel time for the "daily-release group" from Lower Granite Dam tailrace to Lower Monumental Dam tailrace (i.e., through two dams and two reservoirs).

A difficulty with this approach was in obtaining groups of sufficient size to estimate survival probabilities with high precision. To obtain reasonably sized groups, daily-release groups were made up of fish from all twelve primary release groups (six each from Pittsburg

Landing and Big Canyon Creek) and fish from the secondary release groups from Pittsburg Landing (only those fish *not* handled at Lower Granite Dam via the separation-by-code system for use in post-detection bypass survival releases). Daily-release groups were further pooled by week. Thus, we estimated the survival probability and median travel time from Lower Granite Dam tailrace to Lower Monumental Dam tailrace for seven groups of fish passing Lower Granite Dam during the following intervals: 6-12 July, 13-19 July, 20-26 July, 27 July-2 August, 3-9 August, 10-16 August, and 17-23 August. The indices of environmental exposure to flow, water temperature, and turbidity were the averages of the daily values at Lower Granite Dam during the period that fish were released from Lower Granite Dam. Daily-release groups of subyearling fall chinook salmon from 1995 and 1996 were combined in the analysis.

RESULTS

Primary Release Groups

A total of 7,155 subyearling fall chinook salmon were PIT tagged and released at Pittsburg Landing and 7,143 fish were tagged and released at Big Canyon Creek (Table 1). Tagging and handling mortality at the hatchery averaged 1.0% and transport mortality (including all mortality that occurred from the time trucking began to the time of release from net-pens) averaged 2.1% (Table 2). Water temperatures at release ranged from 16.0 to 20.0°C in the Snake River and from 10.4 to 16.6°C in the Clearwater River (Table 1).

Table 1. Information for primary release groups of PIT-tagged hatchery subyearling fall chinook salmon in 1996, including release site, purpose of release, date of release, number released, water temperature at release, and mean fork length at time of release.

Site	Purpose of release	Release date	Number released	Water temp. (°C)	Mean length (mm)
Pittsburg Landing	Primary	6 June	1,189	16.0	72
	Primary	13 June	1,119	16.9	74
	Secondary	13 June	6,870	17.5	74
	Primary	20 June	1,189	17.7	75
	Secondary	20 June	6,929	17.8	75
	Primary	27 June	1,214	17.6	76
	Primary	3 July	1,220	18.9	77
	Primary	10 July	1,224	20.0	83
Big Canyon Creek	Primary	6 June	1,198	10.7	73
	Primary	13 June	1,166	11.8	74
	Primary	20 June	1,218	10.4	75
	Primary	27 June	1,189	12.5	78
	Primary	3 July	1,161	15.9	79
	Primary	10 July	1,211	16.6	83

Secondary Release Groups

A total of 13,799 subyearling fall chinook salmon were released at Pittsburg Landing in the Snake River for post-detection bypass evaluation (Table 1). Tagging mortality for these releases averaged 0.5%, similar to tagging mortality of primary release groups. However, average transport mortality (0.3%) was lower than for the primary release groups, probably due to their release after short-term acclimation to ambient river water instead of the 48-hour acclimation used for the primary groups (Table 2).

Post-detection bypass releases were made at Lower Granite Dam between 18 July and 11 August (Table 3). During this time, water temperatures were about 20-21°C. A total of 2,057 of the 13,799 fish (14.9%) released at Pittsburg Landing were recaptured at Lower Granite Dam by the separation-by-code system; 999 were eventually rereleased into the collection channel and 954 were rereleased into the tailrace. Mortality of fish recovered at Lower Granite Dam using the separation-by-code system, then held for 24 hours before rerelease into the collection channel or tailrace, averaged 5.1% (Table 2).

Data Analyses

Validity of Secondary Releases

Subyearling fall chinook salmon from primary and secondary release groups at Pittsburg Landing were similar in size and migrational timing at downstream dams. Fall chinook salmon from primary release groups averaged 157 mm fork length and 50 g when recaptured at Little Goose Dam. Fish used for secondary release groups at Lower Granite Dam averaged 148 mm fork length and 44 g. Arrival of the secondary release groups at Lower Granite Dam

Table 2. PIT-tagging and transport mortality (including acclimation mortality) for hatchery subyearling fall chinook salmon used in primary releases (Pittsburg Landing and Big Canyon Creek) and secondary releases (released at Pittsburg Landing, recaptured and rereleased at Lower Granite Dam) in 1996.

Release site	Release date	Tagging mortality		Transport mortality		Overall mortality	
		N	%	N	%	N	%
Pittsburg Landing	6 June	19	1.5	25	2.0	44	3.6
	13 June	47	3.9	33	2.7	80	6.7
	20 June	5	0.4	17	1.4	22	1.8
	27 June	8	0.6	8	0.6	16	1.3
	3 July	0	0.0	10	0.8	10	0.8
	10 July	1	0.1	6	0.5	7	0.6
Big Canyon Creek	6 June	15	1.2	25	2.0	40	3.2
	13 June	16	1.3	55	4.4	71	5.7
	20 June	12	1.0	11	0.9	23	1.8
	27 June	12	1.0	32	2.6	44	3.6
	3 July	7	0.6	75	6.0	82	6.6
	10 July	6	0.5	16	1.3	22	1.8
Primary release totals		148	1.0	313	2.1	461	3.1
Pittsburg Landing	13 June	40	0.6	30	0.4	70	1.0
	20 June	24	0.3	10	0.1	34	0.5
Lower Granite Dam	18 July-11 August	--	---	104	5.1	104	5.1

Table 3. Information for secondary release groups of hatchery subyearling fall chinook salmon at Lower Granite Dam in 1996, including release location, date of release, number released, and water temperature at release.

Location	Date	Number	Temp. (°C)
bypass	18-24 July	89	19.9
tailrace	18-24 July	82	19.9
bypass	25-31 July	311	20.8
tailrace	25-31 July	290	20.8
bypass	1-7 August	457	20.6
tailrace	1-7 August	443	20.6
bypass	8-11 August	142	19.9
tailrace	8-11 August	139	19.9

overlapped that of the primary release groups with sufficient numbers collected for rerelease from 18 July to 11 August. Thus, our method for making secondary releases in 1996 was an improvement over the method used in 1995 because fish in the secondary release groups were similar in size to those in primary groups at Lower Granite Dam and had similar passage distribution at Lower Granite Dam.

However, the performance of the post-detection evaluation fish after recapture and rerelease at Lower Granite Dam appeared compromised, probably from the effects of handling. Of the 954 fish released in the tailrace of Lower Granite Dam as reference groups for post-detection evaluation, only 347 (36.4%) were detected again at a dam downstream from Lower Granite Dam. During the same period (18 July to 11 August), 2,280 of our PIT-tagged fish released in the Snake and Clearwater Rivers were detected at Lower Granite Dam and returned to the river without handling. Of these, 56.9% were detected again downstream from Lower Granite Dam.

The post-detection bypass survival estimate (weighted average of estimates for four weekly pooled groups) for fish released into the collection system at Lower Granite Dam was 0.787 (s.e. 0.040), suggesting substantial post-detection bypass mortality at this site. However, the poor post-release performance of these fish compared to fish that were not handled at Lower Granite Dam makes the post-detection survival estimate suspect. Therefore, we did not use the estimate of post-detection bypass survival, and could use only the SR model to estimate detection and survival probabilities for primary release groups.

Tests of Model Assumptions

Only a few--no more than expected by chance alone--tests of assumptions showed violations significant at the 0.05 significance level. In general, detected and nondetected fish at a particular dam were mixed as they passed dams farther downstream (Table 4), and detection history at upper dams did not affect probabilities of survival or detection at downstream dams (Table 5). On the basis of these results, we found no reason to reject the validity of parameter estimates from the Single-Release Model.

Detection Probabilities

Among primary release groups of hatchery fish, detection probabilities at Lower Granite Dam were similar, averaging 0.609 (s.e. 0.015) across all 12 groups (Table 6). Detection probabilities at Little Goose and Lower Monumental Dams were lower, averaging 0.309 (s.e. 0.014) and 0.361 (s.e. 0.018), respectively.

Detection probabilities were higher in 1996 than in 1995 at Lower Granite Dam and lower at Little Goose and Lower Monumental Dams (Fig. 2). The higher detection probability at Lower Granite Dam can be attributed to the extended length bar screens installed prior to the 1996 migration. The reason for lower detection probabilities at Little Goose and Lower Monumental Dams is unknown.

Survival Probabilities

Because of the problems with our post-detection bypass releases described previously, post-detection bypass survival was assumed to be 100%, and the SR Model was used to estimate survival for all primary release groups. If post-detection mortality occurred at all dams, then the SR Model would tend to overestimate survival from release to Lower Granite

Table 4. Tests of homogeneity of passage distributions at Little Goose, Lower Monumental, and McNary Dams for subgroups of primary (PL) and secondary (PD) release groups from Pittsburg Landing and primary release groups from Big Canyon Creek (CW). Subgroups defined by detection histories at previous dams. P values calculated using Monte Carlo approximation of the exact method.

