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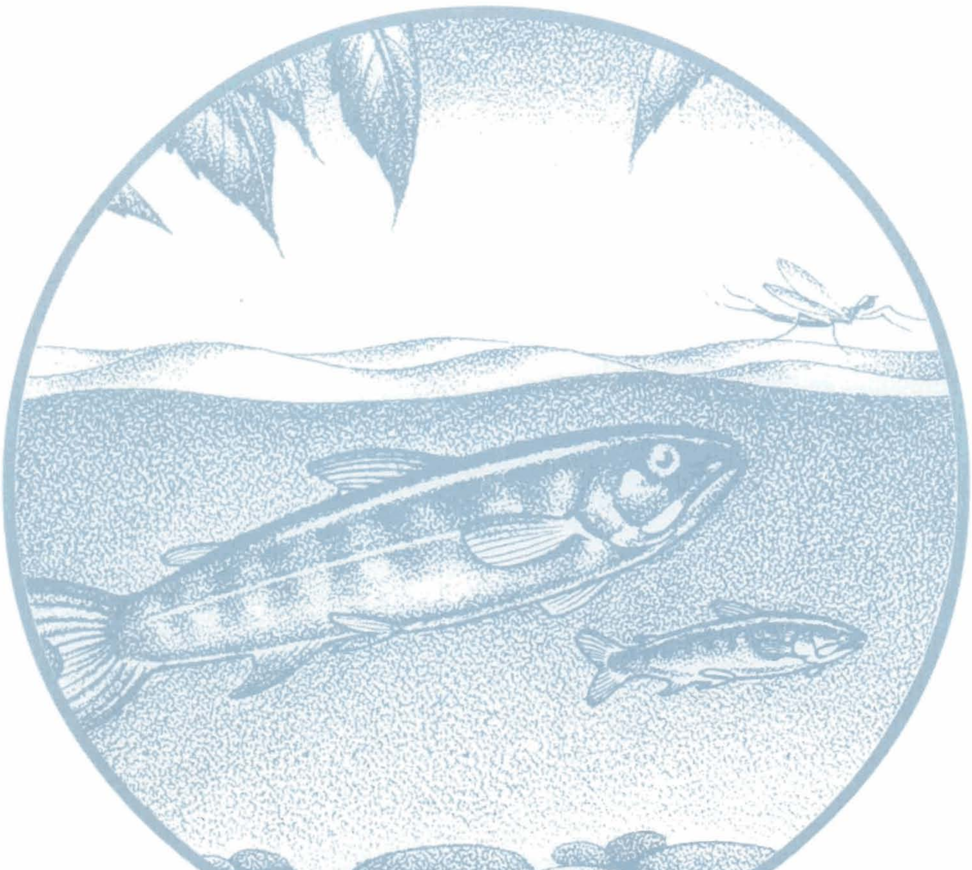
FALL CHINOOK SALMON SURVIVAL AND SUPPLEMENTATION STUDIES IN THE SNAKE AND LOWER SNAKE RIVER RESERVOIRS, 1995

Williams

Annual Report 1995



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FALL CHINOOK SALMON SURVIVAL AND SUPPLEMENTATION STUDIES IN THE SNAKE RIVER AND LOWER SNAKE RIVER RESERVOIRS, 1995

ANNUAL REPORT

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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 1994, the National Marine Fisheries Service and the U.S. Fish and Wildlife Service began a cooperative study to investigate migrational characteristics of subyearling fall chinook salmon in the Snake River. The primary study objectives were to 1) determine the feasibility of estimating detection and passage survival probabilities of natural and hatchery subyearling fall chinook salmon released in the Snake River (Chapter 1), 2) investigate relationships between detection and passage survival probabilities and travel time of subyearling fall chinook salmon and environmental influences such as flow volume and water temperature (Chapter 1), 3) monitor and evaluate dispersal of hatchery subyearling chinook salmon into nearshore rearing areas used by natural fish (Chapter 2), and 4) monitor and evaluate travel time to Lower Granite Dam, growth from release in the Snake River to recapture at Lower Granite Dam, ATPase levels of fish recaptured at Lower Granite Dam, and survival from release in the free-flowing Snake River to the tailrace of Lower Granite Dam (Chapter 2).

In fall 1994, CWT-tagged adult fall chinook salmon not native to the Snake River were removed from the adult trap at Lower Granite Dam and taken to Lyons Ferry Hatchery for spawning. In spring 1995, we PIT tagged the progeny at Lyons Ferry Hatchery and released them at various sites in the Snake River to collect data on survival and detection probabilities and travel time. In addition, we captured natural subyearling fall chinook salmon by beach seine, PIT tagged them, and released them at various locations in the Snake River.

In Chapter 1, survival and travel-time estimates are reported for both natural and hatchery subyearling fall chinook salmon. For natural fish, survival from release in the upper and downstream stretches of the Snake River (as defined in the text) to the tailrace of Lower Granite Dam was approximately 66%. For hatchery fish released in the same general vicinities, survival was approximately 62%. Median travel time from release to Lower Granite Dam for hatchery fish was approximately 57 days. Travel times for natural fish were up to 10 days shorter over the same reach. Generally, natural subyearling chinook salmon continued to travel faster than hatchery counterparts through the lower reaches of the Snake River. A small proportion of hatchery subyearling fall chinook salmon residualized and migrated early in spring 1996; however, the number residualizing was small and had minimal effect on survival estimates.

Migration rates from release to Lower Granite Dam had a very strong relationship with fish size. Within each of the nine primary release groups, fish were divided into small, average, and large size classes. For all nine groups, migration rates from release to Lower Granite Dam were fastest for large fish and slowest for small fish. On average, fish of the average size class traveled 9% faster than the small size class, and large fish traveled 5% faster than average-length fish.

average size class traveled 9% faster than the small size class, and large fish traveled 5% faster than average-length fish.

Determining the relationship between survival, flow, and water temperature for subyearling fall chinook salmon will be difficult because of their protracted migration. Future studies releasing more fish from a single location over time, and additional years of data will help to define these relationships. During the period that the number of PIT-tagged fish migrating between Lower Granite and Lower Monumental Dams was sufficient for survival estimation, significant correlations were found among travel time, survival, and flow, with survival decreasing as flows and migration rates decreased. During the period that survival could be estimated, water temperatures did not vary sufficiently to determine if any relationship existed between survival and temperature.

A number of comparisons of characteristics of natural and wild fish are reported in Chapter 2. Results generally support the use of hatchery fall chinook salmon as surrogates for natural fall chinook salmon in survival research. Replicate data sets collected over a period of several years will be required to define the relationships among fall chinook salmon survival, flow, and water temperature. Additionally, supplementation research will require the provision of research fish at the time of spawning to allow control of fish size at release.

CHAPTER 1

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

by

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CONTENTS

INTRODUCTION

Snake River fall chinook salmon (*Oncorhynchus tshawytscha*) were listed as threatened under the Endangered Species Act in April 1992 (National Marine Fisheries Service [NMFS] 1992). The status was downgraded to endangered by emergency action in 1994, then restored to threatened in 1995. At present, limited data exist on the migrational characteristics of Snake River subyearling fall chinook salmon. Although some data have recently been collected on migrational timing (Connor et al. 1993, 1994a, 1994b), almost nothing is known about what proportion of migrants survive passage through the Snake River dams and reservoirs, how flows and temperatures affect survival, or what percentage of subyearlings 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. Specific information on Snake River migrants is necessary to develop and assess the effects of possible restoration strategies such as supplementation, flow augmentation, or drawdown.

NMFS/University of Washington (UW) survival studies demonstrated that both passage survival and PIT-tag detection probabilities (an approximation of fish guidance efficiency (FGE)) for hatchery-reared and natural yearling spring/summer chinook salmon and hatchery-reared yearling steelhead (*O. mykiss*) could be estimated with the Single-Release (SR) and Paired-Release (PR) methodologies (Iwamoto el al. 1994; Muir et al. 1995, 1996). The key to accurate and precise estimates was the serial release of PIT-tagged fish collected by purse seine in Lower Granite Reservoir and serial releases of PIT-tagged fish at Lower Granite, Little Goose, and Lower Monumental Dams to estimate post-detection survival in the juvenile bypass systems.

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 (USFWS, unpublished data), numbers are still insufficient to make replicate releases within a single year. Two options are available to increase the number of subyearling fall chinook salmon available for tagging: 1) augment the collection of natural river migrants using alternative capture methods, and 2) release hatchery-reared subyearling fall chinook salmon as surrogates of naturally produced migrants. Survival estimates derived from hatchery-reared fish are acceptable for wild/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 initially behave similarly to natural migrants. Acclimation to ambient environmental conditions prior to release, releasing fish of appropriate size, and timing of releases to coincide with the migration of wild/natural fish may, however, lessen differences between hatchery-reared and natural migrants. Chapter 2 focuses on the appropriateness of using hatchery subyearling fall chinook salmon as surrogates for natural salmon in survival studies.

Study objectives addressed in this chapter are: 1) determine the feasibility of estimating detection and passage survival probabilities of natural and hatchery subyearling fall chinook salmon released in the Snake River, and 2) investigate relationships between detection and passage survival probabilities of subyearling fall chinook salmon and environmental influences such as flow volume and water temperature.

METHODS

Study Area

The study was conducted from Two Corral Creek on the Snake River (Snake River km 357) to McNary Dam on the Columbia River (Columbia River km 470, 52 km below the Snake/Columbia River confluence; Fig. 1). The area included a 122-km free-flowing reach of the Snake River and five dams and reservoirs: Lower Granite (Snake River km 173), Little Goose (Snake River km 113), Lower Monumental (Snake River km 67), Ice Harbor (Snake River km 16), and McNary. The river sections above the mouth of the Imnaha River (Snake River km 308) and downstream from the Grande Ronde River (Snake River km 271) are herein designated as upstream Snake River and downstream Snake River, respectively. We also collected natural subyearling chinook salmon in the Clearwater River from Rkm 14 to 64. Primary releases of hatchery subyearling fall chinook salmon were made in the Snake River at Pittsburg Landing (Snake River km 346), Billy Creek (Snake River km 265), and Asotin, WA (Snake River km 235; Fig. 1).

Primary Release Groups of Natural Subyearling Chinook Salmon

Natural subyearling chinook salmon were collected by beach seine and PIT tagged (Prentice et al. 1990) as described by Connor et al. (1994a). We PIT tagged natural fall chinook salmon in the Snake River from 11 April to 6 July and in the Clearwater River from 23 May to 26 July. Sites were sampled once a week and normally seined three times in an upriver direction, with each consecutive set starting where the previous set ended.

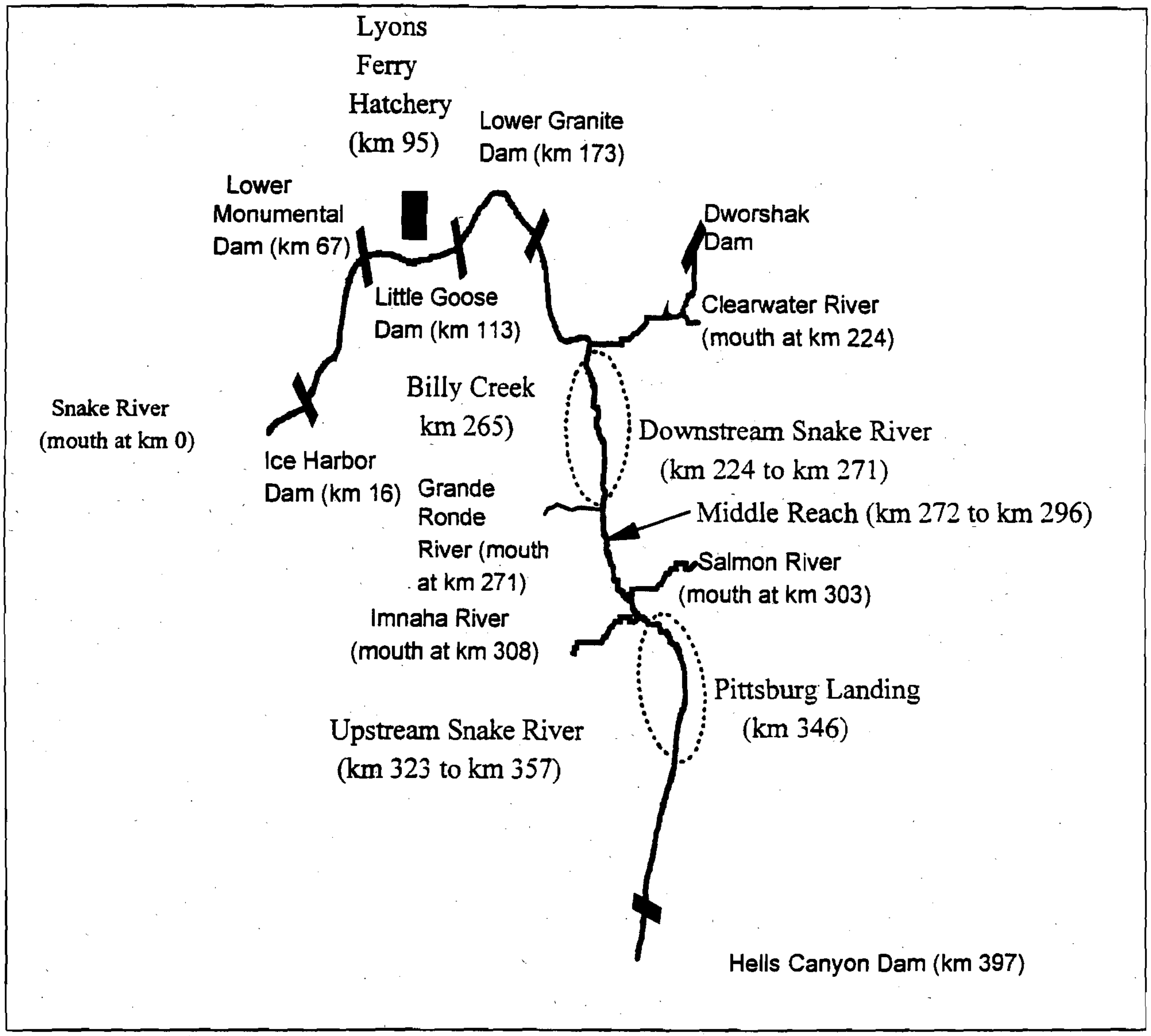

Figure 1.-Snake River study area including the locations of the upstream Snake River reach, downstream Snake River reach, Pittsburg Landing, Billy Creek, Lyons Ferry Fish Hatchery, and major tributaries, and dams. Study reaches where natural fall chinook salmon are seined and PIT tagged are identified by dotted ovals.

During each week of seining, we calculated theoretical upper size limits for natural subyearling chinook salmon juveniles to separate them from yearling chinook salmon, which are generally larger (Connor et al., Chapter 2). We PIT tagged natural subyearling chinook salmon between the lower size limit of 60 mm in fork length and the calculated upper size limit.

Primary Release Groups of Hatchery Subyearling Fall Chinook Salmon

Hatchery subyearling fall chinook salmon used in this study were the progeny of coded-wire tagged, 5-year-old fall chinook salmon strays removed from the adult trap at Lower Granite Dam in fall 1994 and transported to Lyons Ferry Hatchery for spawning. These fish were an unknown mixture of Lyons Ferry Hatchery and Umatilla Hatchery fall chinook salmon stocks. The progeny were deemed undesirable for Lyons Ferry Hatchery broodstock and were taken to Klickitat Hatchery for rearing until early May. However, it was determined that these fish were acceptable for research if all were coded-wire tagged to allow the eventual removal of returning adults at Lower Granite Dam. Approximately 30,000 of these fish were coded-wire tagged (tag codes 23-27-12 and 23-27-13) and adipose-fin clipped at Klickitat Hatchery and then returned to Lyons Ferry Hatchery in early May 1995.

Our goal was to release experimental fish of approximately the same length as wild/natural fall chinook salmon present in the river at a particular release site and time. Target length for release groups in the free-flowing Snake River was 75 mm (presmolts) to 95 mm (smolts) in fork length. Target size for reservoir-released fish was 95-100 mm (smolts) in fork length at release. However, because of the late date that experimental fish were obtained, we had little control over fish size at release.

We PIT tagged hatchery subyearling fall chinook salmon on 22 and 23 May for all primary release groups at Pittsburg Landing and Billy Creek. Fish for the primary release groups at Asotin were tagged on 19 June, 27 June, and 5 July. All fish for primary release groups were PIT tagged using the techniques of Iwamoto et al. (1994). At Lyons Ferry Hatchery, well water was supplied at a relatively constant temperature, ranging from 12.0 to 13.0°C during PIT tagging and loading for transportation. During tagging, we checked each fish for coded-wire tag retention and measured fork length. Fish that did not retain coded-wire tags were not used in our study.

We transported fish by truck in an aerated 1,325-L fiberglass transport tank to Pittsburg Landing for releases on 31 May and 7 and 14 June, and to Billy Creek for releases on 1, 8, and 15 June. Fish for Pittsburg Landing and Billy Creek releases were tagged about 1 to 3 weeks before release and held in a common raceway. To determine which fish were in each release group, PIT-tag codes were interrogated by an in-line PIT-tag monitor as the fish were loaded for transport.

We tagged salmon for Asotin release groups on the day of release, with fish allowed to recover from tagging during the transport and river acclimation process. Fish for the Asotin release groups were transported by truck in 1.8 x 1.8 x 0.9-m aerated aluminum tanks. Fish were acclimated at each primary release site by pumping river water into the transport tank for about 2 to 4 hours to slowly replace the hatchery water with river water at the correct temperature. Holding densities were kept below 8 kg/m^3. We monitored post-transport mortality by holding a subsample of 50 to 100 fish in the river in a 2 x 1 x 1-m floating net-pen for about 24 hours.

Secondary Release Groups of Hatchery Subyearling Fall Chinook Salmon

We PIT tagged hatchery subyearling fall chinook salmon on 19 and 20 June for secondary releases at Lower Granite, Little Goose, and Lower Monumental Dams. The tagging technique and transport vehicle were the same as those used for the Asotin primary release groups. Fish for secondary release groups were transported to Lower Granite Dam immediately after tagging and held and fed there in covered raceways. They were supplied with Snake River water to accelerate growth and acclimation.