	Little Goose Dam			Lower Monumental Dam			McNary Dam		
Release	χ^2	d.f.	P value	χ^2	d.f.	P value	χ^2	d.f.	P value
PL 1	42.82	45	0.614	112.60	129	0.882	237.30	224	0.262
PL 2	57.83	49	0.113	109.90	114	0.642	238.70	210	0.093
PL 3	45.27	37	0.078	95.68	96	0.525	169.60	182	0.764
PL 4	30.86	30	0.464	80.53	72	0.180	86.63	90	0.675
PL 5	16.32	16	0.782	31.00	30	0.835	NA	NA	NA
PL 6	7.00	5	0.520	NA	NA	NA	NA	NA	NA
PD 1	90.57	73	0.042	214.70	198	0.164	331.40	315	0.233
PD 2	74.45	76	0.554	176.70	186	0.730	308.20	308	0.505
CW 1	57.47	52	0.242	156.20	138	0.096	303.10	266	0.030
CW 2	42.45	46	0.697	126.80	120	0.293	240.20	238	0.478
CW 3	41.34	36	0.190	96.31	63	0.008	153.30	150	0.465
CW 4	25.80	29	0.780	42.69	54	0.944	76.89	90	0.906
CW 5	9.33	11	0.591	24.00	18	0.284	45.27	44	0.767
CW 6	9.94	10	0.446	NA	NA	NA	NA	NA	NA

Table 5. Results of tests of goodness of fit to the Single Release Model for primary (PL) and secondary (PD) release groups from Pittsburg Landing and primary release groups from Big Canyon Creek (CW).

	Overall		Test 2		Test 2.C2		Test 2.C3	
Release	χ^2	P value	χ^2	P value	χ^2	P value	χ^2	P value
PL 1	11.728	0.068	0.996	0.802	0.691	0.708	0.305	0.581
PL 2	5.325	0.503	2.840	0.417	1.632	0.442	1.208	0.272
PL 3	5.063	0.536	2.698	0.441	1.946	0.378	0.752	0.386
PL 4	7.649	0.177	6.628	0.085	1.281	0.527	5.347	0.021
PL 5	6.153	0.406	2.982	0.394	2.821	0.244	0.161	0.688
PL 6	7.346	0.119	5.471	0.140	2.042	0.360	3.429	0.064
PD 1	6.358	0.384	4.788	0.188	4.493	0.106	0.295	0.587
PD 2	8.115	0.230	7.977	0.046	0.815	0.665	7.162	0.007
CW 1	5.976	0.426	3.866	0.276	3.110	0.211	0.756	0.385
CW 2	1.506	0.959	0.735	0.865	0.037	0.982	0.698	0.403
CW 3	9.679	0.139	2.208	0.530	2.149	0.341	0.059	0.808
CW 4	6.749	0.345	1.426	0.699	1.420	0.492	0.006	0.938
CW 5	6.606	0.359	3.447	0.328	2.565	0.277	0.882	0.348
CW 6	4.345	0.361	4.151	0.246	2.951	0.229	1.200	0.273

Table 5. Continued.

	Test 3		Test 3.SR3		Test 3.Sm3		Test 3.SR4	
Release	χ^2	P value	χ^2	P value	χ^2	P value	χ^2	P value
PL 1	10.732	0.013	8.383	0.004	1.105	0.293	1.244	0.265
PL 2	2.485	0.478	0.874	0.350	0.396	0.529	1.215	0.270
PL 3	2.365	0.500	1.953	0.162	0.014	0.906	0.398	0.528
PL 4	1.021	0.600	0.566	0.452	NA	NA	0.455	0.500
PL 5	3.171	0.366	0.505	0.477	1.333	0.248	1.333	0.248
PL 6	1.875	0.171	NA	NA	NA	NA	1.875	0.171
PD 1	1.570	0.666	1.346	0.246	0.200	0.655	0.024	0.877
PD 2	0.138	0.987	0.055	0.815	0.000	1.000	0.083	0.773
CW 1	2.110	0.550	0.761	0.383	0.181	0.671	1.168	0.280
CW 2	0.771	0.856	0.098	0.754	0.673	0.412	0.000	1.000
CW 3	7.471	0.058	1.476	0.224	5.462	0.019	0.533	0.465
CW 4	5.323	0.150	1.529	0.216	3.600	0.058	0.194	0.660
CW 5	3.159	0.368	0.139	0.709	3.000	0.083	0.020	0.888
CW 6	0.194	0.660	0.194	0.660	NA	NA	NA	NA

Table 6. Detection probability estimates (based on the Single-Release Model) for PIT-tagged hatchery subyearling fall chinook salmon released at Pittsburg Landing on the Snake River and Big Canyon Creek on the Clearwater River in 1996. Standard errors are in parentheses.

Release		Estimated detection probabilities		
Site	Date	Lower Granite	Little Goose	Lower Monumental
Pittsburg Landing	6 June	0.612 (0.026)	0.323 (0.032)	0.407 (0.048)
	13 June	0.628 (0.027)	0.290 (0.033)	0.345 (0.050)
	20 June	0.577 (0.034)	0.267 (0.040)	0.447 (0.063)
	27 June	0.569 (0.049)	0.256 (0.071)	0.286 (0.084)
	3 July	0.550 (0.083)	0.353 (0.120)	0.333 (0.157)
	10 July	0.591 (0.130)	0.200 (0.163)	0.375 (0.284)
	Mean	0.588 (0.012)	0.282 (0.022)	0.366 (0.023)
Big Canyon Creek	6 June	0.576 (0.026)	0.382 (0.033)	0.424 (0.052)
	13 June	0.640 (0.027)	0.364 (0.034)	0.393 (0,049)
	20 June	0.668 (0.035)	0.343 (0.047)	0.392 (0.065)
	27 June	0.537 (0.048)	0.302 (0.070)	0.297 (0.075)
	3 July	0.625 (0.084)	0.375 (0.119)	0.385 (0.135)
	10 July	0.729 (0.105)	0.255 (0.203)	0.250 (0.217)
	Mean	0.629 (0.028)	0.337 (0.020)	0.357 (0.028)
Overall mean		0.609 (0.015)	0.309 (0.014)	0.361 (0.018)

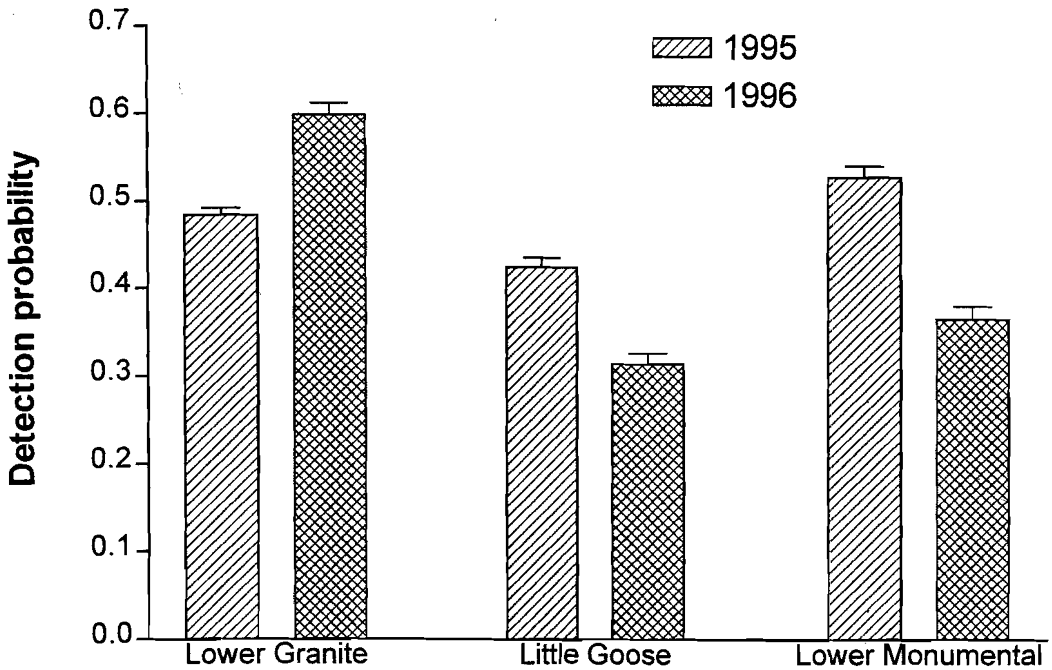

Figure 2. Average detection probabilities at Snake River dams for PIT-tagged hatchery subyearling fall chinook salmon in 1995 and 1996.

Dam. Survival estimates would also be biased for reaches below Lower Granite Dam, but the direction of the bias would depend on the relative degree of post-detection mortality at each dam.

Survival estimates from the point of release to Lower Granite Dam tailrace were similar between the two primary release sites (Table 7). The average of the six survival estimates from each site were 0.317 (s.e. 0.087) from Pittsburg Landing and 0.322 (s.e. 0.085) Big Canyon Creek. Survival estimates for both series of releases decreased with later release date.

There were also no significant differences between release sites in survival estimates in the reaches downstream from Lower Granite Dam. There was a general downward trend in survival estimates with later release date for series of releases from both sites, particularly for survival from Lower Granite Dam tailrace and Little Goose Dam tailrace (Table 7). Survival estimates from the point of release to the tailrace of Lower Monumental Dam followed the same patterns as survival to Lower Granite Dam tailrace; survival decreased with later release date (Table 7). Survival estimates to Lower Monumental Dam tailrace averaged 0.193 (s.e. 0.066) for Pittsburg Landing release groups, and 0.183 (s.e. 0.065) for Big Canyon Creek release groups.

Travel Time

The median time elapsed from release to arrival at Lower Granite Dam was about the same for PIT-tagged hatchery subyearling chinook salmon released from Pittsburg Landing (173 km from Lower Granite Dam) as for those released at Big Canyon Creek (108 km from Lower Granite Dam) (Table 8). That is, migration rates (km/day) were higher for fish released at Pittsburg Landing than at Big Canyon Creek. Migration rates between each pair of dams (Lower Granite to Little Goose, Little Goose to Lower Monumental, and Lower Monumental to McNary) were more similar between release sites (Tables 9, 10, 11, and 12). For all groups, migration rates between Lower Monumental and McNary Dams were substantially higher than in the previous reaches (Tables 9, 10, 11, and 12).

Table 7. Survival probability estimates (based on the Single-Release Model) for PIT-tagged hatchery subyearling fall chinook salmon released at Pittsburg Landing on the Snake River and Big Canyon Creek on the Clearwater River in 1996. Standard errors are in parentheses. Abbreviations: Rel-Release site; LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

Release		Estimated survival probabilities by reach			
Site	Date	Rel to LGR	LGR to LGO	LGO to LMO	Rel to LMO
Pittsburg Landing	6 June	0.559 (0.022)	0.907 (0.077)	0.727 (0.098)	0.370 (0.040)
	13 June	0.528 (0.022)	0.925 (0.091)	0.780 (0.126)	0.381 (0.051)
	20 June	0.391 (0.022)	0.776 (0.102)	0.730 (0.132)	0.221 (0.029)
	27 June	0.247 (0.021)	0.736 (0.193)	0.668 (0.260)	0.122 (0.033)
	3 July	0.124 (0.019)	0.425 (0.144)	0.727 (0.397)	0.038 (0.017)
	10 July	0.054 (0.012)	0.556 (0.431)	0.500 (0.538)	0.015 (0.011)
	Mean	0.317 (0.087)	0.721 (0.080)	0.689 (0.040)	0.191 (0.066)
Big Canyon Creek	6 June	0.567 (0.022)	0.829 (0.062)	0.819 (0.107)	0.385 (0.044)
	13 June	0.545 (0.021)	0.794 (0.063)	0.826 (0.108)	0.358 (0.040)
	20 June	0.362 (0.020)	0.672 (0.082)	0.797 (0.151)	0.194 (0.030)
	27 June	0.262 (0.023)	0.665 (0.147)	0.633 (0.206)	0.110 (0.025)
	3 July	0.134 (0.019)	0.298 (0.092)	0.903 (0.386)	0.036 (0.011)
	10 July	0.063 (0.011)	0.664 (0.512)	0.286 (0.322)	0.012 (0.009)
	Mean	0.322 (0.085)	0.654 (0.077)	0.711 (0.092)	0.183 (0.065)
Overall mean		0.322 (0.058)	0.688 (0.054)	0.699 (0.048)	0.188 (0.045)

Table 8. Travel times and migration rates between the point of release and Lower Granite Dam for hatchery subyearling fall chinook salmon released at Pittsburg Landing (PL and PD) (173 km) and Big Canyon Creek (CW) (108 km).

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
CW1	6 June	393	1.3	42.4	52.9	61.7	141.8	0.8	1.8	2.0	2.6	83.1
CW2	13 June	407	2.7	40.8	48.7	59.6	139.5	0.8	1.8	2.2	2.6	40.0
CW3	20 June	294	2.4	38.4	45.0	70.4	130.9	0.8	1.5	2.4	2.8	45.2
CW4	27 June	167	3.0	34.2	39.9	76.4	124.3	0.9	1.4	2.7	3.2	35.5
CW5	3 July	97	4.8	33.2	50.7	81.3	119.5	0.9	1.3	2.1	3.3	22.6
CW6	10 July	56	7.3	26.1	57.0	85.4	112.5	1.0	1.3	1.9	4.1	14.8
PL1	6 June	411	6.1	38.2	51.4	58.6	123.1	1.4	3.0	3.4	4.5	28.5
PD1	13 June	2,255	3.1	39.4	48.1	57.2	139.5	1.2	3.0	3.6	4.4	55.8
PL2	13 June	380	2.2	39.7	49.0	57.9	131.4	1.3	3.0	3.5	4.4	77.6
PD2	20 June	1,872	2.8	38.4	45.2	63.6	132.5	1.3	2.7	3.8	4.5	62.2
PL3	20 June	270	3.7	39.4	45.4	63.8	128.6	1.4	2.7	3.8	4.4	46.6
PL4	27 June	171	4.5	35.8	45.9	79.5	125.5	1.4	2.2	3.8	4.8	38.4
PL5	3 July	83	19.2	32.9	47.5	76.9	107.4	1.6	2.3	3.6	5.3	9.0
PL6	10 July	39	7.3	30.6	54.1	84.4	111.8	1.6	2.1	3.2	5.7	23.9

Table 9. Travel times and migration rates between Lower Granite Dam and Little Goose Dam (60 km) for hatchery subyearling fall chinook salmon released at Pittsburg Landing (PL and PD) and Big Canyon Creek (CW).

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
CW1	6 June	102	1.9	2.5	4.0	7.6	62.1	1.0	7.9	15.0	23.8	32.4
CW2	13 June	106	1.6	2.6	4.0	9.5	53.6	1.1	6.3	14.9	22.8	38.7
CW3	20 June	64	2.1	2.7	5.1	13.2	43.1	1.4	4.6	11.8	22.3	28.4
CW4	27 June	30	1.8	3.1	5.1	18.0	73.7	0.8	3.3	11.7	19.1	33.3
CW5	3 July	8	2.0	4.0	7.2	13.0	16.2	3.7	4.6	8.3	14.9	30.5
CW6	10 July	7	3.1	6.6	13.5	45.6	58.1	1.0	1.3	4.4	9.2	19.1
PL1	6 June	103	1.4	2.6	3.9	7.9	36.3	1.7	7.6	15.6	23.2	41.7
PD1	13 June	411	1.8	3.7	6.0	10.9	80.6	0.7	5.5	10.1	16.4	33.3
PL2	13 June	96	1.6	2.9	4.7	11.1	51.0	1.2	5.4	12.9	20.5	37.7
PD2	20 June	269	1.9	3.8	6.0	10.2	71.5	0.8	5.9	10.1	16.0	32.1
PL3	20 June	49	1.7	2.8	4.7	11.6	63.1	1.0	5.2	12.8	21.3	34.5
PL4	27 June	27	2.1	3.0	5.5	14.5	68.4	0.9	4.1	10.9	19.8	29.3
PL5	3 July	11	1.5	2.9	4.5	31.6	37.4	1.6	1.9	13.5	21.0	40.8
PL6	10 July	5	2.2	3.3	4.0	70.2	70.2	0.9	0.9	14.9	18.2	27.4

Table 10. Travel times and migration rates between Little Goose Dam and Lower Monumental Dam (46 km) for hatchery subyearling fall chinook salmon released at Pittsburg Landing (PL and PD) and Big Canyon Creek (CW).

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
CW1	6 June	54	1.1	2.1	4.4	7.4	24.9	1.9	6.2	10.5	22.2	42.6
CW2	13 June	48	1.2	2.3	5.6	12.4	54.1	0.9	3.7	8.3	19.7	39.7
CW3	20 June	18	1.6	2.6	5.0	6.9	20.9	2.2	6.7	9.3	17.5	28.6
CW4	27 June	5	4.1	5.5	6.3	25.4	25.4	1.8	1.8	7.3	8.4	11.3
CW5	3 July	1	3.5	3.5	3.5	3.5	3.5	13.1	13.1	13.1	13.1	13.1
CW6	10 July	1	3.8	3.8	3.8	3.8	3.8	12.0	12.0	12.0	12.0	12.0
PL1	6 June	42	1.7	2.6	5.0	8.2	48.9	0.9	5.6	9.2	18.0	27.9
PD1	13 June	243	1.1	2.5	5.0	9.3	63.8	0.7	5.0	9.2	18.6	40.4
PL2	13 June	30	1.9	2.5	4.0	10.4	15.1	3.0	4.4	11.5	18.2	24.1
PD2	20 June	154	1.2	2.3	3.9	7.1	63.9	0.7	6.5	11.9	19.9	39.3
PL3	20 June	21	1.9	3.1	5.4	7.3	14.8	3.1	6.3	8.5	14.9	23.8
PL4	27 June	7	2.1	2.7	3.2	6.3	6.5	7.0	7.3	14.3	17.2	22.4
PL5	3 July	3	2.2	2.5	2.7	1.9	3.1	14.7	24.6	17.0	18.4	21.0
PL6	10 July	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 11. Travel times and migration rates between Lower Monumental Dam and McNary Dam (119 km) for hatchery subyearling fall chinook salmon released at Pittsburg Landing (PL and PD) and Big Canyon Creek (CW).