Secondary releases consisted of a pair of release groups: the treatment group released into the juvenile bypass system at each dam, and the reference group released into the tailrace (Iwamoto et al. 1994). On the day of each secondary release, we loaded fish into 1.8 x 1.8 x 0.9-m aluminum tanks mounted on trucks. PIT-tag codes were read as fish were loaded using the in-line system described for the primary release groups. Tanks were supplied with aeration and at least 2 L/min of water per tank. Holding densities did not exceed 850 fish per tank. After loading, we allowed fish to recover for 1 to 24 hours.

Treatment groups were released directly from the truck-mounted tanks through a 7.6-cm-diameter hose into the collection channel of each dam. Reference groups were transferred to similar-sized containers on board a vessel, transported to the tailrace release site, and released water-to-water. Mortalities were recorded and loose tags recovered and recorded just before live fish were released. We released post-detection bypass groups to coincide with the period that PIT-tagged fish from the primary release groups were passing Lower Granite Dam (13 July and 3 August), Little Goose Dam (21 July and 10 August), and Lower Monumental Dam (26 July and 17 August).

Operation of PIT-Tag Interrogation and Slide-Gate Systems

Most detected PIT-tagged fish were automatically diverted back to the river by slide gates (details of their operation in Muir et al. 1995) beginning on 19 August at Lower Granite Dam, on 13 July at Little Goose Dam, and on 14 July at Lower Monumental Dam. Prior to these dates, many 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. PIT-tag interrogation was terminated in 1995 on 2 November at Lower Granite, Little Goose, and Lower Monumental Dams and on 13 December at McNary Dam. In 1996, operations resumed on 27, 28, and 29 March at Lower Granite, Little Goose, and Lower Monumental Dams, respectively, and on 18 April at McNary 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, assumption testing, estimation of survival and detection probabilities, and travel time. The statistical models used to estimate survival from PIT-tag data were the Single-Release and Paired-Release Models. Background information and statistical theory underlying these models was described by Iwamoto et al. (1994).

The following information was tabulated for each primary and secondary release: release site, date of release, number of fish released, and release water temperature. We calculated the percentage of fish that died during transport from both primary and secondary release groups.

Delayed mortality for each primary group was calculated and expressed as a percentage of the total number of fish held for 24 hours in net-pens.

Residualization and Interpretation of Model Parameters

Subyearling fall chinook salmon have a tendency to residualize. That is, some individuals cease migrating and spend the winter in the Snake River, then resume migration as yearlings the following spring. This life history does not comport well with the assumptions of the Single-Release Model. For example, fish that were released in Lower Granite Reservoir in June and migrated directly to Lower Granite Dam clearly did not have the same probability of surviving to the dam as fish from the same release group that residualized and spent the winter in the reservoir.

One solution to the problems caused by residualization of fall chinook salmon was to base analyses solely on PIT-tag detections that occurred during the summer and fall following release, and ignore detections that occurred the following spring. Estimates obtained from the Single-Release Model were then statistically valid, but the interpretation of the parameters was different. For example, the parameter previously defined as the probability of survival within a particular reach (Iwamoto et al. 1994 and 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.

If an estimate of the proportion of fish in a particular group that residualized could be developed, then the "survival" estimate from the Single-Release Model, based on year-of-release detections, could be divided by the proportion of fish migrating as subyearlings to give a refined estimate of the true survival probability. We attempted to estimate the proportion of fish tagged in 1995 that residualized, based on the proportion detected in the spring of 1996 and estimated detection probabilities based on PIT-tagged fall chinook salmon released as yearlings in the spring of 1996. Ultimately, the Single-Release Model might be modified to account for residualizing fish, but such a modification will require that detection systems be operated essentially all year.

Two events in late 1995 further complicated the interpretation of parameters and application of the Single-Release Model. First, monitoring of PIT-tags ended at Lower Granite, Little Goose, and Lower Monumental Dams on 2 November, but continued at McNary Dam until 13 December. Second, a large flood occurred in the Snake River Basin in late November and early December. River flows peaked on 1 December at about twice the volume of the preceding and following weeks, and turbidity increased dramatically. These conditions led to a pulse of PIT-tag detections at McNary Dam. Presumably, pulses of subyearling fall chinook salmon also passed the Snake River dams, but because PIT-tag monitoring had been stopped, no detections were recorded. If not for the flood, these fish may not have migrated in 1995, but may have waited until favorable conditions prevailed again in spring 1996.

With regard to application of the Single-Release Model to capture history data, two options were available to deal with the data anomaly that resulted from the pulse of PIT-tagged fish being detected at McNary Dam but not at the Snake River dams. First, we could construct capture histories from observations at Snake River dams through 1 November and at McNary Dam through 13 December. In this case, detection probabilities for Snake River dams would include not only the probability that a live fish passing the dam was detected, but also the probability that the fish passed the dam when the monitoring system was operating. In this case, the relationship between detection probability and fish guidance efficiency described in the following section would not hold. However, survival probabilities could be interpreted as the combined probability of migrating before 13 December and the probability of surviving the reach.

The second option for dealing with the differential shut-down dates of the monitoring systems was to ignore detections at McNary Dam after 1 November to "simulate" shut down at McNary Dam on the same date as the Snake River dams. The benefit of this option is that because detection systems were on at all sites throughout the entire period, detection probabilities retain their relationship with fish guidance efficiency. However, survival probabilities would be underestimated because information on fish known to have survived to McNary Dam would be ignored. In the following, we present detection probability estimates based on McNary Dam detections through 1 November and survival probability estimates based on detections through 13 December.

Validity of Secondary Releases

We assessed the validity of our secondary releases by comparing detection rates and travel times 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 Lower Granite Dam.

Detection Probability and 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 informally as:

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

where: A = number of fish diverted from the turbine intake that will pass into the bypass system; and

B = number of fish not diverted from the turbine that will pass through the turbines.

The informal expression for the detection probability (P) estimated by the Single-Release Model is similar in form, 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: the difference is whatever small amount of mortality that may occur in the bypass system components between diversion away from the turbine intake to the point of detection. The value B includes only fish that entered the powerhouse, while D also includes fish that passed via the spillway.

However, under conditions of no spill at the dam, the values of B and D are still different, 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 the same, except that 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. Under conditions where A and C are equal, an estimate of FGE can be derived from $\hat{P}$ as follows:

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

Fish Size vs. Detection and Survival Probabilities and Travel Time

To investigate effects of fish size on survival probabilities, detection probabilities, and travel time, we divided each primary release group into three size classes based on the measured length at the time of tagging. The Single-Release Model was used to analyze capture history data for each size class within each primary release group. Fish released at Pittsburg Landing and Billy Creek were tagged 1 to 3 weeks before release. While fish continued to grow between the times of tagging and release, we assumed that the size classes defined at the time of tagging remained appropriate at the time of release. Fish for release groups at Asotin were measured on the date of release, and the size classes for those groups were defined as appropriate to the size at time of tagging.

When classified by size, the nine primary release groups produced nine sets of three "matched" release groups. Because of the complexities of multiple reaches and dams and the differences between when and where fish length was measured for different release groups, we did not attempt a fully quantitative analysis (e.g. multiple regression) of effects of size on the various parameters. The first step of analysis was to summarize the ordering of the estimates for the size classes within each release group. For example, if the "large" class of a particular release group had the highest survival in a particular reach, the "average" class the next highest, and the "small" class the lowest survival, then the ordering for survival in that reach has "large-average-small." If the summary of the ordering of estimates suggested a sufficient effect of size on the parameter, a more quantitative summary was constructed.

Flow, Water Temperature, and Survival

Identifying and quantifying relationships between environmental variables and release groups of PIT-tagged migrant juvenile salmonids have presented difficult challenges. Chief among these is that fish from a single release group do not migrate as a group, but spread out over time. If conditions change over a short period of time relative to the time it takes for the bulk of a release group to migrate through a particular river section, then different fish from the group experience different levels of various environmental factors. In this situation, estimated survival probabilities (defined for the entire release group) are usually valid estimates of average survival for the group. However, it is difficult to accurately quantify the environmental conditions to which the entire release group was exposed and to relate them to the survival estimates. Moreover, if a series of releases is made and migrations are protracted, the various release groups may have considerable overlap in passage distributions, further clouding the relationship between survival probabilities and environmental variables.

Among migration seasons of juvenile salmonids, that of subyearling fall chinook salmon is particularly protracted. Thus, the ability to define meaningful exposures to environmental variables for release groups appears particularly limited. This is especially true for subyearlings taken directly from hatcheries and released into rivers, because both timing of onset of migration and migration rates vary widely among individuals. Thus, for series of release groups within a single year, such as those from Pittsburg Landing, Billy Creek, and Asotin, only general descriptive statements regarding the relationships between survival and environmental variables can be made. Data from multiple years under varying flow volumes, water temperatures, etc. may be easier to relate statistically with survival of subyearling fall chinook salmon.

To surmount this complication, we attempted an alternative approach to within-season analysis: groups were formed based on the date of passage at a particular dam of interest, rather than based on the date and location of initial release. Using this approach, we identified groups of fish known to be actively migrating, and which had passed a certain identifiable point within the same 24-hour period. For example, all the fish passing Lower Granite Dam on a particular day would be expected to arrive at Little Goose Dam over a much shorter time period than all the fish released at Pittsburg Landing on a particular day, almost 60 days earlier. The "post-Lower Granite" capture histories of all fish returned to the tailrace of Lower Granite Dam on a particular day were grouped, and the Single-Release Model was applied to estimate survival for the "daily-passage group" from Lower Granite Dam tailrace to Little Goose Dam tailrace. We used a

Lower Granite Dam on a particular day were grouped, and the Single-Release Model was applied to estimate survival for the "daily-passage group" from Lower Granite Dam tailrace to Little Goose Dam tailrace. We used a similar procedure to identify daily-passage groups at Little Goose Dam, for which we estimated survival from Little Goose Dam tailrace to Lower Monumental Dam tailrace.

The main problem with this approach was the difficulty in obtaining groups of sufficient size to estimate survival probabilities with high precision using the Single-Release Model. To obtain reasonably sized groups, we pooled fish from all nine primary release groups (three each from Pittsburg Landing, Billy Creek, and Asotin). Further pooling of the daily groups by week was necessary. We estimated the survival probability from Lower Granite Dam tailrace to Little Goose Dam tailrace for groups of fish passing Lower Granite Dam during the following nine intervals: 11-17 July, 18-24 July, 25-31 July, 1-7 August, 8-14 August, 15-22 August, 12-18 September, 19-25 September, and 26 September-2 October. From 23 August to 11 September, no PIT-tagged fish were returned directly to the river at Lower Granite Dam because the Smolt Monitoring Program was using a 100% sampling rate. We estimated the survival probability from Little Goose Dam tailrace to Lower Monumental Dam tailrace for groups of fish passing Little Goose Dam during the following 12 intervals: 11-17 July, 18-24 July, 25-31 July, 1-7 August, 8-14 August, 15-21 August, 22-28 August, 29 August-4 September, 5-11 September, 12-18 September, 19-25 September, and 26 September-2 October. To investigate correlations of flow and temperature with estimated survival probabilities, we calculated corresponding weekly average flow and water temperature at Lower Granite and Little Goose Dams.

RESULTS

Primary Release Groups of Natural Subyearling Chinook Salmon

We PIT tagged and released natural subyearling fall chinook salmon between the weeks of 9 April and 23 July (Table 1). Totals of 569, 666, and 457 natural subyearling fall chinook salmon were tagged and released in the upstream reach of the Snake River, downstream reach of the Snake River, and the Clearwater River, respectively. Mean weekly water temperatures ranged from 8.4 to 18.4°C.

Primary Release Groups of Hatchery Subyearling Fall Chinook Salmon

A total of 7,681 fish were PIT tagged for releases at Pittsburg Landing and Billy Creek and 8,790 fish were tagged for releases at Asotin (Table 2). Tagging and handling mortality at the hatchery averaged 0.8%, including immediate mortalities and all subsequent mortalities removed from the raceway by hatchery personnel up to 5 July. Transport mortality, delayed mortality, and tag loss were low for all release groups (Table 3). At release sites, Snake River water temperatures ranged from 12.3 to 17.6°C (Table 2). The similarity between hatchery and Snake River water temperatures simplified acclimation.

Hatchery subyearling fall chinook salmon for the Pittsburg Landing and Billy Creek release groups were grouped by length at tagging into three size classes: less than 70 mm ("small"), between 70 and 73 mm inclusive ("average"), and greater than 73 mm ("large"). Each size class had approximately the same number of fish (Table 2). Size classes for fish released at Asotin depended on the time of tagging and release. "Average" size classes

Table 1. Release information for groups of PIT-tagged natural subyearling fall chinook salmon released in 1995, including week of release, number released/site, and mean weekly water temperatures.

	Snake River upstream reach		Snake River downstream reach		Clearwater River	
Week	N	temperature (°C)	N	temperature (°C)	N	temperature (°C)
9 April	0	--	1	8.5	0	--
16 April	0	--	0	--	0	--
23 April	0	--	2	12.2	0	--
30 April	3	10.1	2	10.6	0	--
7 May	30	11.6	6	12.9	0	--
14 May	16	12.9	19	13.3	0	--
21 May	121	14.5	16	14.1	1	10.0
28 May	247	16.0	82	14.8	0	--
4 June	96	16.1	268	11.8	5	8.4
11 June	50	17.2	154	15.1	20	13.0
18 June	6	16.6	55	13.2	31	9.9
25 June	0	--	44	17.9	102	15.9
2 July	0	--	17	16.9	122	16.9
9 July	0	--	0	--	114	18.4
16 July	0	--	0	--	47	16.1
23 July	0	--	0	--	15	15.0

Table 2. Information for primary release groups of PIT-tagged hatchery subyearling fall chinook salmon in 1995, including release site, date of release, number released, water temperature at release, mean fork length at time of release,and number of fish in each size class at time of tagging.

Site	Release date	Number released	Water temp. (°C)	Mean length (mm)	Number released by size group		
					small	average	large
Pittsburg Landing	31 May	1,353	15.7	73	502	419	432
	7 June	1,341	16.0	76	458	445	438
	14 June	1,326	16.9	79	394	434	498
Billy Creek	1 June	1,220	13.5	72	486	386	348
	8 June	1,317	12.3	75	456	412	449
	15 June	1,124	14.2	81	311	363	450
Asotin	19 June	2,778	13.5	82	916	1,005	857
	27 June	2,489	16.5	85	920	720	849
	5 July	3,523	17.6	90	1,263	1,035	1,225

Table 3. Transport mortality, delayed mortality, and tag loss for hatchery subyearling fall chinook salmon used in primary (Pittsburg Landing, Billy Creek, and Asotin) and secondary (Lower Granite, Little Goose, and Lower Monumental Dam) releases in 1995.

Release site	Release date	Transport mortality N	Transport mortality %	Number held N	Delayed mortality N	Delayed mortality %	Tag loss N	Tag loss %
Pittsburg Landing	31 May	0	0.0	105	1	0.9	0	0.0
	7 June	0	0.0	54	0	0.0	0	0.0
	14 June	0	0.0	95	0	0.0	1	1.1
Billy Creek	1 June	0	0.0	103	1	1.0	0	0.0
	8 June	1	0.1	101	0	0.0	0	0.0
	15 June	0	0.0	92	0	0.0	3	3.1
Asotin	19 June	3	0.1	94	1	1.1	0	0.0
	27 June	0	0.0	110	2	1.8	0	0.0
	5 July	1	0.1	92	0	0.0	1	1.1
Primary release totals		5	0.1	852	5	0.6	5	0.6
Lower Granite	13 July	0	0.0	-	-	-	-	-
	3 August	5	0.4	-	-	-	-	-
Little Goose	21 July	12	0.8	-	-	-	-	-
	10 August	6	0.4	-	-	-	-	-
Lower Monumental	26 July	12	0.8	-	-	-	-	-
	17 August	3	0.5	-	-	-	-	-
Secondary release totals		38	0.5	-	-	-	-	-

were 80-84 mm, 85-89 mm, and 89-93 mm (all inclusive), respectively, for groups released on 19 June, 27 June, and 5 July.

Secondary Release Groups of Hatchery Subyearling Fall Chinook Salmon

A total of 7,843 fish were released for post-detection bypass evaluation (Table 4). Snake River water temperatures during these releases ranged between 18.5 and 20.5°C, and transport mortality from the raceway at Lower Granite Dam to release sites was low, averaging 0.5% (Table 3). Average fork length for these release groups ranged from 89 to 99 mm between 19 July and 8 August.

Data Analyses

Validity of Secondary Releases

Hatchery subyearling fall chinook salmon from primary release groups averaged from 146.3 to 149.7 mm fork length when recaptured at Lower Granite Dam (Table 5). Fish used for secondary release groups at Lower Granite Dam averaged 93.0 mm fork length. Detection proportions at downstream dams for PIT-tagged fish from secondary release groups were low, averaging 10.2, 16.6, and 19.8% for releases made at Lower Granite, Little Goose, and Lower Monumental Dams, respectively (Table 5). In contrast, average downstream detection rates for PIT-tagged fish released above Lower Granite Dam and then detected and re-released at the same dams were 52.8, 52.0, and 38.2%, respectively.

Median travel times between dams were from 3 to 7.5 times longer for secondary release groups than for fish from primary release groups above Lower Granite Dam (Table 5).

Table 4. Information for secondary release groups of hatchery subyearling fall chinook salmon in 1995, including release site, type of release, date of release, number released, and water temperature at release. For bypass releases, only fish known to be successfully routed to the river by the slide-gate were included.

	Release			
Site	Location	Date	Number	Temp. (°C)
Lower Granite Dam	bypass	13 July	714	20.5
	tailrace	13 July	700	20.5
	bypass	3 August	690	19.0
	tailrace	3 August	674	19.0
Little Goose Dam	bypass	21 July	809	20.0
	tailrace	21 July	698	20.0
	bypass	10 August	809	20.0
	tailrace	10 August	710	20.0
Lower Monumental Dam	bypass	26 July	815	20.5
	tailrace	26 July	665	20.5
	bypass	17 August	348	18.5
	tailrace	17 August	211	18.5

Table 5. Mean fork length of hatchery fall chinook salmon recaptured at Lower Granite Dam and mean length of fish in secondary release groups at Lower Granite Dam, detection rates and median travel time to next downstream dam for fish from primary release groups captured and released at each dam and for fish from secondary release groups released at each dam. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

Detection/Release site	Original release site	Mean fork length at LGR (mm)	Mean downstream detection rate (%)	Median travel time to next dam (days)
Lower Granite Dam	Pittsburg Landing	149.7	59.0	6.08
	Billy Creek	146.3	61.9	6.46
	Asotin	149.0	42.2	9.40
	Secondary @ LGR	93.0	10.2	45.20
Little Goose Dam	Pittsburg Landing	----	55.7	5.14
	Billy Creek	----	56.4	5.11
	Asotin	----	44.1	6.44
	Secondary @ LGO	----	16.6	32.60
L. Monumental Dam	Pittsburg Landing	----	40.8	5.19
	Billy Creek	----	39.7	5.03
	Asotin	----	32.4	6.74
	Secondary @ LMO	----	19.8	20.40

Thus, our method for making secondary releases in 1995 was not valid because fish from the secondary release groups 1) were smaller, 2) had lower detection rates, and 3) migrated slower than the fish they were intended to represent. Therefore, we did not estimate 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

With one notable exception, tests of model assumptions did not indicate any systematic violations (Tables 6,7,8,9). The exception was that detection distributions at McNary Dam for hatchery subyearling chinook salmon released at Asotin depended on detection history at Lower Granite, Little Goose, and Lower Monumental Dams (TEST 2.C3, Table 6, and Table 9). This violation was due to the combination of differential detection-system shutdown times at the dams and the pulse of fish migrating during the December flood. The proportion of fish detected at McNary Dam that were previously undetected was larger than expected because detection systems at the upper dams were not operational when the pulse of fish came down the river. The measures described in the previous section corrected the effects of these problems.

Detection Probabilities

To use the SR Model to obtain reliable estimates of survival and detection probabilities for natural subyearling chinook salmon, it was necessary to pool all fish that were PIT tagged and released in a certain area throughout the entire season and treat them as a single release group.

Table 6. Results of tests of goodness of fit to the Single-Release Model for Pittsburg Landing (PL), Billy Creek (BC), and Asotin (AS) release groups.

	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
PL1	5.215	0.517	3.779	0.286	0.175	0.916	3.604	0.058
PL2	4.287	0.638	2.416	0.491	0.741	0.690	1.675	0.196
PL3	18.445	0.005	9.137	0.028	6.762	0.034	2.375	0.123
BC1	5.154	0.524	0.778	0.855	0.448	0.799	0.330	0.566
BC2	3.245	0.778	2.499	0.475	0.445	0.801	2.054	0.152
BC3	7.613	0.268	5.221	0.156	2.590	0.274	2.631	0.105
AS1	28.299	0.000	17.774	0.000	11.683	0.003	6.091	0.014
AS2	38.811	0.000	35.203	0.000	3.929	0.140	31.274	0.000
AS3	31.776	0.000	26.167	0.000	0.263	0.877	25.904	0.000

Table 6. Continued.

Release	TEST 3		TEST 3.SR3		TEST 3.Sm3		TEST 3.SR4	
	χ^2	P value	χ^2	P value	χ^2	P value	χ^2	P value
PL1	1.436	0.697	0.024	0.877	0.035	0.852	1.377	0.241
PL2	1.871	0.600	1.856	0.173	0.006	0.938	0.009	0.924
PL3	9.308	0.025	7.037	0.008	1.484	0.223	0.787	0.375
BC1	4.376	0.224	3.963	0.047	0.396	0.529	0.017	0.896
BC2	0.746	0.862	0.696	0.404	0.009	0.924	0.041	0.840
BC3	2.392	0.495	1.481	0.224	0.737	0.391	0.174	0.677
AS1	10.525	0.015	3.378	0.066	3.007	0.083	4.140	0.042
AS2	3.608	0.307	3.506	0.061	0.096	0.757	0.006	0.938
AS3	5.609	0.132	0.002	0.964	3.379	0.066	2.228	0.136

Table 7. Tests of homogeneity of Little Goose Dam passage distributions for subgroups of Pittsburg Landing, Billy Creek, and Asotin releases defined by capture history at Lower Granite Dam. P values calculated using Monte Carlo approximation of the exact method.

Release	χ^2	Degrees of freedom	P value
PL1	66.49	69	0.479
PL2	61.65	64	0.471
PL3	49.98	63	0.935
BC1	62.35	61	0.296
BC2	77.38	79	0.401
BC3	55.20	66	0.881
AS1	104.90	90	0.020
AS2	84.08	86	0.416
AS3	65.35	68	0.471

Table 8. Tests of homogeneity of Lower Monumental Dam passage distributions for subgroups of Pittsburg Landing, Billy Creek, and Asotin releases defined by capture history at Lower Granite and Little Goose Dams. P values calculated using Monte Carlo approximation of the exact method.

Release	χ^2	Degrees of freedom	P value
PL1	181.1	204	0.607
PL2	177.2	189	0.159
PL3	179.1	189	0.860
BC1	186.2	216	0.732
BC2	203.9	222	0.263
BC3	189.8	195	0.036
AS1	221.3	228	0.065
AS2	166.5	192	0.680
AS3	160.7	180	0.509

Table 9. Tests of homogeneity of McNary Dam passage distributions for subgroups of Pittsburg Landing, Billy Creek, and Asotin releases defined by capture history at Lower Granite, Goose, and Lower Monumental Dams. P values calculated using Monte Carlo approximation of the exact method.

Release	χ^2	Degrees of freedom	P value
PL1	427.5	448	0.690
PL2	418.6	441	0.141
PL3	452.3	448	0.592
BC1	439.8	462	0.311
BC2	472.6	483	0.257
BC3	443.8	434	0.324
AS1	560.5	539	0.002
AS2	521.8	434	<0.001
AS3	631.8	406	<0.001

Detection probabilities at Lower Granite Dam differed among groups of natural fish released in the upstream (0.530, s.e. 0.043) and downstream (0.445, s.e. 0.056) reaches of the Snake River and in the Clearwater River (0.313, s.e. 0.226; Table 10). Among primary release groups of hatchery fish, detection probabilities at Lower Granite Dam were similar, averaging 0.484 across all nine groups (Table 10). Detection probabilities of hatchery fish at Little Goose and Lower Monumental Dams averaged 0.424 and 0.527, respectively.

Survival Estimation

Because of the problems with our post-detection bypass releases described above, post-detection bypass survival was assumed to be 100%, and the SR Model was used to estimate survival for all primary release groups. For natural subyearling fall chinook salmon, survival estimates from the point of release to Lower Granite Dam tailrace were similar for fish released in the upstream (0.672, s.e. 0.049) and downstream (0.655, s.e. 0.071; Table 11) reaches of the Snake River. Survival to Lower Granite Dam tailrace was lowest for natural fish released in the Clearwater River (0.156, s.e. 0.044). Patterns of survival estimates from the three release locations to Lower Monumental Dam tailrace were similar (Table 11).

For hatchery subyearling fall chinook salmon, survival estimates from the point of release to Lower Granite Dam tailrace averaged 0.633 (s.e. 0.023) and 0.611 (s.e. 0.023) for Pittsburg Landing and Billy Creek release groups, respectively. This is only slightly lower than the corresponding survival estimates for natural fish. Survival was lower for Asotin release groups (average 0.448, s.e. 0.040) than for upstream release groups. For the series of primary releases at each release site, survival estimates decreased with later release dates,

Table 10. Detection probability estimates (based on the Single-Release Model) for PIT-tagged natural subyearling fall chinook salmon released in the upstream and downstream reaches of the Snake River and in the Clearwater River and PIT-tagged hatchery subyearling fall chinook salmon released at Pittsburg Landing, Billy Creek, and Asotin in 1995. Standard errors are in parentheses.

Rearing type	Release		Estimated detection probabilities		
	Site	Date(s)	Lower Granite	Little Goose	Lower Monumental
Natural	Snake upstream	4 May-22 Jun	0.530 (0.043)	0.502 (0.049)	0.623 (0.067)
	Snake downstream	25 Apr - 6 Jul	0.445 (0.056)	0.581 (0.056)	0.455 (0.079)
	Clearwater	12 Jun - 26 Jul	0.313 (0.226)	0.250 (0.217)	0.500 (0.250)
	Weighted mean		0.494 (0.035)	0.528 (0.043)	0.551 (0.058)
Hatchery	Pittsburg Landing	31 May	0.475 (0.023)	0.404 (0.027)	0.491 (0.039)
		7 June	0.499 (0.023)	0.405 (0.027)	0.562 (0.037)
		14 June	0.469 (0.026)	0.437 (0.032)	0.505 (0.044)
	Billy Creek	1 June	0.476 (0.024)	0.444 (0.029)	0.509 (0.041)
		8 June	0.502 (0.023)	0.408 (0.028)	0.541 (0.039)
		15 June	0.463 (0.028)	0.473 (0.035)	0.567 (0.050)
	Asotin	19 June	0.509 (0.021)	0.390 (0.026)	0.478 (0.039)
		27 June	0.499 (0.028)	0.487 (0.038)	0.563 (0.060)
		5 July	0.421 (0.035)	0.443 (0.049)	0.619 (0.078)
	Weighted mean		0.484 (0.008)	0.424 (0.011)	0.527 (0.013)

Table 11. Survival probability estimates (based on the Single-Release Model) for PIT-tagged natural subyearling fall chinook salmon released in the upstream and downstream reaches of the Snake River and in the Clearwater River and PIT-tagged hatchery subyearling fall chinook salmon released at Pittsburg Landing, Billy Creek, and Asotin in 1995. Standard errors are in parentheses. Abbreviations: Rel-Release site; LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

Rearing type	Release		Estimated survival probabilities by reach			
	Site	Date(s)	Rel to LGR	LGR to LGO	LGO to LMO	Rel to LMO
Natural	Snake upstream		0.672 (0.049)	0.844 (0.117)	0.788 (0.088)	0.446 (0.051)
	Snake downstream		0.655 (0.071)	0.472 (0.085)	1.0* (0.190)	0.364 (0.063)
	Clearwater		0.156 (0.044)	1.0* (1.113)	0.250 (0.217)	0.048 (0.012)
Hatchery	Pittsburg Landing	31 May	0.656 (0.025)	0.842 (0.053)	0.799 (0.066)	0.441 (0.032)
		7 June	0.648 (0.023)	0.840 (0.050)	0.755 (0.054)	0.411 (0.025)
		14 June	0.596 (0.028)	0.705 (0.051)	0.864 (0.075)	0.363 (0.029)
	Billy Creek	1 June	0.644 (0.026)	0.804 (0.049)	0.871 (0.069)	0.451 (0.033)
		8 June	0.594 (0.022)	0.904 (0.055)	0.752 (0.058)	0.404 (0.026)
		15 June	0.594 (0.029)	0.777 (0.059)	0.792 (0.073)	0.366 (0.030)
	Asotin	19 June	0.498 (0.018)	0.761 (0.047)	0.860 (0.077)	0.326 (0.026)
		27 June	0.460 (0.022)	0.653 (0.055)	0.855 (0.103)	0.257 (0.028)
		5 July	0.387 (0.024)	0.570 (0.069)	0.839 (0.148)	0.185 (0.028)

* Estimated value greater than 1.0.

particularly for Asotin release groups. There were no apparent trends between release locations or release dates and survival between Lower Granite Dam tailrace and Little Goose Dam tailrace or between Little Goose Dam tailrace and Lower Monumental Dam tailrace (Table 11). Estimated survival from the various release points to the tailrace of Lower Monumental Dam followed the same patterns as survival to Lower Granite Dam tailrace; survival decreased with later release date. Survival through this reach was similar for Pittsburg Landing (average 0.405, s.e. 0.028) and Billy Creek (0.407, s.e. 0.032) release groups, and lower for Asotin release groups (0.256, s.e. 0.049) (Table 11).

Travel Time

Median travel times from the point of release to Lower Granite Dam were similar between release sites, averaging about 57 days (Table 12). However, because of differences in distance from release point to Lower Granite Dam, computed migration rates were very different: rates for fish from Pittsburg Landing were nearly twice those for fish from Billy Creek and Asotin (Fig. 2). Migration rates between each pair of dams (Lower Granite and Little Goose, Little Goose and Lower Monumental, and Lower Monumental and McNary) were more similar between release groups.

Migration rates increased substantially between Lower Monumental and McNary Dams for all groups (Figs. 3, 4, and 5 and Tables 13, 14, and 15). The unusual flood event and consequent pulse of fish migrating in early December resulted in exceptionally long median travel times for the second and third release groups at Asotin (Fig. 6 and Table 16). Of fish from these groups that were detected at McNary Dam, more were detected in the

Table 12. Travel times and migration rates between the point of release and Lower Granite Dam for hatchery subyearling fall chinook salmon released at Pittsburg Landing (173 km), Billy Creek (92 km), and Asotin (63 km) and natural subyearling fall chinook salmon released in the upstream (average 167 km) and downstream (average 67 km) reaches of the Snake River and in the Clearwater River (average 77 km).

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
Hatchery												
PL1	31 May	423	2.31	49.38	58.48	69.12	150.05	1.15	2.50	2.96	3.50	74.89
PL2	7 June	439	3.21	46.67	55.39	64.41	141.90	1.22	2.69	3.12	3.71	53.89
PL3	14 June	366	4.79	44.71	53.38	69.86	138.10	1.25	2.48	3.24	3.87	36.12
BC1	1 June	373	1.94	48.42	57.67	66.40	138.41	0.66	1.39	1.60	1.90	47.42
BC2	8 June	389	2.09	45.24	54.64	66.73	128.80	0.71	1.38	1.68	2.03	44.02
BC3	15 June	302	3.13	44.45	53.41	73.70	137.96	0.67	1.25	1.72	2.07	29.39
AS1	19 June	682	1.66	42.96	52.40	82.42	131.89	0.48	0.76	1.20	1.47	37.95
AS2	27 June	539	3.13	40.76	59.36	83.76	123.87	0.51	0.75	1.06	1.55	20.13
AS3	5 July	569	2.93	40.10	66.09	86.77	118.50	0.53	0.73	0.95	1.57	21.50
Natural												
Snake Up.	4 May-22 Jun	201	4.29	32.09	46.85	61.27	145.82	1.15	2.73	3.56	5.20	38.93
Snake Down.	25 Apr-6 Jul	226	2.80	23.08	48.84	67.97	139.53	0.48	0.99	1.37	2.90	23.93
Clearwater	23 May-26 Jul	30	5.01	30.57	71.48	99.20	123.21	0.62	0.78	1.08	2.52	15.37

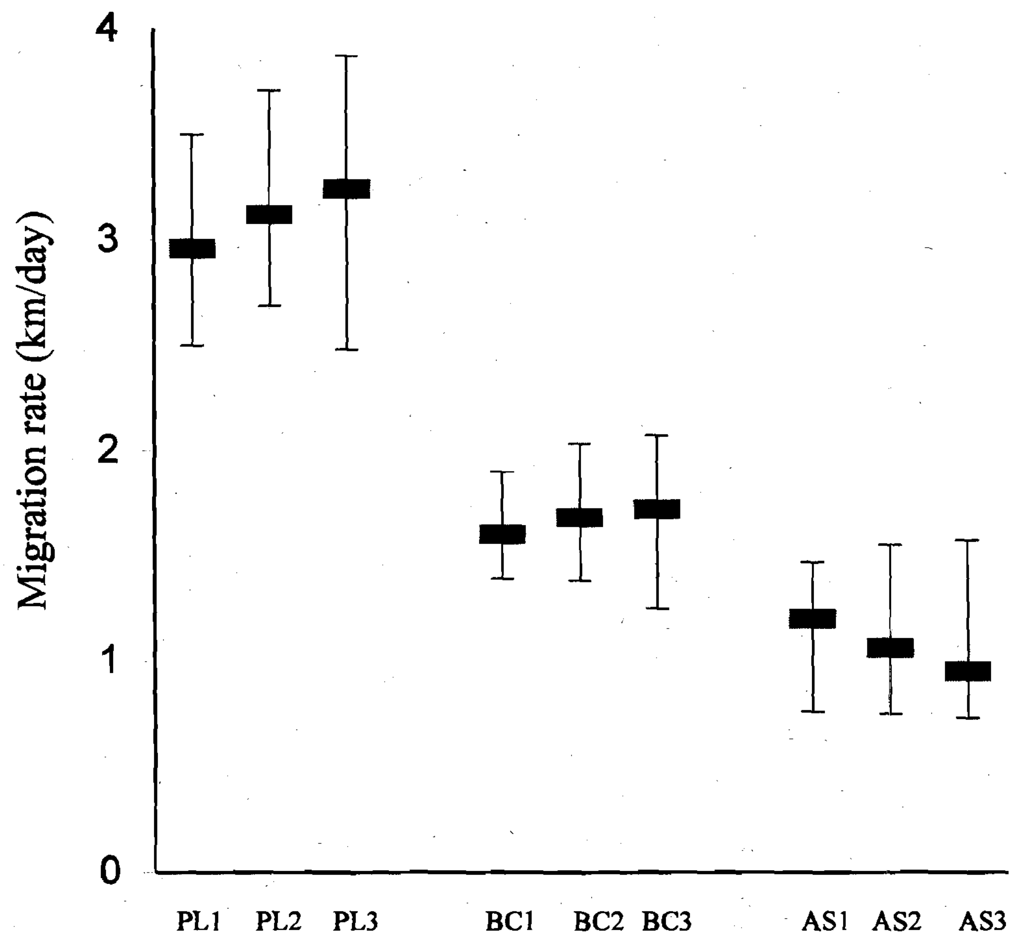

Figure 2. Median migration rate (km/day) from release point to Lower Granite Dam for PIT-tagged subyearling fall chinook salmon released in 1995 at Pittsburg Landing (PL), Billy Creek (BC), and Asotin (AS). Ends of thin lines show 20th and 80th percentiles.