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
CW1	6 June	38	2.4	3.1	4.2	6.8	12.9	9.2	17.4	28.5	38.5	50.4
CW2	13 June	39	2.5	3.4	5.0	6.9	9.2	13.0	17.4	23.9	35.3	47.4
CW3	20 June	21	2.5	3.1	4.2	7.6	13.1	9.1	15.7	28.4	38.3	47.4
CW4	27 June	11	2.8	3.2	4.0	5.2	6.7	17.8	23.1	30.1	37.0	42.2
CW5	3 July	6	3.2	3.5	4.8	8.7	9.0	13.2	13.6	24.8	33.6	37.8
CW6	10 July	1	8.0	8.0	8.0	8.0	8.0	15.0	15.0	15.0	15.0	15.0
PL1	6 June	41	2.3	3.4	4.4	6.2	13.7	8.7	19.2	27.2	35.1	51.7
PD1	13 June	205	2.3	3.2	4.6	6.9	19.2	6.2	17.3	26.1	36.8	50.9
PL2	13 June	31	1.9	3.1	4.7	6.1	55.8	2.1	19.5	25.6	38.9	63.0
PD2	20 June	129	2.4	3.7	4.8	7.0	43.9	2.7	17.1	25.0	32.4	50.2
PL3	20 June	28	2.8	3.6	5.3	8.5	61.9	1.9	14.0	22.5	32.7	42.4
PL4	27 June	8	2.3	3.4	4.3	9.4	12.5	9.5	12.7	27.9	34.8	51.3
PL5	3 July	3	4.8	6.7	7.9	5.2	8.6	13.8	23.0	15.0	17.8	24.6
PL6	10 July	1	5.1	5.1	5.1	5.1	5.1	23.3	23.3	23.3	23.3	23.3

Table 12. Travel times and migration rates between the point of release and McNary Dam for hatchery subyearling fall chinook salmon released at Pittsburg Landing (PL and PD) (398 km) and Big Canyon Creek (CW) (288 km).

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
CW1	6 June	93	42.4	60.7	68.1	78.3	106.7	3.1	4.3	4.9	5.5	7.9
CW2	13 June	101	33.4	52.7	63.6	72.4	138.5	2.4	4.6	5.2	6.3	10.0
CW3	20 June	55	44.2	48.6	57.7	65.4	79.5	4.2	5.1	5.8	6.9	7.5
CW4	27 June	36	35.6	46.9	54.4	59.6	62.2	5.4	5.6	6.1	7.1	9.4
CW5	3 July	14	39.2	41.2	46.5	57.1	60.2	5.5	5.8	7.2	8.1	8.5
CW6	10 July	4	41.8	42.2	43.9	36.5	45.6	7.3	9.1	7.6	7.9	8.0
PL1	6 June	103	34.6	58.9	67.0	74.3	85.6	4.7	5.4	5.9	6.8	11.5
PD1	13 June	472	30.4	53.0	62.3	71.3	118.1	3.4	5.6	6.4	7.5	13.1
PL2	13 June	93	47.4	53.7	61.1	67.7	120.4	3.3	5.9	6.5	7.4	8.4
PD2	20 June	355	39.9	49.4	58.1	65.9	126.1	3.2	6.0	6.9	8.1	10.0
PL3	20 June	63	42.2	54.3	61.1	66.6	132.7	3.0	6.0	6.5	7.3	9.4
PL4	27 June	29	38.9	45.8	53.5	61.3	67.1	5.9	6.5	7.4	8.7	10.2
PL5	3 July	9	32.1	39.6	53.5	60.1	64.0	6.2	6.6	7.4	10.0	12.4
PL6	10 July	3	35.4	38.5	40.5	25.2	42.1	9.5	15.8	9.8	10.4	11.2

Effects of Acclimation on Travel Time and Survival

Gill Na^+-K^+ ATPase activity at release increased significantly ($F = 13.57$, $P = 0.0005$) during the 48-hour acclimation period during all releases at Pittsburg Landing and Big Canyon Creek (Fig. 3). There was no significant difference in gill ATPase activity levels between release sites.

Travel times to Lower Granite Dam were nearly the same for releases of acclimated and nonacclimated fish on 13 and 20 June (Table 13). For both releases, estimated survival to Lower Granite Dam tailrace was higher for the nonacclimated fish, but was lower to Lower Monumental Dam tailrace (Table 13).

Comparison of Natural and Hatchery Subyearling Chinook Salmon

Hatchery subyearling chinook salmon released at both Pittsburg Landing and Big Canyon Creek were similar in size to natural fall chinook salmon PIT tagged in the upstream and downstream reaches of the Snake River in 1996 (Table 14). When recaptured at Lower Granite Dam, hatchery fish were generally larger than natural fish. Mean gill Na^+-K^+ ATPase activity at the time of release was similar between natural and hatchery subyearlings (Table 14). Hatchery subyearling fall chinook salmon exhibited the characteristic protracted travel times of natural subyearling fall chinook salmon from release to Lower Granite and Little Goose Dams. Hatchery fish passed Lower Granite Dam with natural fish primarily in the summer months of July and August (Fig. 4). Passage of subyearling hatchery fall chinook salmon overlapped passage of natural subyearling fall chinook salmon PIT tagged in the downstream reach of the Snake River (see Fig. 4 in Part One). Hatchery subyearling fall chinook salmon grew rapidly after release, at rates similar to natural fish (Table 14). Natural

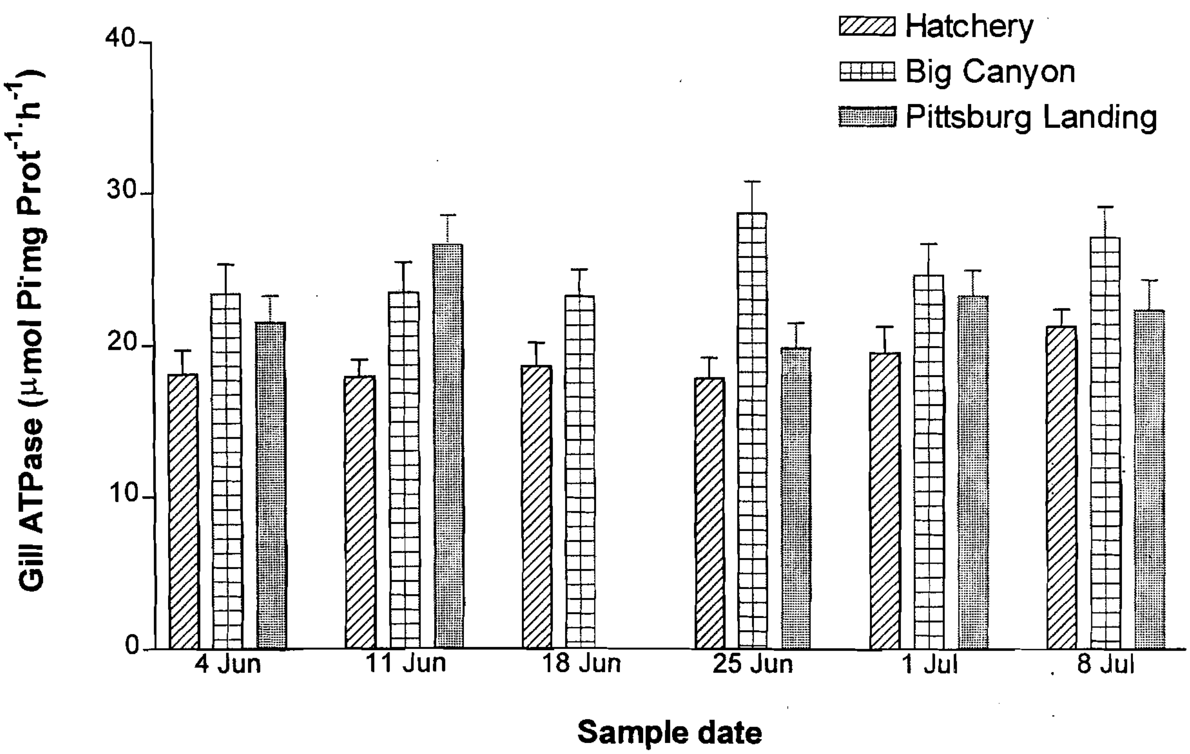

Figure 3. Gill Na^{+}-K^{+} ATPase activity during PIT tagging at Lyons Ferry Hatchery and at release at Big Canyon Creek and Pittsburg Landing after 48 hours acclimation.

Table 13. Attributes and performance of acclimated and nonacclimated subyearling fall chinook salmon. Gill ATPase units are μmol Pi·mg Prot^{-1}·h^{-1}. Abbreviations: LGR-Lower Granite Dam; LMO-Lower Monumental Dam; s.e.-standard error.