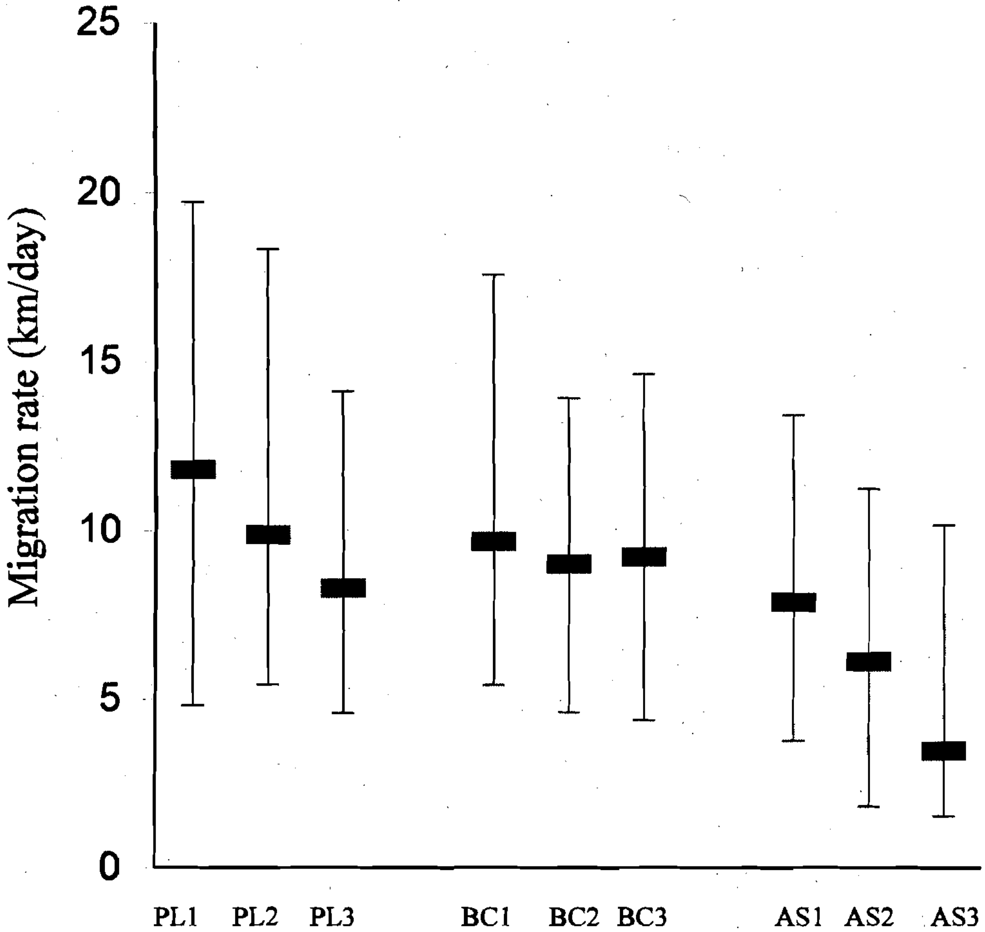

Figure 3. Median migration rate (km/day) between Lower Granite and Little Goose Dams for PIT-tagged subyearling fall chinook salmon released in 1995 at Pittsburg Landing (PL), Billy Creek (BC), and Asotin (AS). Ends of thin lines show 20th and 80th percentiles.

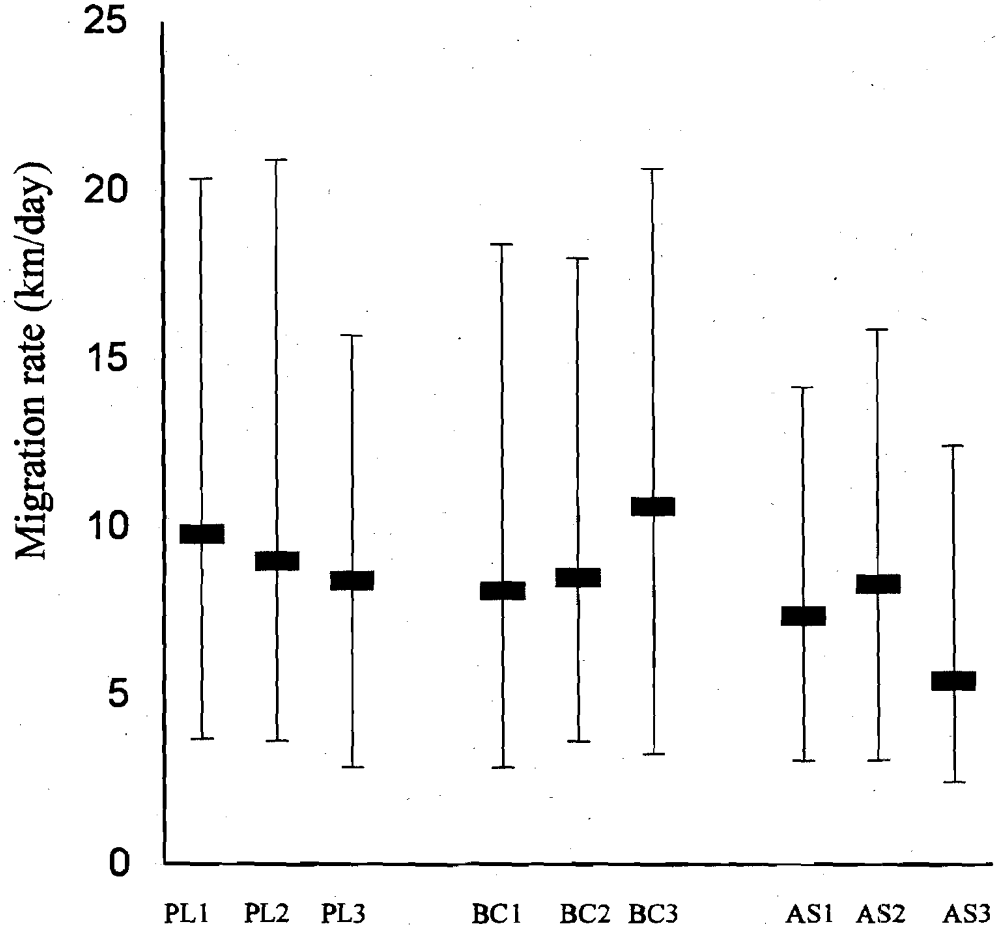

Figure 4. Median migration rate (km/day) between Little Goose and Lower Monumental Dams for PIT-tagged subyearling fall chinook salmon released in 1995 at Pittsburg Landing (PL), Billy Creek (BC), and Asotin (AS). Ends of thin lines show 20th and 80th percentiles.

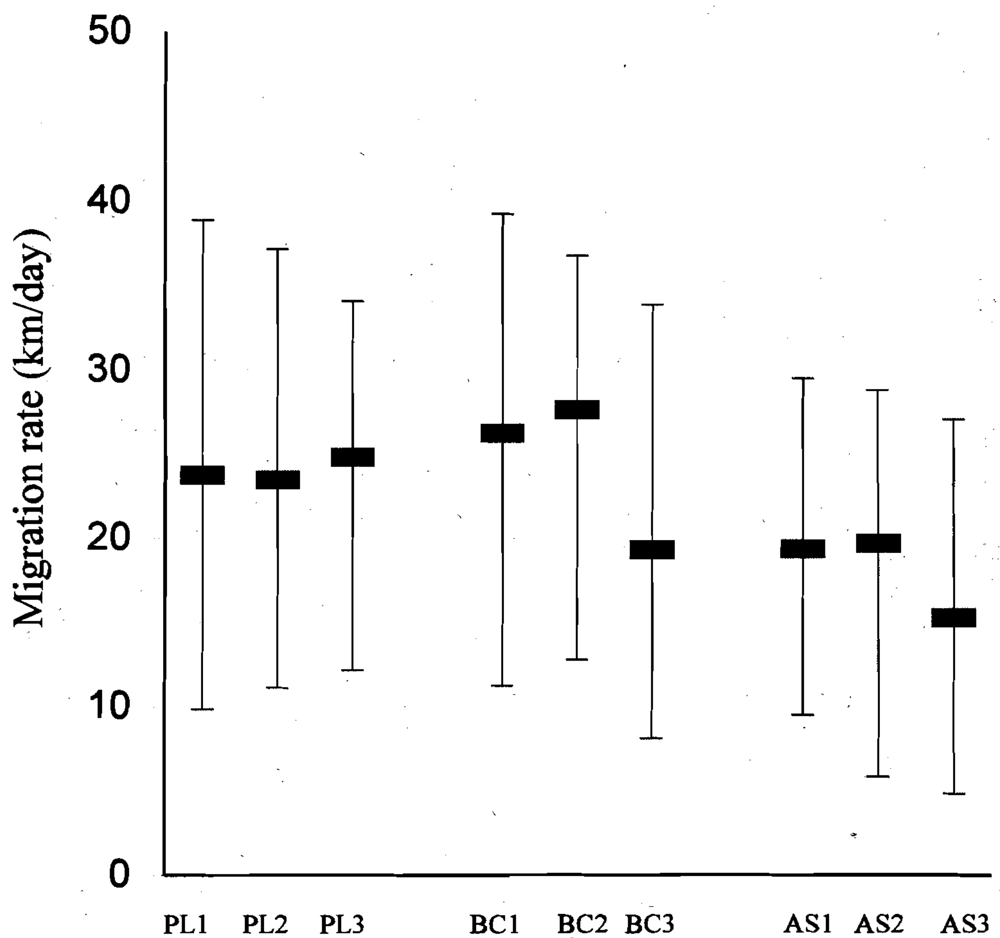

Figure 5. Median migration rate (km/day) between Lower Monumental and McNary Dams for PIT-tagged subyearling fall chinook salmon released in 1995 at Pittsburg Landing (PL), Billy Creek (BC), and Asotin (AS). Ends of thin lines show 20th and 80th percentiles.

Table 13. 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, Billy Creek, and Asotin and natural subyearling fall chinook salmon released in the upstream and downstream reaches of the Snake River and in the Clearwater River.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
Hatchery												
PL1	31 May	127	1.81	3.04	5.08	12.44	56.66	1.06	4.82	11.81	19.74	33.15
PL2	7 June	121	1.27	3.27	6.07	11.03	47.16	1.27	5.44	9.88	18.35	47.24
PL3	14 June	81	1.75	4.24	7.23	13.03	69.68	0.86	4.60	8.30	14.15	34.29
BC1	1 June	120	1.99	3.41	6.19	11.04	66.14	0.91	5.43	9.69	17.60	30.15
BC2	8 June	121	1.71	4.30	6.65	12.96	68.24	0.88	4.63	9.02	13.95	35.09
BC3	15 June	89	1.91	4.09	6.49	13.64	83.24	0.72	4.40	9.24	14.67	31.41
AS1	19 June	174	2.03	4.46	7.60	15.86	70.08	0.86	3.78	7.89	13.45	29.56
AS2	27 June	136	2.23	5.33	9.79	32.89	85.49	0.70	1.82	6.13	11.26	26.91
AS3	5 July	89	3.17	5.89	17.26	38.99	78.82	0.76	1.54	3.48	10.19	18.93
Natural												
Snake Up.	4 May-22 Jun	38	3.23	5.67	9.06	17.63	56.46	1.06	3.40	6.62	10.58	18.58
Snake Down.	25 Apr-6 Jul	57	3.14	4.31	6.42	12.84	64.55	0.93	4.67	9.35	13.92	19.11
Clearwater	23 May-26 Jul	0	---	---	---	---	---	---	---	---	---	---

Table 14. 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, Billy Creek, and Asotin and natural subyearling fall chinook salmon released in the upstream and downstream reaches of the Snake River and in the Clearwater River.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
Hatchery												
PL1	31 May	108	1.24	2.26	4.69	12.38	76.52	0.60	3.72	9.81	20.35	37.10
PL2	7 June	109	1.18	2.20	5.11	12.54	58.45	0.79	3.67	9.00	20.91	38.98
PL3	14 June	85	1.42	2.93	5.46	15.92	50.75	0.91	2.89	8.42	15.70	32.39
BC1	1 June	118	1.09	2.50	5.67	15.99	73.01	0.63	2.88	8.11	18.40	42.20
BC2	8 June	102	1.17	2.56	5.41	12.64	51.71	0.89	3.64	8.50	17.97	39.32
BC3	15 June	81	1.20	2.23	4.34	14.02	81.82	0.56	3.28	10.60	20.63	38.33
AS1	19 June	119	1.14	3.25	6.26	14.97	81.57	0.56	3.07	7.35	14.15	40.35
AS2	27 June	88	1.38	2.90	5.54	14.92	85.70	0.54	3.08	8.30	15.86	33.33
AS3	5 July	51	2.05	3.71	8.47	18.90	42.27	1.09	2.43	5.43	12.40	22.44
Natural												
Snake Up.	4 May-22 Jun	56	1.23	2.52	4.30	11.36	96.70	0.48	4.05	10.70	18.25	37.40
Snake Down.	25 Apr-6 Jul	63	1.20	2.73	4.67	10.85	64.27	0.72	4.24	9.85	16.85	38.33
Clearwater	23 May-26 Jul	0	---	---	---	---	---	---	---	---	---	---

Table 15. Travel times and migration rates between Lower Monumental Dam and McNary Dam (119 km) for hatchery subyearling fall chinook salmon released at Pittsburg Landing, Billy Creek, and Asotin and natural subyearling fall chinook salmon released in the upstream and downstream reaches of the Snake River and in the Clearwater River.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
Hatchery												
PL1	31 May	83	2.39	3.06	5.01	12.08	89.59	1.33	9.85	23.75	38.89	49.79
PL2	7 June	109	2.34	3.20	5.07	10.69	132.63	0.90	11.13	23.47	37.19	50.85
PL3	14 June	69	2.46	3.49	4.79	9.77	105.88	1.12	12.18	24.84	34.10	48.37
BC1	1 June	91	2.26	3.03	4.53	10.57	95.19	1.25	11.26	26.27	39.27	52.65
BC2	8 June	102	2.02	3.23	4.30	9.30	98.33	1.21	12.80	27.67	36.84	58.91
BC3	15 June	66	2.63	3.51	6.15	14.64	112.13	1.06	8.13	19.35	33.90	45.25
AS1	19 June	83	2.25	4.03	6.13	12.54	106.55	1.12	9.49	19.41	29.53	52.89
AS2	27 June	52	2.76	4.12	6.03	20.29	91.80	1.30	5.86	19.73	28.88	43.12
AS3	5 July	31	2.65	4.39	7.79	24.61	81.24	1.46	4.84	15.28	27.11	44.91
Natural												
Snake Up.	4 May-22 Jun	37	2.46	3.10	4.95	9.80	69.37	1.72	12.14	24.04	38.39	48.37
Snake Down.	25 Apr-6 Jul	29	2.37	3.75	4.82	11.24	23.66	5.03	10.59	24.69	31.73	50.21
Clearwater	23 May-26 Jul	1	---	---	9.19	---	---	---	---	12.95	---	---

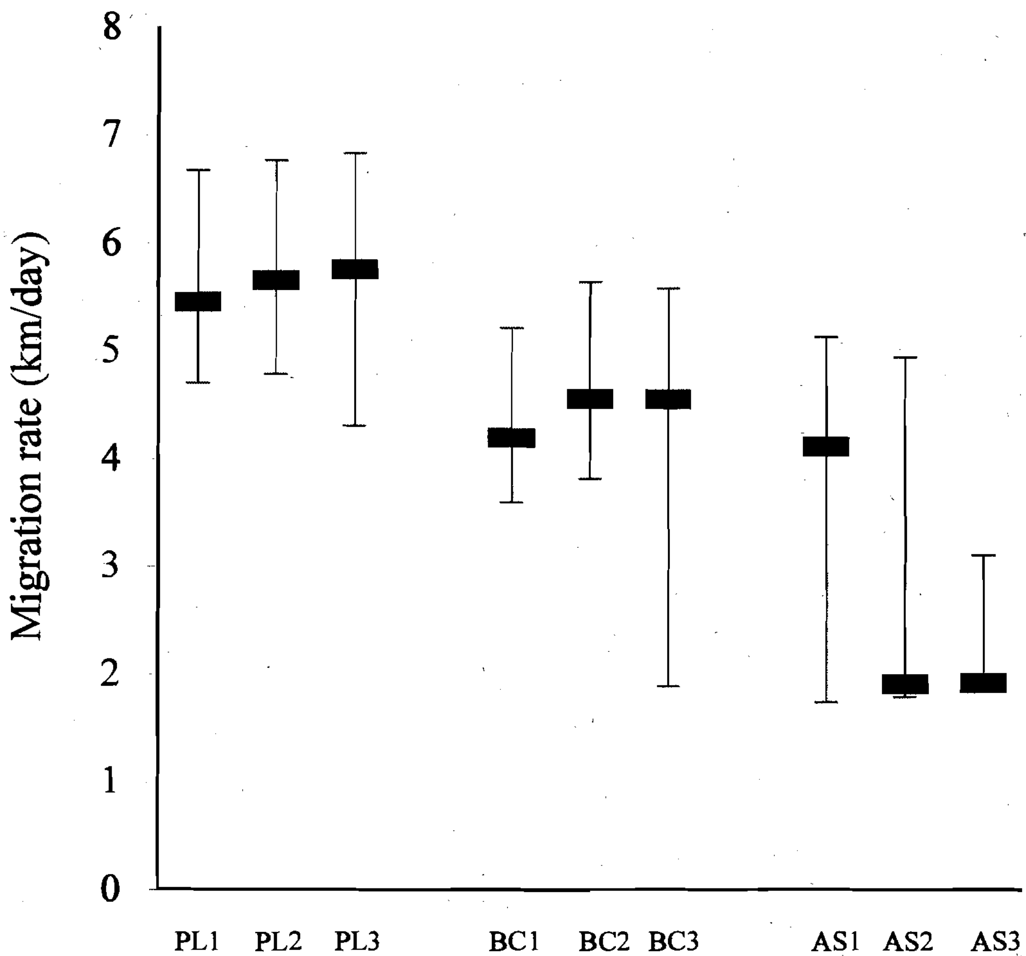

Figure 6. Median migration rate (km/day) from release point to McNary Dam for PIT-tagged subyearling fall chinook salmon released in 1995 at Pittsburg Landing (PL), Billy Creek (BC), and Asotin (AS). Ends of thin lines show 20th and 80th percentiles.

Table 16. Travel times and migration rates between the point of release and McNary Dam for hatchery subyearling fall chinook salmon released at Pittsburg Landing (398 km), Billy Creek (317 km), and Asotin (288 km) and natural subyearling fall chinook salmon released in the upstream (average 392 km) and downstream (average 292 km) reaches of the Snake River and in the Clearwater River (average 302 km).

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
Hatchery												
PL1	31 May	181	20.83	59.58	72.95	84.56	192.66	2.07	4.71	5.46	6.68	19.11
PL2	7 June	206	18.79	58.75	70.27	83.10	184.91	2.15	4.79	5.66	6.77	21.18
PL3	14 June	161	24.18	58.21	69.12	92.42	179.52	2.22	4.31	5.76	6.84	16.46
BC1	1 June	179	25.40	60.69	75.54	88.06	192.20	1.65	3.60	4.20	5.22	12.48
BC2	8 June	201	34.84	56.06	69.51	82.97	185.33	1.71	3.82	4.56	5.65	9.10
BC3	15 June	137	21.17	56.71	69.46	167.91	178.54	1.78	1.89	4.56	5.59	14.97
AS1	19 June	249	17.71	56.07	69.86	165.86	174.45	1.65	1.74	4.12	5.14	16.26
AS2	27 June	184	32.47	58.24	150.53	160.89	166.75	1.73	1.79	1.91	4.95	8.87
AS3	5 July	185	32.51	92.46	150.14	153.85	158.55	1.82	1.87	1.92	3.11	8.86
Natural												
Snake Up.	4 May-22 Jun	67	23.35	51.04	66.35	86.03	213.78	1.83	4.56	5.91	7.68	16.79
Snake Down.	25 Apr-6 Jul	77	14.62	36.88	63.01	102.38	190.71	1.53	2.85	4.63	7.92	19.97
Clearwater	23 May-26 Jul	19	63.40	141.52	145.88	169.04	186.47	1.62	1.79	2.07	2.13	4.76

2 weeks following the flood than in the previous 5 months. Among fish that migrated before the flood, median travel times were similar among all three Asotin release groups and shorter for Asotin release groups than for those released upriver.

Natural subyearling fall chinook PIT tagged and released in the Snake River generally traveled faster than hatchery fish released in the same vicinity. This difference was most marked in migration from release sites to Lower Granite Dam (Table 12). Natural fish from the upstream reach of the Snake River arrived at Lower Granite Dam almost 10 days sooner than hatchery fish released nearby at Pittsburg Landing. Natural fish released in the downstream reach arrived at Lower Granite Dam more than 10 days sooner than their hatchery counterparts released at Asotin. Natural fish tagged and released in the Clearwater River arrived later at Lower Granite Dam than natural fish released in the downstream reach of the Snake River or hatchery fish released near Asotin, locations that are similar in distance from Lower Granite Dam.

Generally, natural subyearling chinook salmon continued to travel faster than hatchery counterparts through the lower reaches of the Snake River (Tables 13, 14, 15). The number of natural fish released in the Clearwater River and detected at consecutive downstream dams was insufficient to calculate travel time statistics. Median travel time from release to McNary Dam of natural fish released in the upstream reach of the Snake River was 66 days, about 1 week less than that of hatchery fish released at Pittsburg Landing.

A much higher proportion of hatchery fish released at Asotin, in contrast to natural fish released in the downstream reach of the Snake River, was detected at McNary Dam during and after the early December flood event, evidence that hatchery fish were more likely to residualize. However, the hatchery fish were released later than the natural fish. Almost all natural fish released in the Clearwater River that were detected at McNary Dam were detected during and after the flood.

Fish Size vs. Detection and Survival Probabilities and Travel Time

Detection probability estimates did not vary significantly between size classes within primary release groups of hatchery fish. No trends were visible in orderings of estimates for any detection site (Table 17). Average detection probability estimates at Lower Granite Dam for small, average, and large size classes were 0.474, 0.494, and 0.483, respectively. At Little Goose Dam, respective average detection probability estimates were 0.426, 0.405, and 0.439, for small, average, and large size classes, and at Lower Monumental Dam the respective estimates were 0.515, 0.533, and 0.527.

Orderings of survival probability estimates suggested substantial differences among size classes in survival from release to Lower Granite Dam tailrace, and from release to Lower Monumental Dam tailrace (Table 18). Survival estimates from release to Lower Granite Dam tailrace were ordered from largest to smallest size class for eight out of nine release groups (Fig. 7). The largest size class had the highest survival probability estimate from release to Lower Monumental Dam tailrace for five of nine release groups (Fig. 8). No relationship was apparent between size class and survival between Lower Granite and Little Goose Dam tailraces for upriver (Pittsburg Landing and Billy Creek pooled) and Asotin release groups (Table 19). Estimates of survival probabilities between Little Goose and Lower Monumental Dam tailraces did not have sufficient precision to make reliable conclusions regarding size class differences.

Table 17. Summary of orderings of detection probability estimates by size classes within primary release groups. Table entries are the number of release groups with each ordering. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; sm-small; av-average; lg-large.

	Detection probability at:		
Ordering	LGR	LGO	LMO
sm-av-lg	1	0	2
sm-lg-av	1	4	1
av-sm-lg	2	2	2
av-lg-sm	2	0	2
lg-sm-av	3	0	1
lg-av-sm	0	3	1

Table 18. Summary of orderings of survival probability estimates by size classes within primary release groups. Table entries are the number of release groups with each ordering. Abbreviations: Rel-Release site; LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam;

	Survival probability between:			
Ordering	Rel-LGR	LGR-LGO	LGO-LMO	Rel-LMO
sm-av-lg	0	0	1	0
sm-lg-av	0	3	1	1
av-sm-lg	0	1	0	0
av-lg-sm	1	2	1	1
lg-sm-av	0	2	4	2
lg-av-sm	8	1	2	5

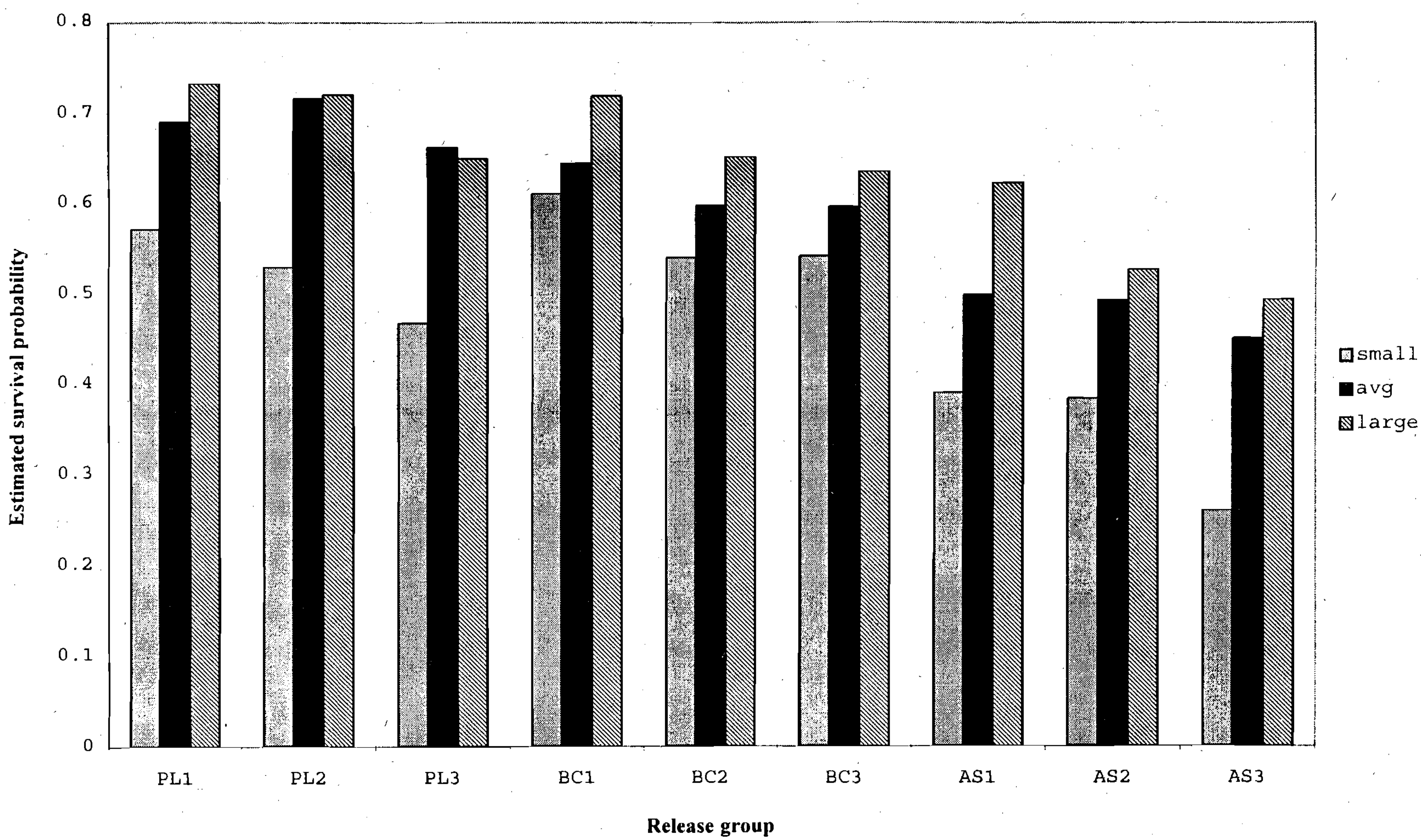

Figure 7. Estimated survival probability from release point to Lower Granite Dam tailrace for subyearling fall chinook salmon released in 1995 at Pittsburg Landing (PL), Billy Creek (BC), and Asotin (AS), by size class.

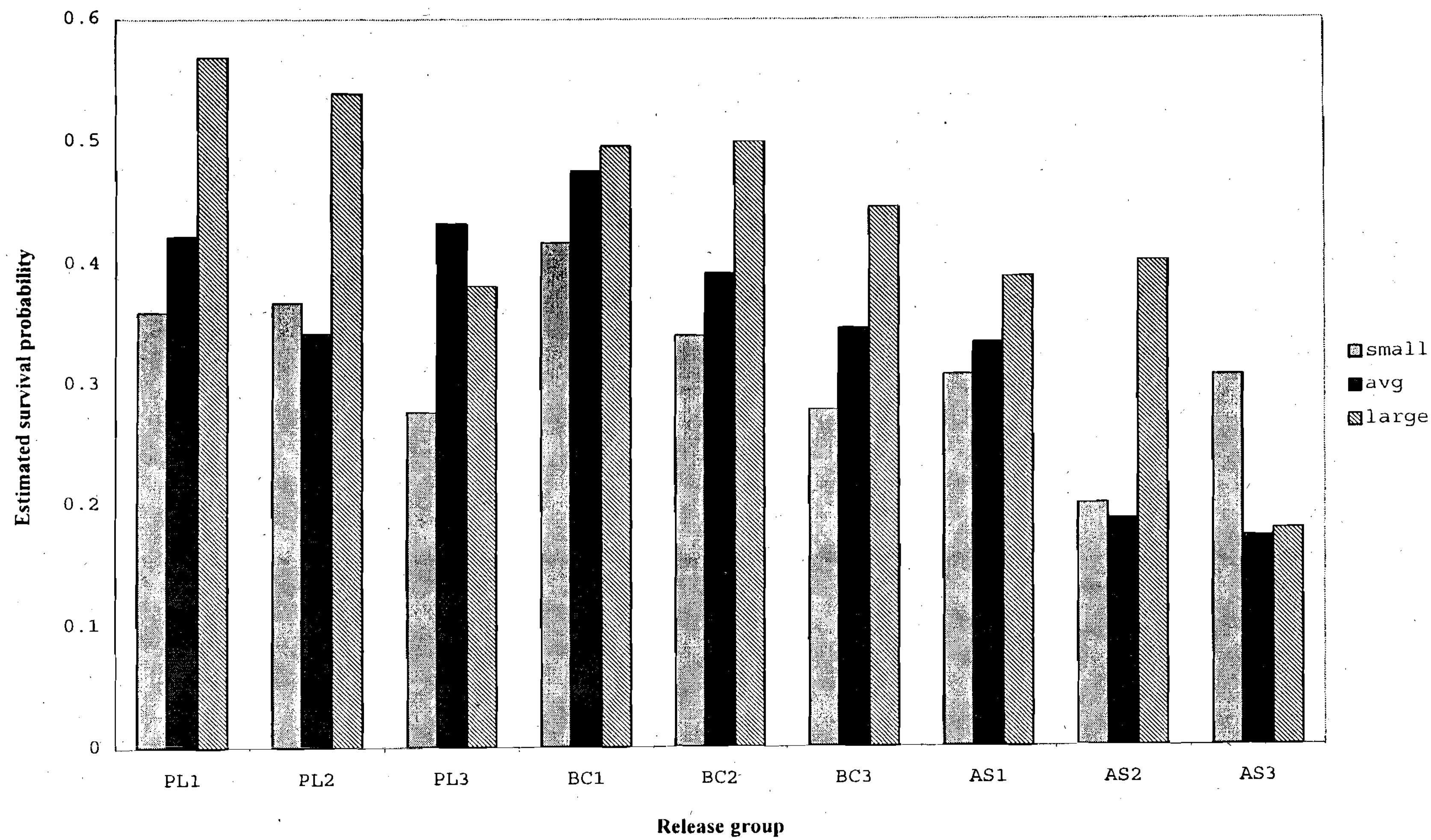

Figure 8. Estimated survival probability from release point to Lower Monumental Dam tailrace for subyearling fall chinook salmon released in 1995 at Pittsburg Landing (PL), Billy Creek (BC), and Asotin (AS), by size class.

Table 19. Average survival probability estimates (based on the Single-Release Model) for PIT-tagged hatchery subyearling fall chinook salmon by release site and size class. Standard errors are in parentheses. Abbreviations: Rel-Release site; LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

		Estimated survival probabilities by reach			
Release Site	Size Class	Rel to LGR	LGR to LGO	LGO to LMO	Rel to LMO
Snake upstream (Pittsburg Landing & Billy Creek)	Small	0.544 (0.018)	0.825 (0.043)	0.772 (0.052)	0.346 (0.021)
	Average	0.650 (0.018)	0.774 (0.036)	0.796 (0.044)	0.400 (0.020)
	Large	0.678 (0.017)	0.839 (0.033)	0.846 (0.043)	0.482 (0.022)
Asotin	Small	0.335 (0.020)	0.655 (0.063)	1.084 (0.181)	0.238 (0.036)
	Average	0.446 (0.021)	0.741 (0.067)	0.722 (0.089)	0.239 (0.024)
	Large	0.534 (0.021)	0.645 (0.043)	0.857 (0.079)	0.295 (0.025)

Migration rates from release to Lower Granite Dam had a very strong relationship with fish size (Table 20). Migration rates were ordered from largest to smallest size class for all nine primary release groups (Fig. 9). On average, fish of the average size class traveled 9% faster from release to Lower Granite Dam than the small size class, and large fish traveled 5% faster than average length fish. Similar relationships were not observed for travel times in the lower reaches of the Snake River. Excluding detections at McNary Dam resulting from the December flood, the overall migration rate from release to McNary Dam averaged about 4% (2.9 days) faster for average-length than small fish, and about 5% faster (3.3 days) for large fish than for average-length fish.

Residualization--PIT-Tag Detections in Spring 1996

A total of 391 fish (2.4%) from primary groups of hatchery fish released in 1995 were detected in spring 1996 (Table 21). For Pittsburg Landing and Billy Creek release groups, the proportion detected did not appear to vary between size classes, but this proportion was more than twice as high for late release groups than for early ones. The proportion of fish released at Asotin detected in 1996 was higher than for the first two groups released at the upriver sites, and similar to the proportion of the latest groups released upriver. The late Asotin group did not have a greater proportion detected in 1996 than the early Asotin group. For Asotin release groups, the probability of detection in 1996 appeared to depend on size; fish that were larger at release were more likely to be detected than those that were smaller (Table 21).

In spring 1996, PIT-tagged yearling fall chinook salmon reared at Lyons Ferry Hatchery were released at Pittsburg Landing. Of 12,419 yearlings released, about 64% were

Table 20. Summary of orderings of median migration rates by size classes within primary release groups. Table entries are the number of release groups with each ordering. Abbreviations: Rel-Release site; LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; sm-small; av-average; lg-large.