Index	Release Date	Acclimated	Nonacclimated
Gill ATPase at release	13 June	26.6 (s.e. 1.94)	19.9 (s.e. 1.14)
	20 June		
Median travel time to LGR	13 June	49.0 days	48.1 days
	20 June	45.4 days	45.2 days
Percent survival to LGR	13 June	52.8 (s.e. 2.2)	57.1 (s.e. 1.3)
	20 June	39.1 (s.e. 2.2)	53.8 (s.e. 1.8)
Percent survival to LMO	13 June	38.1 (s.e. 5.1)	27.9 (s.e. 1.6)
	20 June	22.1 (s.e. 2.9)	18.6 (s.e. 1.4)

Table 14. Comparisons of pre- and post-release attributes of natural and hatchery subyearling fall chinook salmon by release location in 1996. Attributes are reported as means unless noted otherwise. Gill ATPase units are μmol Pi·mg $Prot^{-1} \cdot h^{-1}$. Abbreviations: LGR = Lower Granite Dam and LGO = Little Goose Dam.

	Natural		Hatchery	
	Upstream	Downstream	Big Canyon Creek	Pittsburg Landing
Fork length (mm) at release	70	74	77	76
Median travel time to LGR (days)	42	46	49	49
Median travel time to LGO (days)	57	55	53	52
Fork length at LGO	141	144	155	157
Weight at LGO	31	39	49	51
K at LGO	1.1	1.2	1.3	1.3
Growth rate (mm/d) from release to LGO	1.3	1.4	1.4	1.5
Gill ATPase at LGO	16.1	23.3	18.1	17.8

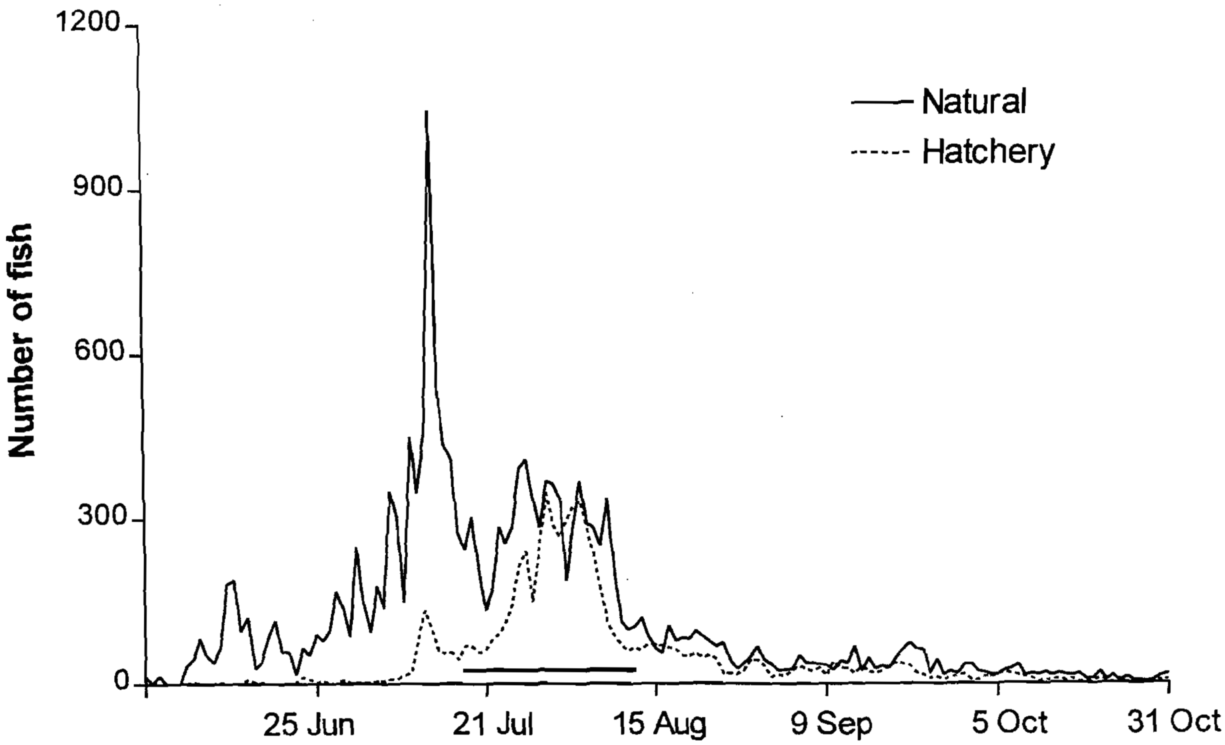

Figure 4. Passage of hatchery and natural subyearling fall chinook salmon at Lower Granite Dam in 1996. Dark horizontal line shows period of secondary releases to evaluate post-detection bypass survival.

subyearling fall chinook salmon survival to Lower Granite Dam tailrace averaged 50% in 1996 (see Table 5 in Part One). For hatchery subyearling fall chinook salmon released on 6 June and 13 June, when most natural fish were rearing in the Snake River, survival estimates bracketed (range 39 to 57%) the survival estimate for natural fish (Table 7). Hatchery subyearling fall chinook salmon released after 13 June approximated the rearing timing of natural subyearling fall chinook salmon produced in Snake River tributaries, specifically the Grande Ronde and Clearwater Rivers.

Residualization--PIT-Tag Detections in Spring 1997

A total of 361 fish (2.5%) from primary groups of hatchery fall chinook salmon released as subyearlings in 1996 were detected at Snake and Columbia River Dams in spring 1997 (Table 15). Detections of residualized fall chinook salmon began soon after the juvenile bypass systems began operation in 1997 and continued into early May (Fig. 5). Detections of residualized fish at dams downstream from Lower Granite Dam early in the spring indicate that some hatchery fall chinook salmon probably migrated from rearing areas to the lower Snake River in 1996 and residualized in the reservoirs between dams. However, because detection systems at Snake and Columbia River dams were not operational until 26 March to 5 April, we were unable to determine exactly in which reservoir fish residualized or when the holdovers resumed migrating in 1997. There was little difference in the percentage of fish residualizing between the two release locations. For both release locations combined, the proportion of fish residualizing from the later release groups was similar to the early groups (Table 15).

Table 15. Detections in spring 1997 of hatchery fall chinook salmon released as subyearlings in 1996 at Pittsburg Landing on the Snake River and Big Canyon Creek on the Clearwater River.

	Percent detected in spring 1997		
Release date	Big Canyon Creek	Pittsburg Landing	Total
6 June	2.1	2.1	2.1
13 June	2.1	2.3	2.2
20 June	3.2	3.5	3.3
27 June	2.8	2.5	2.6
3 July	3.0	2.5	2.8
10 July	2.6	1.5	2.0
All dates	2.6	2.4	2.5

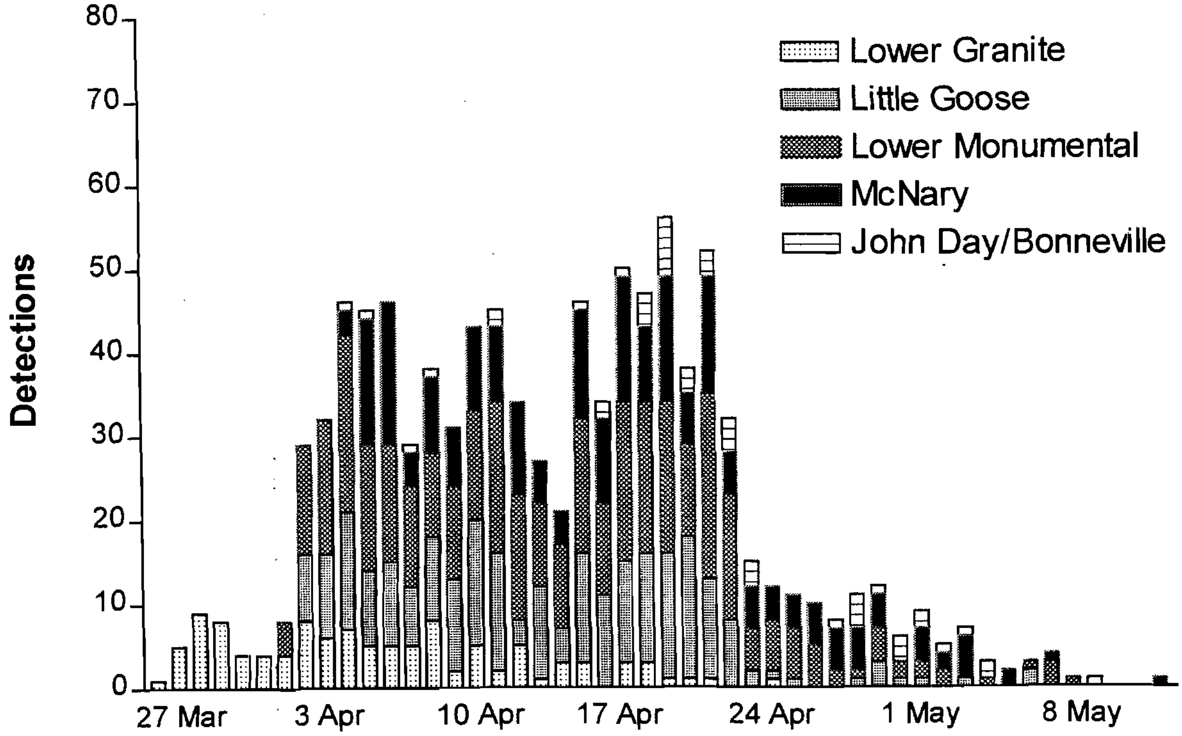

Figure 5. Detections during 1997 of PIT-tagged hatchery fall chinook salmon released above Lower Granite Dam as subyearlings in 1996.