	Migration rate between:				
Ordering	Rel-LGR	LGR-LGO	LGO-LMO	LMO-MCN	Rel-MCN
sm-av-lg	0	1	1	0	0
sm-lg-av	0	2	0	1	0
av-sm-lg	0	1	0	0	0
av-lg-sm	0	2	3	2	2
lg-sm-av	0	1	3	2	2
lg-av-sm	9	2	2	4	5

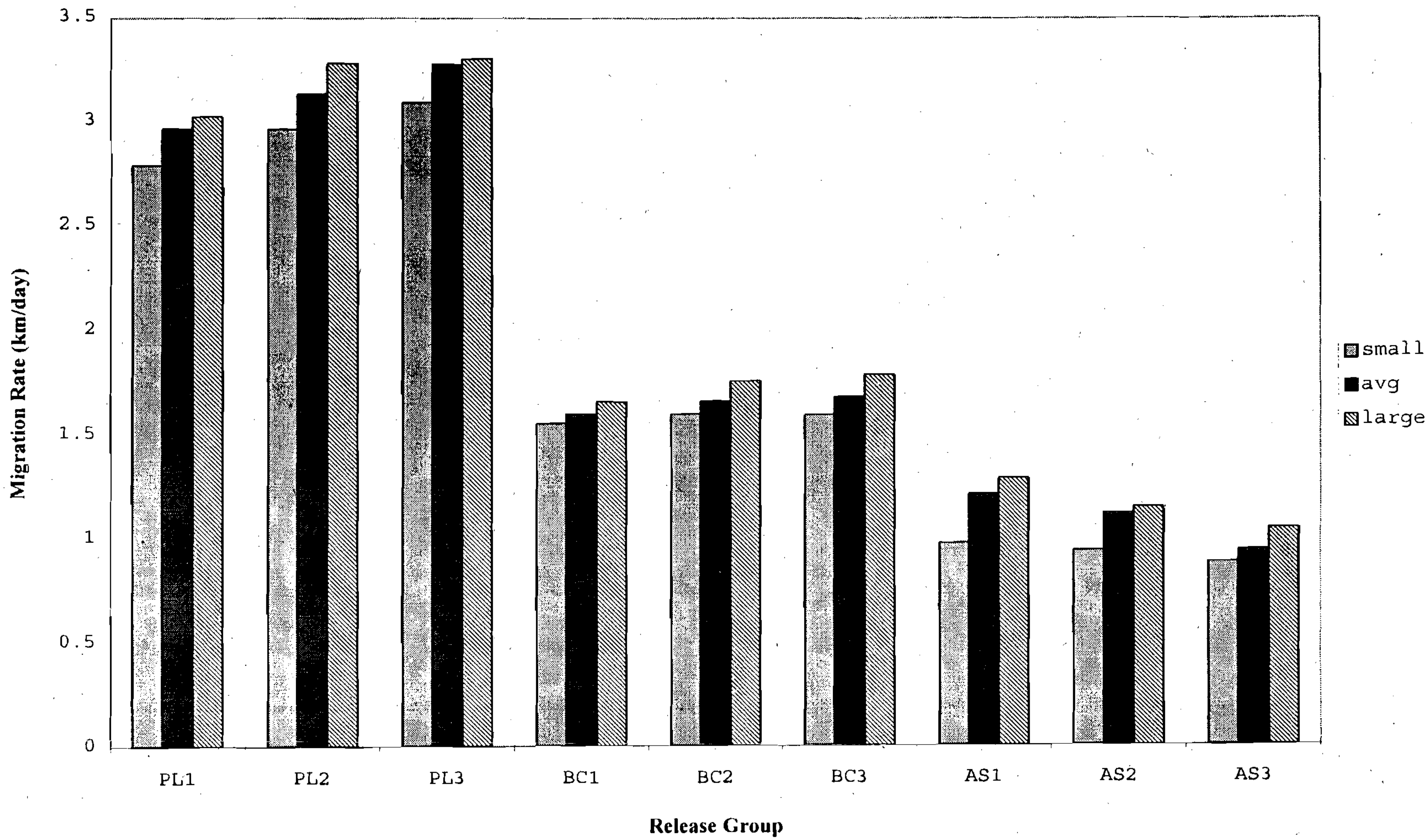

Figure 9. Median migration rate (km per day) from release point to Lower Granite Dam for subyearling fall chinook salmon released in 1995 at Pittsburg Landing (PL), Billy Creek (BC), and Asotin (AS), by size class.

Table 21. Detections in spring 1996 of fish released in primary release groups in summer 1995.

		Size Class			
Release	Date	Small	Average	Large	Total
PL1	31 May	10 (2.0%)	5 (1.2%)	5 (1.2%)	20 (1.5%)
PL2	7 June	7 (1.5%)	11 (2.5%)	10 (2.3%)	28 (2.1%)
PL3	14 June	11 (2.8%)	10 (2.3%)	13 (2.6%)	34 (2.6%)
Pittsburg Landing Total		28 (2.1%)	26 (2.0%)	28 (2.0%)	82 (2.0%)
BC1	1 June	5 (1.0%)	3 (0.8%)	3 (0.9%)	11 (1.0%)
BC2	8 June	5 (1.1%)	9 (2.2%)	10 (2.2%)	24 (1.8%)
BC3	15 June	9 (2.9%)	12 (3.3%)	12 (2.7%)	33 (2.9%)
Billy Creek Total		19 (1.5%)	24 (2.1%)	25 (2.0%)	68 (1.9%)
AS1	19 June	21 (2.3%)	33 (3.3%)	29 (3.4%)	83 (3.0%)
AS2	27 June	25 (2.7%)	22 (3.1%)	29 (3.4%)	76 (3.1%)
AS3	5 July	24 (1.9%)	23 (2.2%)	35 (2.9%)	82 (2.3%)
Asotin Total		70 (2.3%)	78 (2.8%)	93 (3.2%)	241 (2.7%)
Grand Total		117 (2.1%)	128 (2.4%)	146 (2.6%)	391 (2.4%)

detected at least once as they migrated down the Snake River. Assuming fish from our 1995 primary release groups that overwintered were equally likely to be detected as yearlings released in 1996, we estimated that depending on the time of release, between 1.9 and 4.2% of subyearlings in each 1995 release group emigrated from the Snake River in spring 1996. Little is known about the overwinter survival probability (probability of surviving from the time of cessation of migration in the fall/winter and resumption of migration in the spring) for subyearling fall chinook salmon. However, most residualizing fish probably spend the winter in reservoirs where they likely experience low mortality: metabolic needs and predation rates are probably low in these environments, resulting in high overwinter survival. Assuming that winter survival for overwintering fish between 13 December 1995 and 1 April 1996 was about 65% regardless of release date, we estimated that the percentage of subyearlings that actually migrated in 1995 decreased from about 97.1% of those released in early June to about 93.5% of those released in mid-June or later.

Flow, Water Temperature, and Survival

Time between 20 and 80% passage at Lower Granite Dam for groups of hatchery fall chinook salmon released at Pittsburg Landing, Billy Creek, and Asotin ranged from 17 to 47 days (Table 12). During this time, flows generally decreased and water temperatures were relatively high and constant. Because of the protracted time period, it was not possible to relate the water temperature experienced by these groups to survival. Distributions of travel times between Lower Granite and Little Goose Dams for these groups were less spread out (8 to 33 days), but were still too protracted to use to determine relationships between survival and flow and water temperatures. Any possible relationships were further obscured by the confounding effects of differing release dates, release locations, and sizes at release.

By recombining fish into groups based on date of passage at a particular dam, we were able to decrease the variation in passage timing (and accompanying flow and water temperature exposures) considerably. However, this also resulted in smaller sample sizes and decreased precision of the estimates.

Both flow and survival to Little Goose Dam for groups of fish based on passage date at Lower Granite Dam generally decreased through time, while median travel times increased (i.e. migration rates slowed) (Table 22). For weeks 1-6 (consecutive weeks with the number released greater than 100), the statistical correlation of survival with median travel time ($\boldsymbol{R}^2$ = 59.4%, P = 0.07) was greater than with average flow at Lower Granite Dam ($\boldsymbol{R}^2$ = 44.6%, P = 0.15). The correlation between median travel time and average flow was significant ($\boldsymbol{R}^2$ = 83.5%, P = 0.01).

Similar patterns were seen in the relationships among the corresponding variables for groups of fish based on passage date at Little Goose Dam (Table 23). For weeks 1-8, survival from Little Goose Dam to Lower Monumental Dam was strongly correlated with median travel time in the reach ($\boldsymbol{R}^2$ = 86.9%, $P < 0.001$) and the correlation of survival with flow was nearly significant ($\boldsymbol{R}^2$ = 45.9%, P = 0.07). Travel time was also correlated with flow ($\boldsymbol{R}^2$ = 67.6%, P = 0.012). There was little relationship between survival and water temperature, which was not surprising since temperatures changed little during this time period (Tables 22 and 23).

Table 22. Estimated survival probability from Lower Granite Dam tailrace to Little Goose Dam tailrace and weekly average Lower Granite Dam flows and temperatures for Lower Granite Dam daily passage groups.

Passage dates	N	Survival estimate	Average flow (kcfs)	Average temperature	Median travel time (days) LGR-LGO
11-17 July	105	1.0* (0.160)	61.7	20.4	7.0
18-24 July	170	0.944 (0.097)	49.3	21.5	7.7
25-31 July	369	0.834 (0.038)	49.4	20.9	7.7
1-7 August	587	0.841 (0.042)	44.0	20.6	9.0
8-14 August	427	0.999 (0.087)	36.9	20.3	8.6
15-22 August	267	0.581 (0.052)	34.7	19.3	9.5
12-18 September	58	0.698 (0.389)	26.7	20.6	29.8
19-25 September	158	0.696 (0.424)	26.6	19.9	29.2
26 Sept-2 Oct	76	0.263 (0.184)	27.3	18.2	29.4

* Estimated value greater than 1.00.

Table 23. Estimated survival probability from Little Goose Dam tailrace to Lower Monumental Dam tailrace and weekly average Little Goose Dam flows and temperatures for Little Goose Dam daily passage groups.

Passage dates	N	Survival estimate	Average flow (kcfs)	Average temperature	Median travel time (days) LGO-LMO
11-17 July	46	0.863 (0.125)	64.3	19.9	4.8
18-24 July	139	0.785 (0.110)	50.1	21.1	5.7
25-31 July	254	0.827 (0.061)	49.1	21.1	6.5
1-7 August	400	0.793 (0.048)	44.8	20.9	5.6
8-14 August	409	0.733 (0.042)	37.7	21	7.9
15-21 August	267	0.730 (0.070)	36.1	20.3	7.8
22-28 August	165	0.795 (0.115)	34.5	20.0	7.8
29 Aug-4 Sept	142	0.447 (0.072)	31.1	19.8	11.8
5-11 September	64	0.635 (0.165)	25.1	18.8	8.0
12-18 September	67	0.776 (0.330)	25.9	19.6	6.9
19-25 September	44	N/A	26.1	19.1	8.1
26 Sept-2 Oct	13	0.231 (0.117)	27.7	18.7	N/A

DISCUSSION

The use of hatchery subyearling fall chinook salmon as surrogates for natural fish appears feasible when hatchery fish are released at sizes similar to those of natural stocks. We found that survival rates and travel times of the hatchery fish released at Pittsburg Landing and Billy Creek were similar to those of natural fish of the same size released at the same time. The appropriateness of using hatchery subyearling chinook salmon as surrogates for natural salmon is discussed in greater detail in Chapter 2.

However, because of the late date in obtaining fish for this study, some of the hatchery fish were much smaller than desired, particularly fish used for post-detection bypass releases at Snake River dams. These fish were much smaller than either natural migrants or the upstream-released hatchery fish as they passed the Snake River dams. The small fish resulted in slower migration rates and lower survival rates for the post-detection bypass release groups than for the fish they were intended to represent.

Survival of PIT-tagged hatchery fall chinook salmon generally decreased with later release dates, regardless of release location. Survival from release to Lower Monumental Dam tailrace (three dams and reservoirs) ranged from 0.454 for fish released at Billy Creek on 1 June to 0.187 for the last release at Asotin on 5 July. Survival was lower for fish released at Asotin, probably because they were released later than those released at Billy Creek and Pittsburg Landing. There was little difference in survival between Billy Creek and Pittsburg Landing release groups.

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 13 December and the probability of surviving migration in that period.

A small portion of the apparent difference in survival between early and late release groups can be explained by an increased probability of reverting to parr and overwintering in fresh water for later release groups. We estimated that the percentage of fish that did not migrate in 1995 increased from about 2.9% for the first release groups on 31 May and 1 June from Pittsburg Landing and Billy Creek to about 6.5% for groups released after 14 June. These estimates can be used to adjust the joint migration/survival estimates and derive an estimated probability of surviving migration in 1995.

For example, the estimated survival probability for the first Pittsburg Landing release group is the joint probability estimate (0.441) divided by the estimated probability of migrating in 1995 for that group (0.971), resulting in an adjusted survival estimate of 0.454. For the third group released from Pittsburg Landing the adjusted survival estimate is 0.363/0.935 = 0.388. Ultimately, the Single-Release Model might be modified to estimate the proportion of residualizing fish, improving on this ad hoc procedure. Such a modification will require that detection systems be operated essentially year-round.

Determining relationships between survival, flow, and water temperature for subyearling fall chinook salmon will be difficult because of their protracted migration. This task was more difficult during this study because fish were released at three different locations at different times. Future studies releasing more fish from a single location over time, and additional years of data will help to define these relationships. During the period that the number of PIT-tagged fish migrating between Lower Granite and Lower Monumental Dams was sufficient for survival estimation, a significant correlation was found between survival and flow, with survival decreasing as flows decreased.

The decreased survival of later migrants may have been related to increased water temperatures and correspondingly increased predation rates (Curet 1993). 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 fall chinook salmon migration.

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), survival might have been lower. To resolve this issue in the future will require releases of fish that are of the appropriate size and physiological condition. 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 0.656, 0.842, and 0.799 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, for example, 7% (no evidence for this) at all three dams, 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 0.632, 0.867, and 0.827 for the respective reaches.

The overall survival probability estimate from release to Lower Monumental Dam tailrace was 0.441 under the SR Model and, in example above, 0.453 under the MSR Model. For the nine primary release groups, survival estimates under the MSR Model, assuming 7% post-detection mortality at each dam, averaged 4% lower than the SR-Model estimate between release and Lower Granite Dam tailrace, 3% higher than the SR-Model estimate between Lower Granite and Little Goose Dam tailraces, and 3% higher than the SR-Model estimate between Little Goose and Lower Monumental Dam tailraces. Survival estimates from release to Lower Monumental Dam tailrace averaged 2% higher under the MSR Model than under the SR Model.

The apparent faster migration rate of fish released at Pittsburg Landing was likely an artifact of our method to determine rates. Hatchery subyearling fall chinook salmon took about 57 days to migrate from their release point to Lower Granite Dam, regardless of where they were released. Migration rates through downstream reaches were similar for all release groups, and increased substantially from Lower Monumental Dam to McNary Dam. This suggests fish migrated at similar rates in the free-flowing Snake River and that the majority of travel time was spent in Lower Granite Reservoir.

Size at release had little effect on detection probabilities; fish guidance efficiency appeared to be independent of fish size at release. However, smaller fish generally had slower migration rates and lower estimated survival probabilities. 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). Furthermore, Poe et al. (1991)

and Shively et al. (1996) found that predation rates on juvenile salmonids were size dependent, with smaller fish being more vulnerable to predation.

RECOMMENDATIONS

Based on results of the first year 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 (single location on each 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) 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 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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CHAPTER 2

Post-release Attributes and Survival of Natural and Lyons Ferry Hatchery Subyearling Fall Chinook Salmon Released in the Snake River

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CONTENTS

INTRODUCTION

Effective management of natural fall chinook salmon *Oncorhynchus tshawytscha* in the Snake River Basin requires knowledge about the proportion of emigrants that survive passage through Snake River dams and reservoirs, how flows and temperatures affect survival, and what percentage of fish are guided away from turbines into collection facilities and transported around the dams. Because limited numbers of natural fall chinook salmon were available upstream from Lower Granite Dam, we used hatchery subyearling fall chinook salmon for research described in this report. This chapter focuses on the appropriateness of using hatchery subyearling fall chinook salmon as surrogates for natural salmon in survival studies and is a companion to Smith et al. (Chapter 1).

Hatchery subyearling fall chinook salmon were not provided for our research until May of 1995. Consequently, our ability to mimic natural fall chinook salmon size and rearing timing was compromised. We assessed the performance of subyearling hatchery fall chinook salmon as surrogates for natural subyearling fall chinook salmon based on analyses of post-release attributes. Post-release attributes, as defined in the Regional Assessment of Supplementation (RASP; Anonymous 1991), are biological, physiological, and behavioral characteristics of hatchery salmon released in streams. Attributes of hatchery-reared offspring of wild salmonids may be altered within one generation of spawning and affect survival of outplanted smolts (Anonymous 1991). Our objectives in 1995 were to monitor and evaluate post-release attributes including:

1) Dispersal of natural and PIT-tagged hatchery subyearling fall chinook salmon through the Snake River and Lower Granite Reservoir to Lower Granite Dam;

2) Passage at Lower Granite Dam of PIT-tagged natural and hatchery subyearling fall chinook salmon;

3) Growth and condition of PIT-tagged natural and hatchery subyearling fall chinook salmon from release in the Snake River to recapture at Lower Granite Dam;

4) ATPase activity of PIT-tagged natural and hatchery subyearling fall chinook salmon recaptured at Lower Granite Dam; and

5) Survival to Lower Granite and Lower Monumental dams of PIT-tagged natural and hatchery subyearling fall chinook salmon released in the free-flowing Snake River.

Study Area

The description of the Snake River study area given by Smith et al. (Chapter 1) is applicable to the research described in this chapter, with one exception. To recapture hatchery subyearlings throughout the free-flowing Snake River, we seined additional sites between Snake River km (Rkm) 303 and Rkm 272 (Fig. 1). We refer to this as the "middle" study reach. We also collected fish in the upstream (Rkm 357 to Rkm 308) and downstream (Rkm 271 to Rkm 224) reaches of the river.

METHODS

Data Collection

Sampling of Natural Salmon

We sampled three sites in the upstream reach of the Snake River between 1 and 22 June, four sites in the middle reach of the Snake River between 31 May and 6 July, and five sites in the downstream reach of the Snake River between 5 May and 6 July. We classified

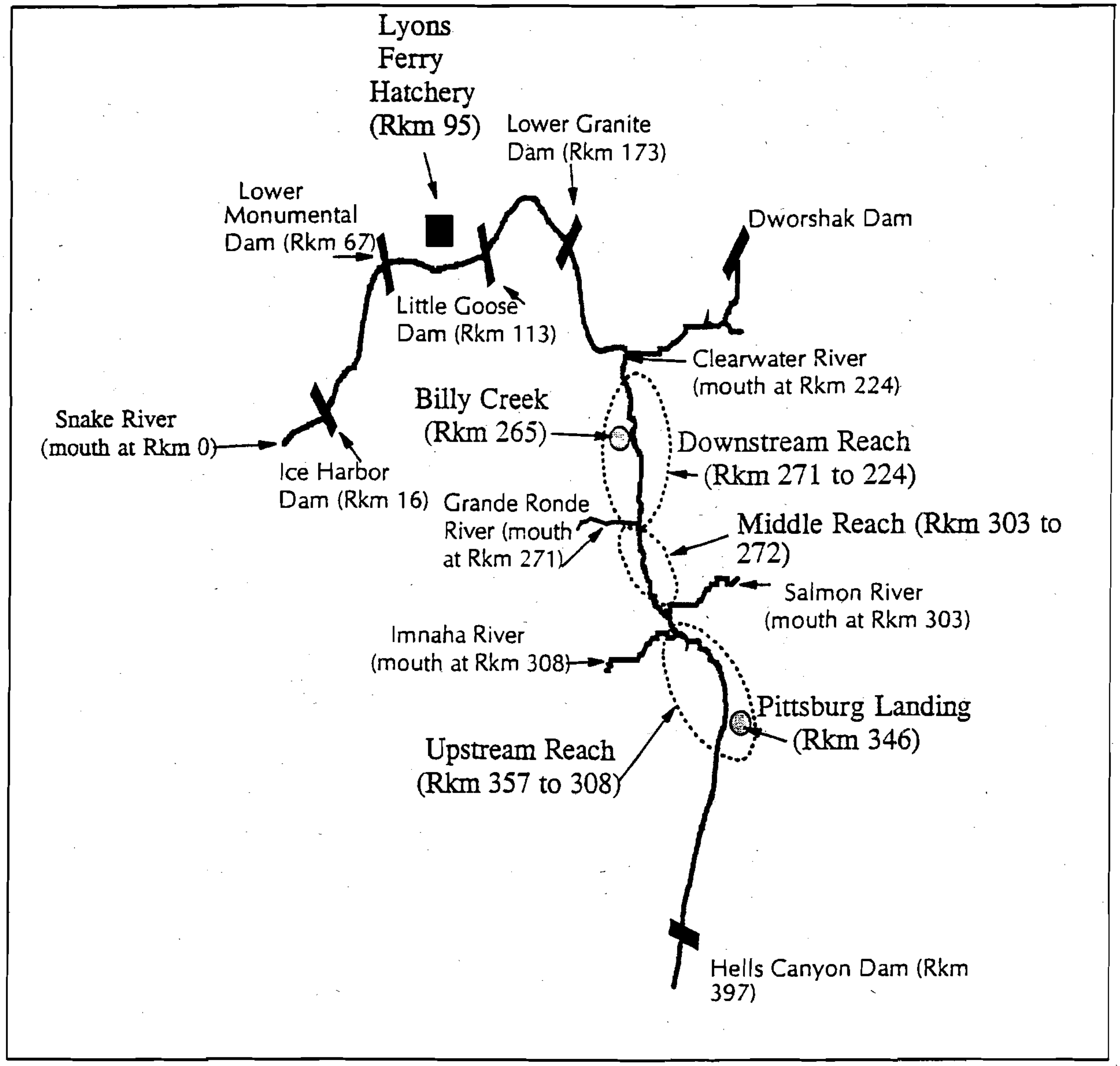

Figure 1. Snake River study area including locations of the upstream, middle, and downstream reaches, Pittsburg Landing, Billy Creek, Lyons Ferry Fish Hatchery, and major tributaries, and dams.

the above 12 sites "permanent". Permanent sites were sampled once a week and normally seined three consecutive times in an upriver direction. Each net set started where the previous one ended. The beach seine had a weighted multistranded mudline, consisted of 0.48 cm mesh, and had dimensions of 30.5 m in length x 1.8 m in depth and contained a 3.9-m^3 bag. Each end of the seine was fitted with a bottom weighted brail, equal in length to net depth, and attached to 15.2-m lead ropes. The seine was set parallel to shore from the stern platform of a 6.7-m jet boat and then hauled straight into shore by both lead ropes. The net sampled approximately 465 m^2 of river to a depth of 1.8 m.

Seine hauls made at locations other than the 12 permanent sites of the three Snake River reaches were classified as "supplemental". Natural subyearling fall chinook salmon PIT-tagged at supplemental sites increased the sample size for analyses of travel time and survival. Supplemental sites (about 40) were selected based upon habitat features that were similar to our systematic seining sites. These sites were characterized by low water velocity and sloping shore with minimal obstructions for landing a beach seine. Supplemental sampling was timed to begin about 30 days after peak fry emergence, resulting in maximum effort about 1 week before, during, and 1 week after peak catches at permanent sites.

PIT-tagged Salmon Release and Recapture

Natural chinook salmon were aged and PIT tagged (Prentice et al. 1990) as described by Connor et al. (1996). Hatchery fish origin, study logistics, including tagging, transportation and data processing are described by Smith et al. (Chapter 1). We measured the fork length of natural subyearling chinook salmon to the nearest mm during PIT tagging and weights were subsampled for subsequent growth analysis. Any previously PIT-tagged hatchery fish that was captured with the natural fish was also measured and weighed. A subsample of PIT-tagged natural and hatchery salmon recaptured at Lower Granite Dam was also weighed and measured. We weighed and measured a subsample of hatchery subyearling fall chinook salmon held for the 24-hour post-transport mortality tests.

We recaptured a subsample of the PIT-tagged chinook salmon detected at Lower Granite Dam using a separation-by-code hardware and software system (S. Downing et al. unpublished protocol, Northwest Fisheries Science Center, Seattle, WA 98112-2097). Fish that were diverted by the separation-by-code system were scanned for PIT-tag code and weighed and measured. A scale sample was taken for aging, and natural chinook salmon were labeled and frozen for subsequent race identification. In addition, gill Na^{+}-K^{+} ATPase samples (Schrock et al. 1994) were collected from natural and hatchery subyearling fall chinook salmon to characterize physiological development. About 20 PIT-tagged fish from each hatchery release group and 150 PIT-tagged natural fall chinook salmon were collected at Lower Granite Dam to assess gill ATPase activity of active migrants.

Data Analysis

Subyearling hatchery fall chinook salmon were not provided until May of 1995. To make data from natural fish more comparable to that from hatchery fish, which were first released on 31 May 1995, we used data from natural subyearling chinook salmon collected during or after the week beginning 28 May. Therefor, estimates of survival probabilities and travel time differ slightly from those presented by Smith et al. (Chapter 1).

Release and Capture Information

We reported the total numbers of natural subyearling chinook salmon captured, PIT tagged, and released by reach and date and the number of PIT-tagged hatchery subyearling fall chinook salmon released by site and date. We also reported mean fork length (L), weight (W), and condition factor (*K;* Piper et al. 1982) where: $K = W/L^3$ for natural and hatchery salmon. The length and weight data for hatchery salmon were from the 24-h post-trucking mortality study, since weights were not taken from any hatchery salmon during PIT tagging (Smith et al. Chapter 1).

Race of Natural Subyearling Chinook Salmon

We made in-season and post-season identifications of race of natural chinook salmon to guide PIT-tagging efforts and post-season analyses as follows: during PIT tagging, preliminary identification of race was made based on morphology of each fish that fit within our size limits. Salmon with pointed snouts, small down-turned eyes, and deep bodies were tagged and identified in PIT-tag files uploaded to the PIT Tag Information System (PTAGIS) as wild fall chinook salmon ("15W" in the PTAGIS data base). Fish that fit in our size limit, but had rounded snouts, large round eyes, and slender bodies, were tagged and identified as chinook salmon of unknown race ("15U"). Fish of unknown race were not used in this report. Post-season race determinations of each natural fish we recaptured at Lower Granite Dam were made by Washington Department of Fish and Wildlife personnel using tissue extracts, horizontal starch-gel electrophoresis (Aebersold et al. 1987), and Maximum Likelihood Estimation (MLE; A. Marshall, Washington Department of Fish and Wildlife, P.O. Box 43135, Olympia, Washington 98504-3135, unpublished protocol). We calculated the percentage of MLE-estimated fall and spring/summer race chinook in our sample, and tabulated the results by river reach and race. We also aged each of the PIT-tagged fish recaptured at Lower Granite Dam and tabulated the results with the race data.

Dispersal

We investigated differences between the dispersal of PIT-tagged hatchery subyearling fall chinook salmon after their release relative to the date and river kilometer of capture and release of natural subyearling fall chinook salmon. Numbers of natural and tagged hatchery fish seined by date and river kilometer were calculated by combining data from the upstream, middle, and downstream reaches. We tested for similarities in means, standard deviations, and shapes of cumulative distribution functions calculated by date and river kilometer between natural and tagged hatchery salmon. We used the two-sample Kolmogorov-Smirnov test (KS test; SYSTAT 1994) to test the following null hypotheses:

H_o: Distribution of catch by date did not differ between natural and PIT-tagged hatchery subyearling fall chinook salmon.

H_o: Distribution of catch by river kilometer did not differ between natural and PIT-tagged hatchery subyearling fall chinook salmon.

We calculated the time between release and detection at Lower Granite Dam (i.e., travel time). We tested for similarities in mean travel times between PIT-tagged natural and hatchery subyearling fall chinook salmon released in the same reach of the Snake River using an independent two-sample T-test (T-test; SYSTAT 1994). We tested the following null hypotheses:

H_o: Mean travel times to Lower Granite Dam did not differ between PIT-tagged natural and hatchery subyearling fall chinook salmon released in the upstream reach and Pittsburg Landing.

H_o: Mean travel times to Lower Granite Dam did not differ between PIT-tagged natural and hatchery subyearling fall chinook salmon released in the downstream reach and Billy Creek.

Passage at Lower Granite Dam

Detection dates (i.e., passage dates) at Lower Granite Dam of PIT-tagged natural and hatchery subyearling fall chinook salmon were tested for similarities in means, standard deviations, and shapes of cumulative distribution functions calculated using a KS test. We tested the following null hypotheses for this comparison:

H_o: Distribution of passage dates at Lower Granite Dam did not differ between PIT-tagged natural and hatchery subyearling fall chinook salmon released in the upstream reach and at Pittsburg Landing.

H_o: Distribution of passage dates at Lower Granite Dam did not differ between PIT-tagged natural and hatchery subyearling fall chinook salmon released in the downstream reach and at Billy Creek.

Growth and Condition During Emigration

We calculated mean growth rates of PIT-tagged natural and hatchery fall chinook salmon recaptured at Lower Granite Dam by subtracting fork length at release from fork length at recapture and dividing by travel time. Fork length at release was estimated for hatchery fish, because up to 3 weeks elapsed between tagging and release of some treatment groups. Growth rates for hatchery fish were based on the fork lengths of the salmon held in net-pens for 24-hour post-transport mortality studies (Smith et al. Chapter 1). We applied a T-test (SYSTAT 1994) to test for differences between treatment means for salmon of different origins (natural or hatchery) released in the same river reach. The following null hypotheses were tested:

H_o: Mean growth rate did not differ between PIT-tagged natural and hatchery subyearling fall chinook salmon released in the same reach of the Snake River and recaptured at Lower Granite Dam.

H_o: Mean condition factors did not differ between PIT-tagged natural and hatchery subyearling fall chinook salmon released in the same reach of the Snake River and recaptured at Lower Granite Dam.

ATPase Activity

We processed gill filaments using the methods of Schrock et al. (1994). We tested for differences in mean ATPase levels of PIT-tagged natural and hatchery subyearling fall chinook salmon smolts recaptured at Lower Granite Dam using a T-test of the null hypothesis:

H_o: Mean ATPase levels at recapture at Lower Granite Dam did not differ between PIT-tagged natural and hatchery subyearling fall chinook salmon smolts released in the same river reach.

Survival

We applied the SR Model to the PIT-tag detection data to calculate survival estimates for natural and hatchery subyearling fall chinook salmon by release reach and site. The details of survival estimates are described in Smith et al. (Chapter 1). In contrast to Smith's analysis of natural subyearling fall chinook salmon, we estimated survival only for fish PIT tagged after the week beginning 28 May, resulting in slightly different estimates than presented in Chapter 1. Also, we pooled the three releases of hatchery salmon from each release site and calculated only one survival estimate per site. We tabulated the survival estimates to the tailrace of Lower Granite Dam for each release group.

RESULTS

Subyearling Chinook Salmon Releases

We captured and released 576, 180, and 910 natural subyearling chinook salmon in the upstream, middle, and downstream reaches of the Snake River between the dates of 28 May and 6 July (Table 1; Fig. 2). The numbers of fish PIT tagged in each respective reach were 398, 136, and 557. Totals of 4,020 and 3,661 hatchery subyearling fall chinook salmon were PIT tagged then released at Pittsburg Landing and Billy Creek at 7-day intervals starting 31 May and 1 June (Table 1; Fig. 2). Natural salmon from the upstream reach of the Snake River were the largest at release, middle and downstream reach natural fish were smallest, and hatchery fish were intermediate in size (Table 1). Condition factors at release were higher for natural salmon than for hatchery salmon and similar between fish of the same origin (Table 1).

Race of Recaptured Fish

PIT-tagged natural chinook salmon from the upstream and middle reaches of the Snake River that we recaptured at Lower Granite Dam were all of the fall race (based on MLE-estimation) and were all subyearlings (Table 2). Natural fish PIT tagged in the downstream reach were mostly fall chinook salmon and subyearlings, but there were a few spring/summer chinook salmon in the recapture sample. All yearlings in the sample were spring/summer chinook salmon. The detection rates were similar between river reaches, but the recapture rate was much higher for fish from the upstream reach. We refer to all natural salmon as subyearling fall chinook salmon for the remainder of this chapter, since a relatively low

Table 1. Number of natural and PIT-tagged hatchery subyearling chinook salmon released after 28 May 1995. Information includes release reach or site, salmon origin (natural or hatchery), mean fork length (mm±SD), weight (g±SD), and condition factor K(±SD).

Reach or site	Origin	Number released	Number PIT tagged	Mean fork length (mm±SD)	Mean weight (g±SD)	Mean K (±SD)
Upstream	Natural	577	398	80±10	6.8±3.0	1.2±0.12
Middle	Natural	180	136	72±14	5.6±3.6	1.2±0.09
Downstream	Natural	910	557	72±14	5.0±3.5	1.2±0.14
Pittsburg Landing	Hatchery	4,020	4,020	79±5	5.2±0.9	1.1±0.07
Billy Creek	Hatchery	3,661	3,661	76±6	4.7±2.0	1.1±0.09

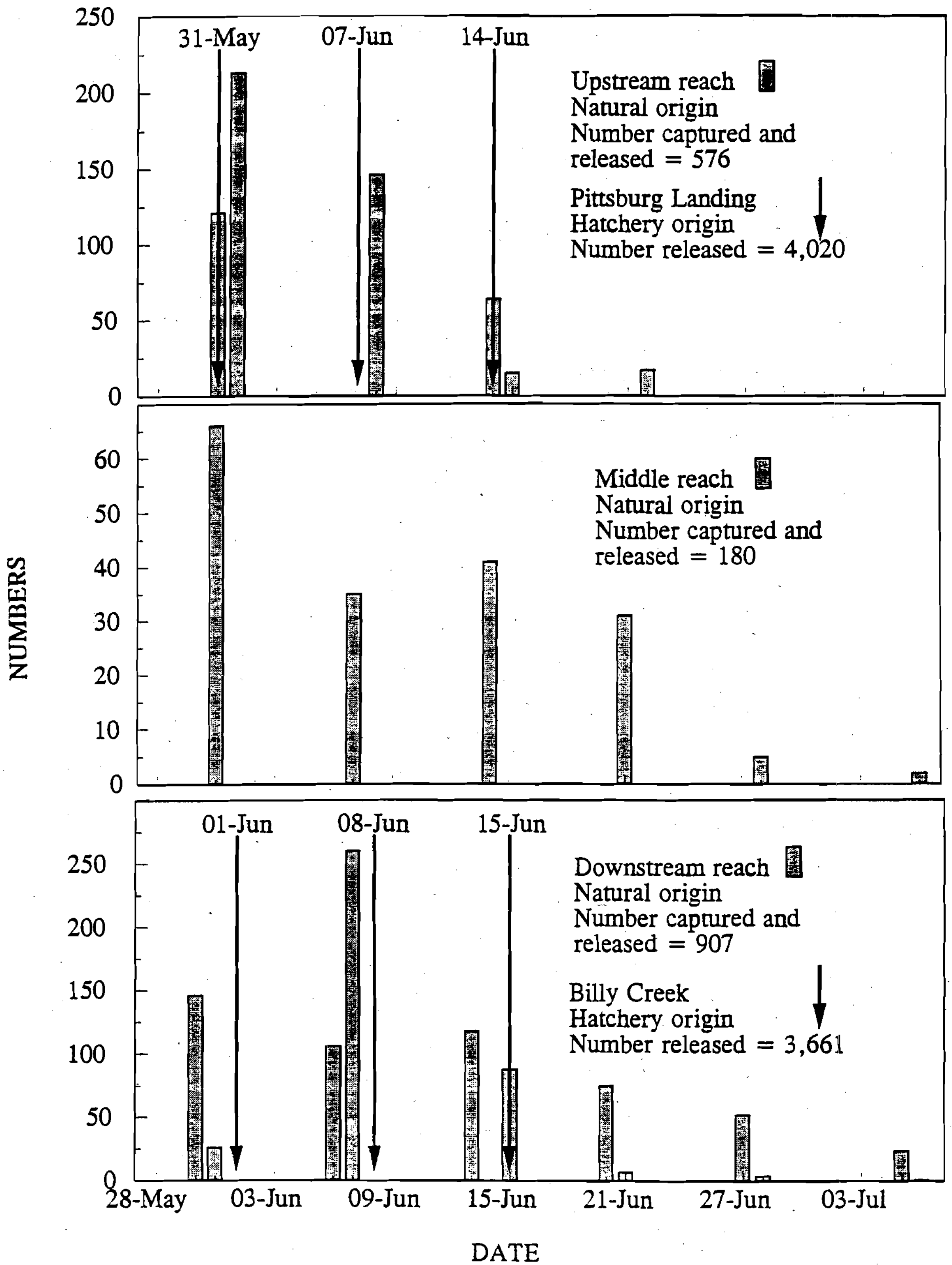

Figure 2. Number of natural and PIT-tagged hatchery subyearling fall chinook salmon released by date, reach,and site in the Snake River, 1995.