In spring 1997, PIT-tagged yearling fall chinook salmon reared at Lyons Ferry Hatchery were released at Pittsburg Landing. Of 9,934 yearlings released, about 65% were detected at least once as they migrated down the Snake River. We assumed fish from our 1996 primary release groups that overwintered were equally likely to be detected as yearlings released in 1997; that is, the 361 fish observed represent 65% of the total that survived overwintering and migrated as yearlings. Thus we estimated that 3.9% (2.5%/0.65) of subyearlings in each 1996 release group migrated from the Snake River in spring 1997.

Little is known about the overwinter survival probability of residualizing subyearling fall chinook salmon. Most subyearlings that cease migrating probably remain in reservoirs where they likely have low metabolic needs because water temperatures are low. Low temperatures likely also result in low predation rates, resulting in high overwinter survival. Assuming that winter survival for overwintering fish between 14 December 1996 and 1 April 1997 was about 65% regardless of release date, we estimated that 6.0% (3.9%/0.65) of the subyearlings released in 1996 did not migrate in 1996. Inversely, we estimated that 94.0% of the subyearlings released in 1996 actually migrated in 1996.

Survival, Travel Time, and Environmental Variables

From release to Lower Granite Dam tailrace, survival estimates were highest for the earliest release groups, and declined for groups released on later dates. A similar trend of decreasing survival over time was also observed in 1995 (Fig. 6). During this time period, flows and turbidity generally decreased and water temperatures generally increased (Fig. 7). Survival estimates were significantly correlated with each of these environmental variables

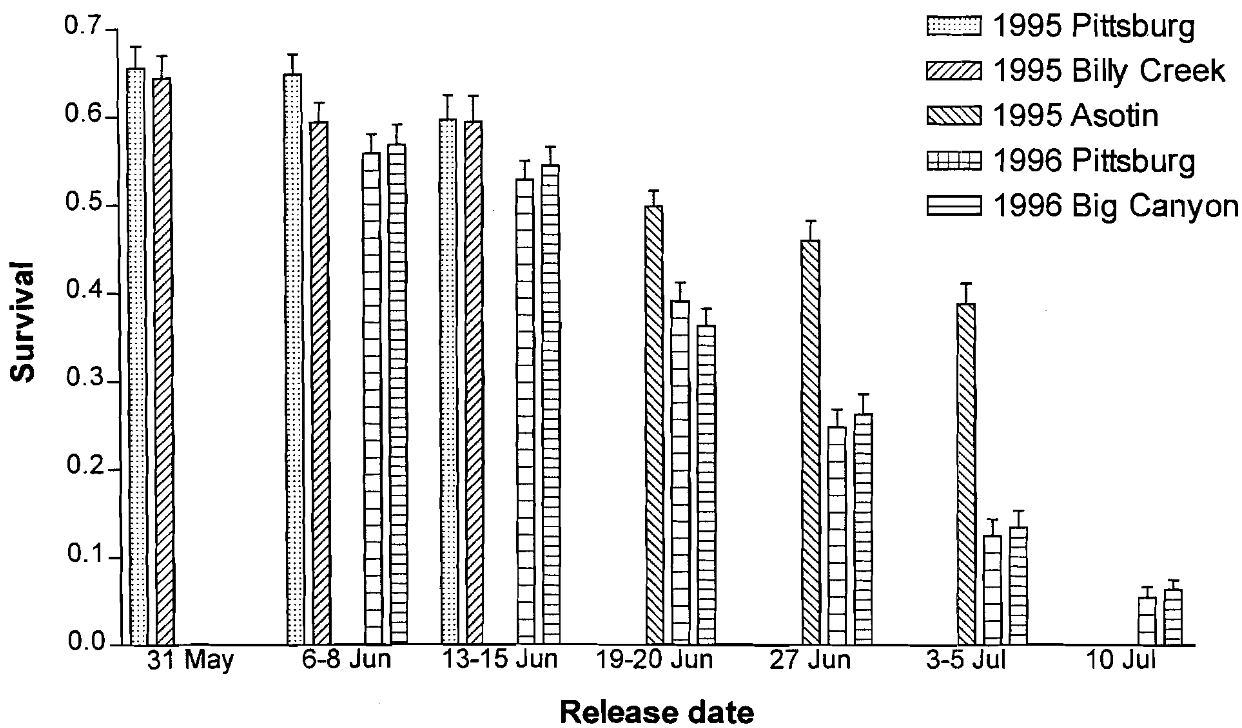

Figure 6. Survival from point of release in the Snake (Pittsburg Landing, Billy Creek, and Asotin) and Clearwater (Big Canyon Creek) Rivers to the tailrace of Lower Granite Dam for 1995 and 1996 releases. Standard errors are also shown.

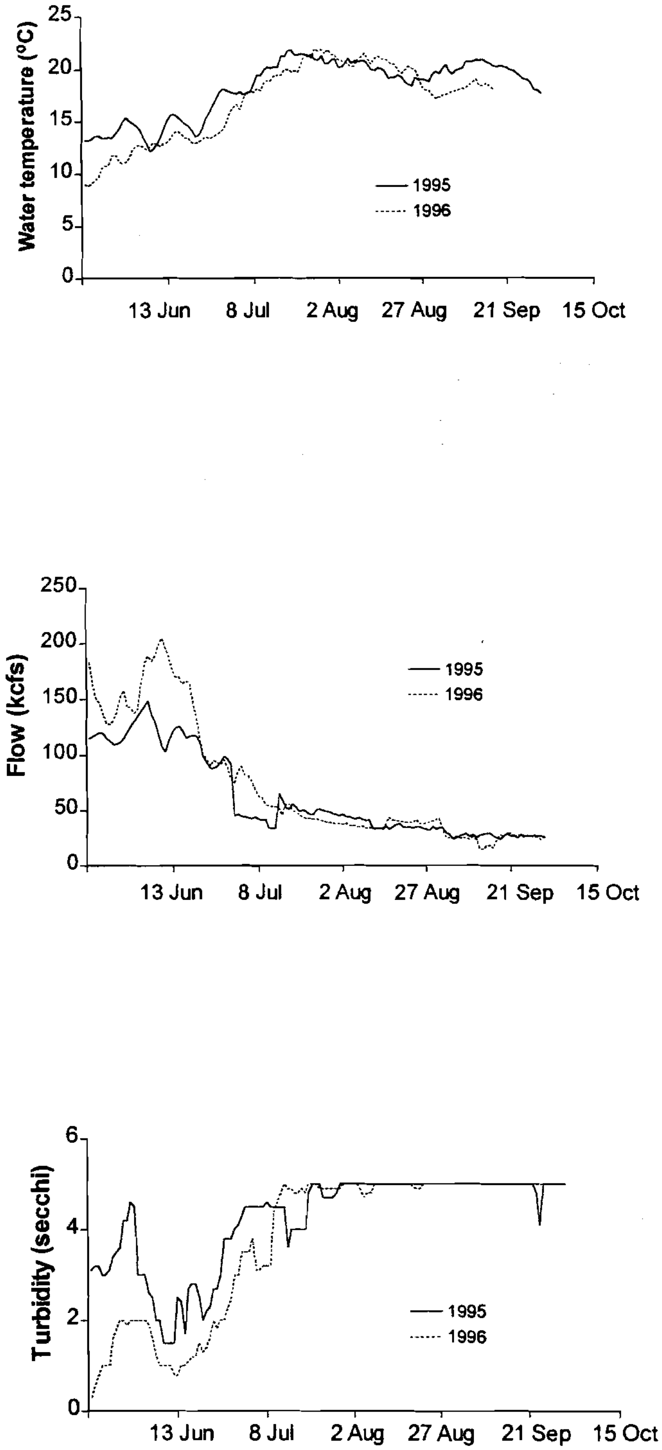

Figure 7. Environmental variables measured at Lower Granite Dam in 1995 and 1996 during migration of subyearling fall chinook salmon.

individually (Fig. 8). The correlation was greatest with flow (r^2 = 73.1%, P < 0.0001), followed by water temperature (r^2 = 57.5%, P < 0.0001), and turbidity (r^2 = 0.56.6%, P < 0.0001). Travel time to Lower Granite Dam and survival were not significantly correlated (r^2 = 4.1%, P > 0.05), nor were travel time and any of the environmental variables (flow: r^2 = 0.6%, P > 0.05; water temperature: r^2 = 4.0%, P > 0.05; turbidity: r^2 = 2.5%, P > 0.05).

For groups of PIT-tagged fish leaving Lower Granite Dam each week, survival to the tailrace of Lower Monumental Dam generally decreased over the migration during 1995 and 1996 (Fig. 9, Table 16). None of the environmental variables was significantly correlated with survival through this reach (Fig. 10). There was also no significant correlation between travel time and flow (r^2 = 2.8%, P > 0.05) or travel time and turbidity (r^2 = 1.3%, P > 0.05), nor between travel time and survival (r^2 = 0.9%, P > 0.05) through this reach. There was significant correlation between travel time and water temperature (r^2 = 32.5%, P < 0.05).

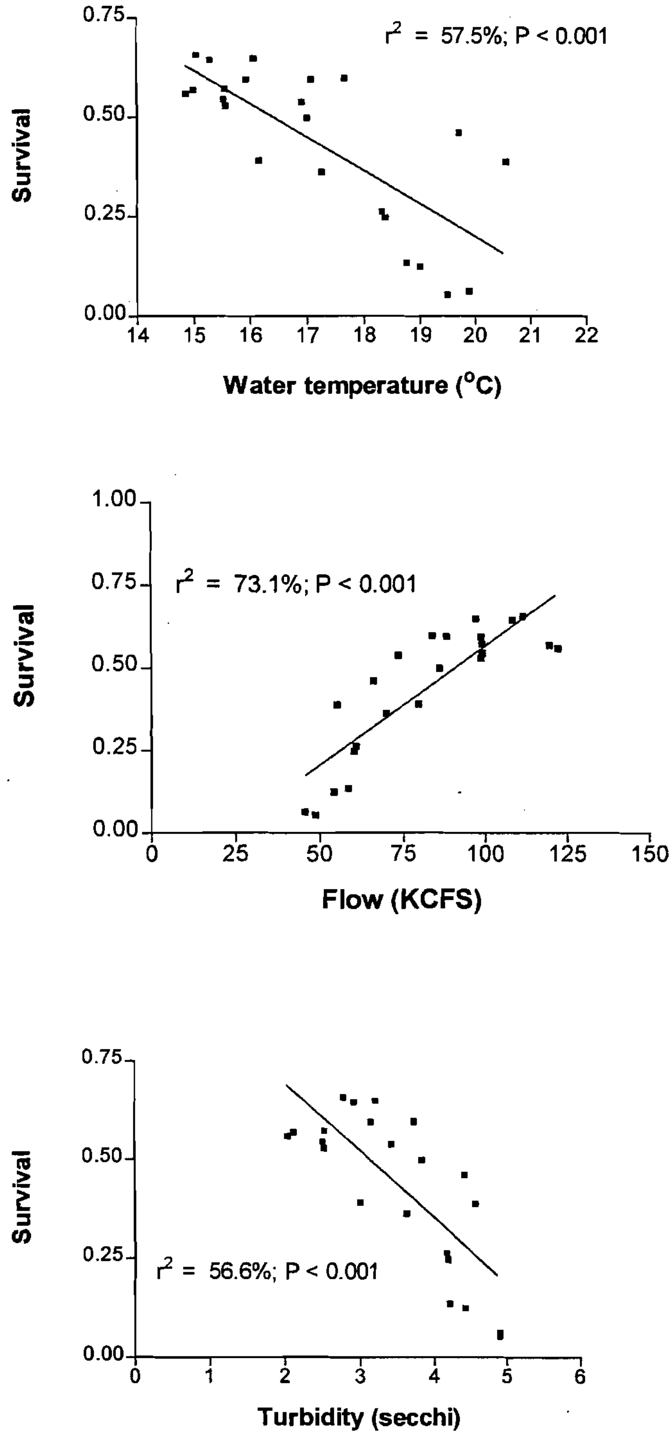

Figure 8. Relationships between survival from release in the free-flowing Snake and Clearwater Rivers to the tailrace of Lower Granite Dam and environmental variables for 1995 and 1996 releases of hatchery subyearling fall chinook salmon.

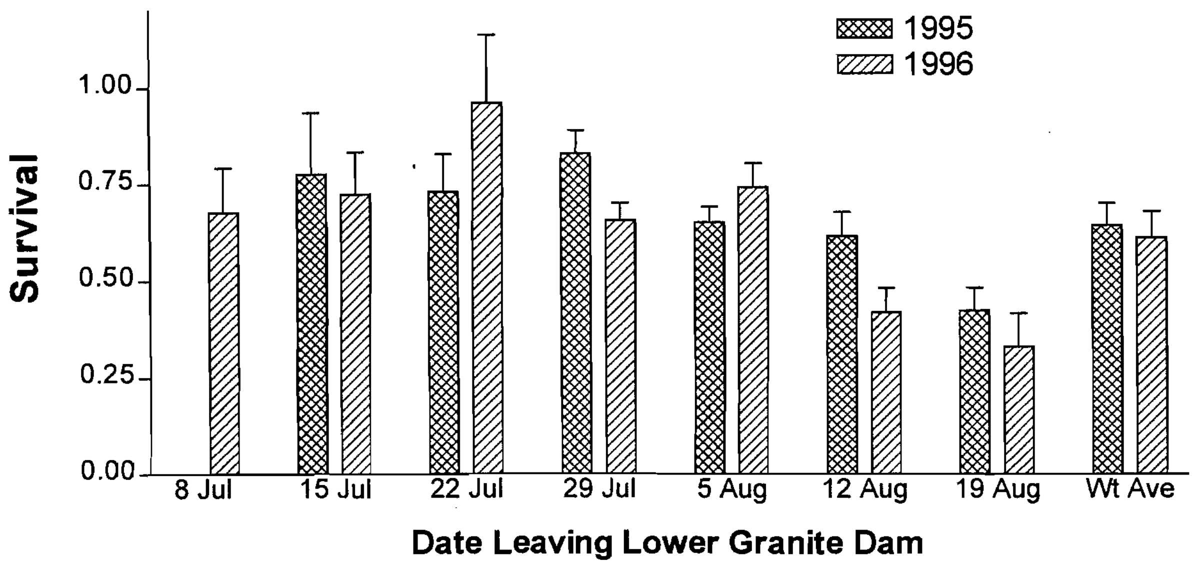

Figure 9. Survival estimates for PIT-tagged hatchery subyearling fall chinook salmon leaving Lower Granite Dam to the tailrace of Lower Monumental Dam each week during 1995 and 1996. Standard errors are also shown.

Table 16. Estimated survival probabilities from Lower Granite Dam tailrace to Lower Monumental Dam tailrace and average Lower Granite Dam flows, water temperatures, and turbidities for Lower Granite Dam weekly passage groups, 1996.

Passage dates	N	Survival estimate	Average flow (kcfs)	Average turbidity (secchi)	Average temperature
6-12 July	228	0.677 (0.116)	61.0	3.8	18.1
13-19 July	373	0.723 (0.110)	51.4	4.9	19.6
20-26 July	329	0.960 (0.176)	42.6	4.9	20.8
27 July-2 August	864	0.656 (0.045)	38.3	5.0	21.5
3-9 August	804	0.741 (0.062)	35.8	4.9	20.6
10-16 August	325	0.418 (0.062)	35.7	5.0	21.0
17-23 August	343	0.331 (0.086)	39.8	5.0	20.2

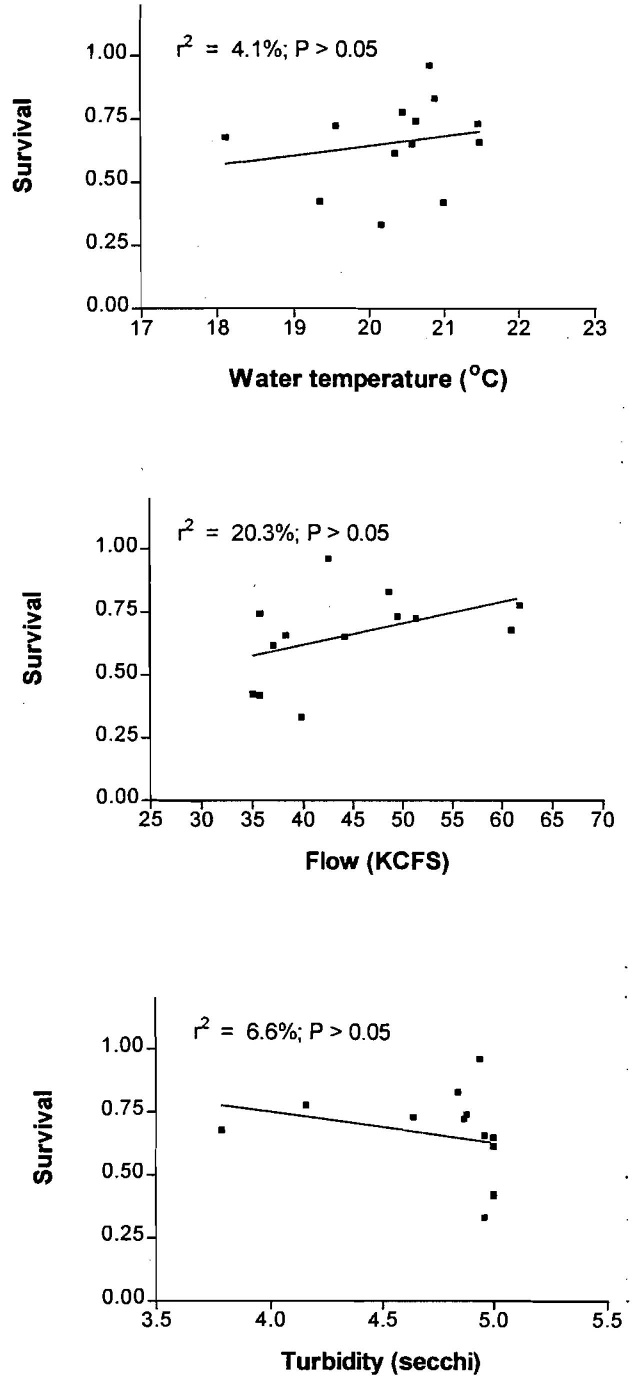

Figure 10. Relationships between survival from the tailrace of Lower Granite Dam to the tailrace of Lower Monumental Dam and environmental variables for weekly passage groups of hatchery subyearling fall chinook salmon leaving Lower Granite Dam in 1995 and 1996.

DISCUSSION

The use of hatchery subyearling fall chinook salmon as surrogates for natural subyearling fall chinook salmon appears feasible when hatchery fish are provided for research in a timely manner and are released at the appropriate size and time. Our release strategy in 1996 resulted in hatchery subyearling chinook salmon with post-release attributes and survival probability estimates similar to natural fish migrating from the free-flowing Snake River. Therefore, estimated survival probability for hatchery subyearling fall chinook salmon released in early June can be viewed as an index of survival for fall chinook salmon produced naturally in the Snake River. Survival probability estimates for hatchery fish released in mid-to-late June and early July can be used as indices of survival for late-hatching subyearling fall chinook salmon produced naturally in the Grande Ronde and Clearwater Rivers.

The life history of juvenile fall chinook salmon, particularly prolonged migrations and the tendency to residualize, presents some unique challenges for statistical analysis of capture-recapture data. Survival probability estimates we obtained were actually estimates of the combined probability of migrating before the PIT-tag interrogation system was shut down at McNary Dam on 14 December and the probability of surviving migration in that period. However, the small percentage that did not migrate as subyearlings (less than 6% estimated for both 1995 and 1996 releases) would have minimal effect on subyearling survival estimates. An exact estimate would require that detection systems be operated essentially year around. However, the shape of the distribution of yearling detections in the spring following the year of release indicates that relatively few migrating fish passed while detection systems are dewatered. An exception might occur during winter flood events when some winter passage has been documented (Connor et al. 1997a,b).

We estimated survival probabilities in 1996 for two segments of the Snake River fall chinook salmon migration corridor: 1) release to the tailrace of Lower Granite Dam, and 2) the reservoir reaches between Snake River Dams. We found survival probability estimates from release to the tailrace of Lower Granite Dam decreased markedly from early to late release dates. This trend was evident for releases of hatchery subyearling chinook salmon made from all upstream release sites in 1995 and 1996. Based on data collected in both years, the estimated survival from release to the tailrace of Lower Granite Dam had highly significant correlation with flow, water temperature, and turbidity. Since the three environmental variables are also correlated with each other, determining which variable is most important to subyearling fall chinook salmon survival is difficult. Therefore, fishery managers are presented with a complex problem when implementing summer flow augmentation, since releases from Brownlee Reservoir increase flow through the free-flowing Snake River and Lower Granite Reservoir, but increase water temperature at the same time (Connor et al. 1998, Part One in this report). Also, fishery managers have notably little control of turbidity levels in Lower Granite Reservoir, since in most years turbidities in all rivers upstream from Lower Granite Dam are at low levels prior to the initiation of summer flow augmentation.

River flow, water temperature, and turbidity may affect survival probability estimates for hatchery subyearling fall chinook salmon in a number of ways. Delays in passage may occur under lower flows experienced by hatchery fish released late in the season, compared to those released early in the season. Such delays have theoretically been tied to disorientation of migrants, increased exposure time to predators, reversal of smoltification, and disease (Berggren and Filardo 1993, Park 1969, Raymond 1988). Warmer water during later releases of hatchery subyearling fall chinook salmon would result in increased predation rates due to increased metabolic demands of predators (Curet 1993, Vigg and Burley 1991, Vigg et al. 1991). Vulnerability to sight-feeding predators would also be expected to increase as turbidity decreases (Hobson 1979, Zaret 1979) by decreasing predator reactive distance and increasing predator encounter rates (Vinyard and O'Brien 1976), as Shively et al. (1991) observed in Lower Granite Reservoir. Higher turbidity could reduce predation rates on juvenile salmonids by providing protective cover during rearing (Gregory 1993, Simenstad et al. 1982).

Predator abundance and feeding selectivity, in concert with decreasing flow and increasing water temperature, may have caused the steady decline in survival probability estimates from early to late release dates. Isaak and Bjornn (1996) found that the abundance of northern squawfish, *Ptychocheilus oregonensis*, in the tailrace at Lower Granite Dam peaked in July during the subyearling fall chinook salmon migration. Poe et al. (1991) and Shively et al. (1996) found that predation rates on juvenile salmonids were size dependent, with smaller fish more vulnerable to predation. Fish size is one of the variables known to affect migration rates in fall chinook salmon, with smaller fish rearing longer in upstream areas before initiating migration (Connor et al. 1994a). Thus, small hatchery subyearling fall chinook salmon released late in the year may experience higher predation rates and lower survival. A similar fate is expected for later emerging natural fall chinook salmon and could account for the low survival probability estimates to the tailrace of Lower Granite Dam (17%) reported for fish from the Clearwater River (Connor et al. 1997a,b).

However, this low survival estimate may be confounded by unseasonably cold water releases from Dworshak Dam during the Clearwater River fall chinook salmon rearing period. This summer flow augmentation to cool the Snake River in July and August may have adverse affects on fall chinook salmon growth and may delay or inhibit subyearling smolt development in the Clearwater River (Arnsberg and Statler 1995).

River flow and water temperature may also affect fish guidance efficiency at Snake River dams. Detection probability, which is an index of fish guidance efficiency, was higher at Lower Granite Dam in 1996 than in 1995, most likely due to the installation of extended length bar screens. At Little Goose and Lower Monumental Dams, detection probabilities were lower in 1996. A possible explanation is that warmer water caused fish to sound in search of cooler water in Little Goose and Lower Monumental pools. Despite increased fish guidance efficiency in 1996, survival estimates for both hatchery and natural subyearling fall chinook salmon to the tailrace of Lower Granite Dam were lower in 1996 than in 1995. A possible explanation for decreased survival in 1996 is the reliance on the warmer Brownlee Reservoir water for the majority of 1996 summer flow augmentation (Connor et al. 1998, Part One in this report).

Our 1995 and 1996 findings regarding survival through the reservoirs between Snake River Dams are less clear than those above Lower Granite Dam. We did not find significant relationships between survival probability estimates and any environmental variable examined, nor between travel time and survival for any reservoir reach. The only significant correlation we found was between travel time through the reservoirs and water temperature. Relating travel time of actively migrating subyearling fall chinook salmon to environmental variables through reservoir reaches has proven difficult for researchers and has produced conflicting results (Berggren and Filardo 1993, Giorgi 1994). Giorgi et al. (1997) found that PIT-tagged subyearling chinook salmon in the mid-Columbia River showed no response to flow or temperature, although there was a significant positive correlation between fish length and migration rate. Additional years of data with variable environmental conditions will help define the relationships between survival of hatchery subyearling fall chinook salmon and travel time, flow, water temperature, and turbidity.

Although we assumed that post-detection bypass survival was 100%, based on evaluations during the spring migration in the Snake River (Iwamoto et al. 1994; Muir et al. 1995, 1996), some mortality might have occurred. To resolve this issue in the future will require releases of fish that are of the appropriate size and physiological condition that have not had their future performance compromised by handling prior to rerelease. If post-detection bypass mortality occurred at Lower Granite Dam, then the SR Model overestimated survival probabilities for the reach from release to Lower Granite Dam tailrace and underestimated survival probabilities for the reach from Lower Granite Dam tailrace to Little Goose Dam tailrace.

For example, based on the SR Model, the survival estimates were 0.559, 0.907, and 0.727 for the first Pittsburg Landing release group from release to Lower Granite Dam tailrace, Lower Granite Dam tailrace to Little Goose Dam tailrace, and Little Goose Dam tailrace to Lower Monumental Dam tailrace, respectively. If post-detection bypass mortality was 20% (based on questionable data) at each dam, then the Modified Single Release (MSR) Model (Dauble et al. 1993) would have been appropriate. Survival probability estimates based on the MSR Model would have been 0.514, 0.981, and 0.799 for the respective reaches. The overall survival probability estimate from release to Lower Monumental Dam tailrace was 0.370 under the SR Model and, in the example above, 0.403 under the MSR Model.

RECOMMENDATIONS

Based on results of the first two years of this study, we recommend the following:

1) Make weekly releases of appropriate-sized, PIT-tagged hatchery subyearling fall chinook salmon from release locations upstream from Lower Granite Dam in the free-flowing Snake River and in the Clearwater River. Releases should be made over as long a time period as practicable, to help determine relationship between travel time, survival, and environmental factors.

2) Make weekly releases at Billy Creek in the Snake River for comparison to the Pittsburg Landing releases to partition where mortality is occurring in-route to Lower Granite Dam.

3) Release fish from an upstream site, collect them at Lower Granite Dam using the separation-by-code system, divide collected fish into two paired release groups, and rerelease them into the bypass and tailrace (with as little handling as possible) to estimate post-detection bypass survival. This method should provide fish that are comparable in size and physiological status to PIT-tagged fish from primary release groups as they pass the dams.

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