Table 2. Number of PIT-tagged natural subyearling chinook salmon detected and recaptured at Lower Granite Dam in 1995 and the results of aging and electrophoresis (Abreviation: sprg/sum=spring/summer).

Reach	Number detected	Number recaptured	Age(%)		Race(%)	
			0	1	fall	sprg/sum
Upstream	168	53	100.0	0.0	100.0	0.0
Middle	37	8	100.0	0.0	100.0	0.0
Downstream	192	38	97.4	2.6	89.5	10.5

percentage of the subyearling chinook salmon recaptured at Lower Granite Dam were of spring/summer race (Table 2).

Dispersal

Distribution of capture by date and river km differed significantly between natural and PIT-tagged hatchery subyearling fall chinook salmon (Table 3). Natural salmon were captured earlier and farther downstream than tagged hatchery salmon. Mean travel times to Lower Granite Dam differed significantly between PIT-tagged natural and hatchery subyearling fall chinook salmon released in the same reaches (Table 4). Natural salmon that we captured, tagged, and released in the upstream reach of the Snake River had significantly shorter travel times to Lower Granite Dam than tagged hatchery fish released at Pittsburg landing. Natural fish captured and tagged in the downstream reach had significantly shorter travel times than tagged hatchery fish released at Billy Creek.

Passage at Lower Granite Dam

Distributions of passage dates at Lower Granite Dam differed significantly between PIT-tagged natural and hatchery subyearling fall chinook salmon released in the same reach of river (Table 5; Figs. 3 and 4). Mean date of passage for tagged natural fish released in the upstream reach was 16 days earlier than tagged hatchery salmon released at Pittsburg Landing. Mean dates of passage were similar between tagged natural salmon in the downstream reach and tagged hatchery fish released at Billy Creek, but the standard deviations differed and relatively small sample sizes resulted in gaps in passage distributions of natural salmon (Table 5; Figs. 3 and 4).

Table 3. Mean date (±SD; days) and river km (±SD) of capture for natural and PIT-tagged hatchery subyearling fall chinook salmon captured by beach seine in the Snake River, 1995. *P* values were calculated using two-sample Kolmorov-Smirnov tests.

Origin	Number captured	Mean date of capture (±SD; days)	*P*	Mean river km of capture (±SD)	*P*
Natural	1,663	9 June±8.2	<0.000	279±47.8	<0.000
Hatchery	130	14 June±7.1		275±39.7	

Table 4. Mean travel times (±SD) to Lower Granite Dam for natural subyearling fall chinook salmon PIT tagged and released in the upstream and downstream reaches of the Snake River and PIT-tagged hatchery subyearling fall chinook salmon released at Pittsburg Landing and Billy Creek in 1995. The *P* values are from independent two-sample T-tests between salmon of different origins released in the same river reach.

Reach or site	Origin	Number detected	Mean travel times days(±SD)	*P*
Upstream	Natural	168	43.4±20.4	<0.000
Pittsburg Landing	Hatchery	1,241	58.9±19.2	
Downstream	Natural	188	52.7±26.6	<0.001
Billy Creek	Hatchery	1,081	58.3±19.4	

Table 5. Mean dates of passage (±SD; days) at Lower Granite Dam for natural subyearling fall chinook salmon captured, PIT tagged and released in upstream and downstream reaches of the Snake River and PIT-tagged hatchery subyearling fall chinook salmon released in the Snake River at Pittsburg Landing and Billy Creek in 1995. The *P* values are from two-sample Kolmogorov-Smirnov tests between fish of different origins released in the same river reach.

Reach or site	Origin	Number released	Mean date of passage (±SD; days)	*P*
Upstream	Natural	168	19 July±20.6	<0.000
Pittsburg Landing	Hatchery	1,241	05 August±19.9	
Downstream	Natural	188	04 August±27.2	0.001
Billy Creek	Hatchery	1,081	05 August±20.2	

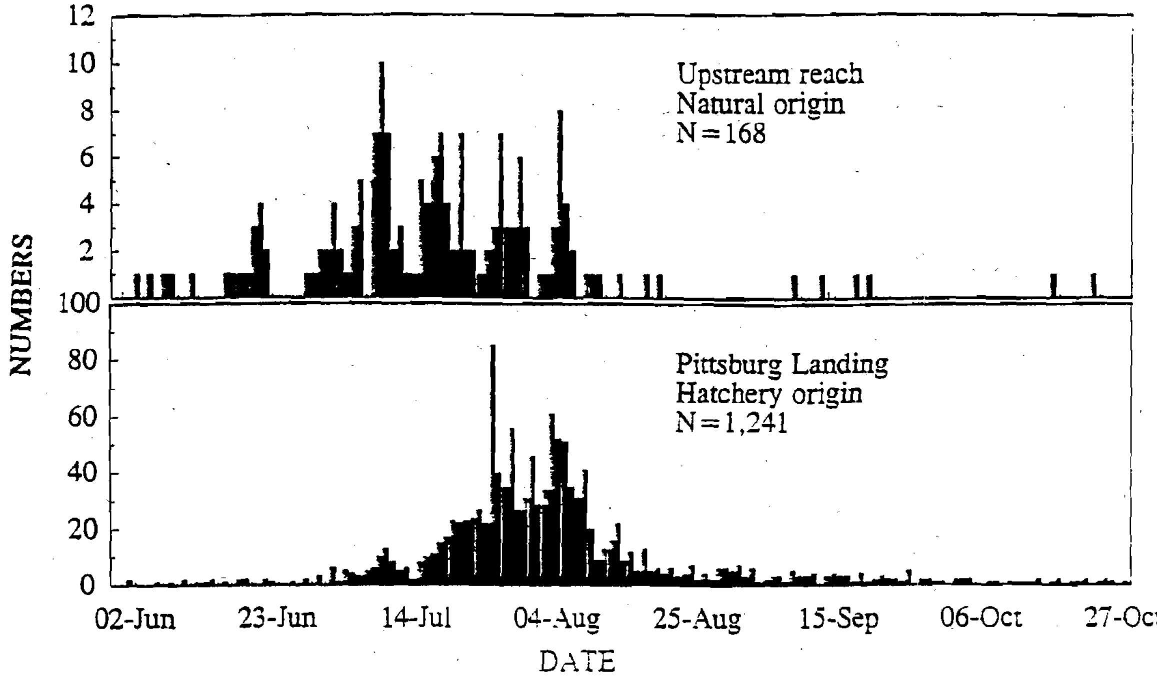

Figure 3. Numbers of PIT-tagged natural and hatchery fall chinook salmon detected passing Lower Granite Dam after release in the Snake River in the upstream reach and Pittsburg Landing in 1995.

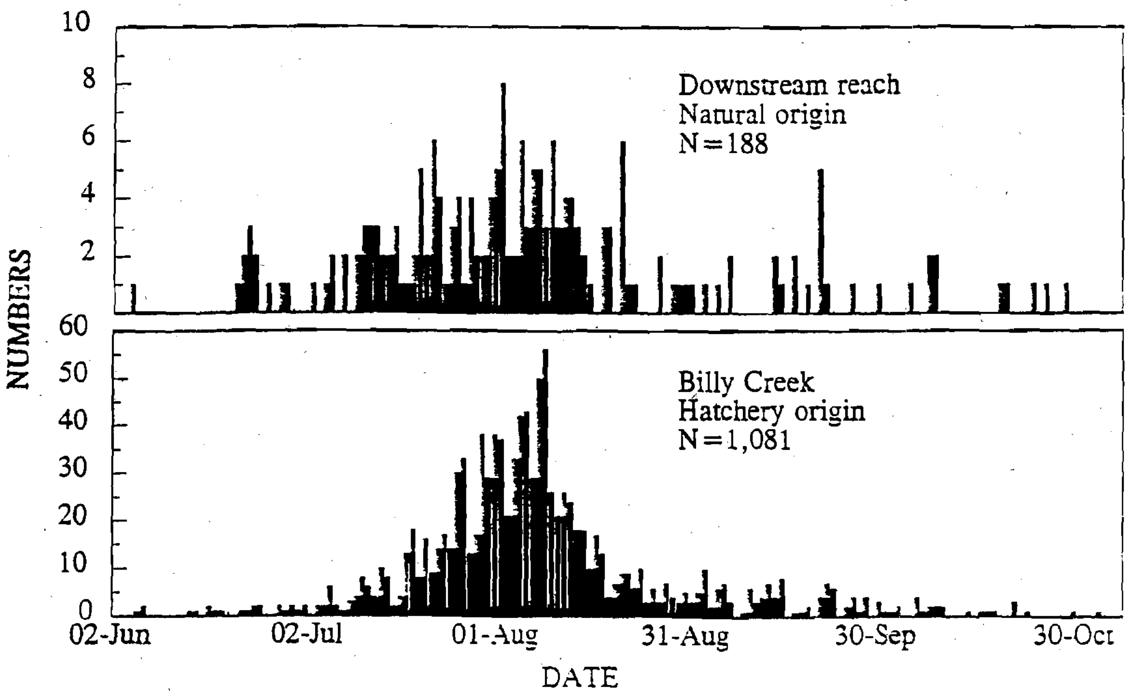

Figure 4. Numbers of PIT-tagged natural and hatchery fall chinook salmon detected passing Lower Granite Dam after release in the Snake River in the downstream reach and Billy Creek in 1995.

Growth and Condition During Emigration

Mean growth rate and condition factor *K* differed significantly between PIT-tagged natural and hatchery subyearling fall chinook salmon released in the same reach of the Snake River and recaptured at Lower Granite Dam (Table 6). Both releases of tagged natural fish grew significantly faster during emigration than either release of tagged hatchery fish. Upon arrival at Lower Granite Dam tagged natural salmon had significantly higher condition factors than tagged hatchery salmon, regardless of release location.

ATPase Activity

Mean ATPase levels at recapture at Lower Granite Dam did not differ between PIT-tagged natural and hatchery subyearling fall chinook salmon smolts released in the same river reach (Table 7). Tagged natural salmon released in the upstream reach of the Snake River had similar ATPase levels as tagged hatchery salmon released at Pittsburg Landing. Mean ATPase levels for tagged natural salmon released in the downstream reach of the Snake River were slightly higher than for tagged hatchery salmon released at Billy Creek, but the difference was not significant.

Survival

Survival to the tailrace of Lower Granite Dam was similar between PIT-tagged salmon of the same origin released in different river reaches and slightly higher for natural fish than for hatchery fish (Table 8). Survival from release to the tailrace of Lower Monumental Dam was similar between tagged salmon of the same origin and higher for tagged hatchery fish than for tagged natural fish. Survival to the tailrace of Lower Granite Dam ranged from 70.6% for the upstream natural releases to 60.9% for the Billy Creek hatchery release. Cumulative

Table 6. Mean growth rate (mm/day; $\pm$SD) and condition factor K ($\pm$SD) for PIT-tagged natural and hatchery subyearling fall chinook salmon recaptured at Lower Granite Dam after release in the Snake River in 1995. The P values are from independent two-sample T-tests between fish of different origins released in the same river reach.

Site or reach	Origin	Number sampled	Growth rate mm/day($\pm$SD)	P	K(+SD)	P
Upstream	Natural	126	1.3$\pm$0.17	<0.000	1.4$\pm$0.17	0.004
Pittsburg Landing	Hatchery	211	1.1$\pm$0.20		1.3$\pm$0.44	
Downstream	Natural	122	1.4$\pm$0.16	<0.000	1.4$\pm$0.20	0.003
Billy Creek	Hatchery	197	1.1$\pm$0.20		1.3$\pm$0.41	

Table 7. Mean ATPase activity in *u*mols **Pi**·(mg protein)$^{-1}$·h^{-1}($\pm$*SD*) for PIT-tagged natural and hatchery subyearling fall chinook salmon recaptured at Lower Granite Dam after release in the Snake River in 1995. The *P* values are from independent two-sample T-tests between fish of different origins released in the same river reach.

Site or reach	Origin	Number sampled	ATPase activity *u*mol **Pi**·(mg protein)$^{-1}$·h^{-1} ($\pm$SD)	*P*
Upstream	Natural	81	19.5$\pm$4.8	0.760
Pittsburg Landing	Hatchery	56	19.8$\pm$5.7	
Downstream	Natural	45	17.2$\pm$4.1	0.180
Billy Creek	Hatchery	56	18.3$\pm$4.3	

Table 8. Survival probability estimates for PIT-tagged natural and hatchery subyearling fall chinook salmon released in the free-flowing Snake River. The estimates are from release to the tail races of Lower Granite and Lower Monumental Dams and include the standard error in parentheses (Abbreviation: Lower Mon. = Lower Monumental).

Release Site/ Origin	Survival from Release to Lower Granite Dam tailrace	Survival from release to Lower Monumental Dam tailrace
Upstream reach/ Natural	0.706 (0.080)	0.366 (0.052)
Downstream reach/ Natural	0.679 (0.085)	0.354 (0.068)
Pittsburg Landing/ Hatchery	0.632 (0.014)	0.404 (0.016)
Billy Creek/ Hatchery	0.609 (0.014)	0.408 (0.017)

mortality measured from release to the tailrace of Lower Monumental Dam, ranged from 59.6% for the Pittsburg Landing hatchery release to 64.6% for the downstream natural release.

DISCUSSION

The management implications of the survival estimates described by Smith et al. (Chapter 1) depend upon the acceptance of hatchery subyearling fall chinook salmon as surrogates for their natural counterparts. We did not expect hatchery fish to mimic natural subyearling fall chinook salmon in all attributes. We did believe that future research could be improved by examining similarities and differences in post-release attributes of natural and hatchery fish. Attributes we examined included: 1) dispersal through the Snake River and Lower Granite Reservoir; 2) dates of passage by Lower Granite Dam; 3) growth and condition during emigration; 4) ATPase activity of emigrants recaptured at Lower Granite Dam; and 5) survival of emigrants to the tail races of Lower Granite and Lower Monumental dams.

Hatchery subyearling fall chinook salmon rearing behavior was similar to natural salmon (Connor et al. 1993, 1994a, 1994b, 1996) in that some hatchery fish dispersed into nearshore rearing areas after release in late spring and reared prior to active emigration. However, timing and location of dispersal differed significantly between the origins of salmon. The difference in timing was expected since we did not receive authorization to use hatchery fish for research until late spring of 1995. The difference in location of capture between the origins was expected because natural fall chinook salmon spawn throughout the Snake River and transportation logistics and availability of hatchery fish limited our releases to two sites.

Hatchery subyearling fall chinook salmon released at both Pittsburg Landing and Billy Creek demonstrated the characteristic protracted travel times of natural subyearling fall chinook salmon (Connor et al. 1993, 1994a, 1994b, 1996). Natural subyearling fall chinook salmon PIT tagged in the Snake River commonly take a month or more to pass Lower Granite Dam after tagging. Long travel times are caused primarily by an extended period of rearing nearshore accompanied by growth. Connor et al. (1993) estimated that natural fall chinook salmon became active emigrants at 85 mm fork length, consistent with most Columbia River fall chinook salmon populations (Nelson et al. 1994). We released hatchery fish at Pittsburg Landing and Billy Creek at average fork lengths of 79 and 76 mm, so they probably reared nearshore in the Snake River and Lower Granite Reservoir before becoming active emigrants. Late acquisition of hatchery fall chinook salmon in 1995 probably influenced the travel time results because hatchery fish were smaller at release than desired and releases were made later than the peak rearing period of natural salmon.

Hatchery subyearling fall chinook salmon passed Lower Granite Dam with natural salmon primarily in the summer months of June, July, and August. Summer passage of natural salmon has occurred consistently since 1991 (Connor et al. 1993, 1994a, 1994b, 1996). We found statistical differences in passage timing between salmon of different origins released in the same river reach. Connor et al. (1996) found that water temperature differences over incubation caused up to 30-d differences in the life cycles of natural subyearling fall chinook salmon in the Snake and Clearwater Rivers in 1994. The timing of natural fall chinook salmon passage by Lower Granite Dam appears to be related to emergence timing; later emergence fosters later emigration. It is not surprising that hatchery salmon released into the Snake River after peak nearshore rearing of natural salmon, would emigrate and pass Lower Granite Dam later than natural salmon.

Hatchery subyearling fall chinook salmon provided for research in 1995 grew only 0.4$\pm$0.02 mm/day while reared in raceways. Hatchery salmon growth increased markedly after release in the Snake River, indicative of adaptation to food availability and habitat. However, natural subyearling fall chinook salmon grew faster and had higher condition factors than hatchery subyearling fall chinook salmon when recaptured at Lower Granite Dam. Natural salmon growth rates have ranged from 1.3 to 1.5 mm/day since 1991 (Connor et al. 1993, 1994a, 1994b, 1996). The above growth rates are faster than those of natural Columbia River fall chinook salmon, possibly because of warmer Snake River water (Key et al. 1994). The fast growth and high condition of natural salmon will be difficult to match. Timely (i.e., soon after ponding) acquisition of hatchery salmon will help reduce growth and condition differences at release by allowing us to adjust rearing strategies in the hatchery, size at release, and time of release.

Similarity in ATPase levels between natural and hatchery subyearling fall chinook salmon released in the same river reach demonstrated the ability of hatchery salmon to undergo smoltification successfully after release. Gill ATPase activity was associated more with release site than with origin, with higher activity being associated with longer emigration distance. Zaugg et al. (1985) demonstrated that increased gill ATPase activity was positively correlated to the distance fall chinook salmon emigrated after being released from a hatchery. Our results were similar to Zaugg's since we found that natural and hatchery fish released in the upstream reach and Pittsburg Landing had higher ATPase activity when recaptured at Lower Granite Dam than fish released in the downstream reach and Billy Creek.

We did not find large differences between survival estimates for natural and hatchery subyearling fall chinook salmon. Survival to Lower Granite Dam tailrace was slightly higher for natural salmon than for hatchery fish. Hatchery fish had slightly higher survival from release to the tailrace of Lower Monumental Dam. This finding was surprising because conventional wisdom suggests survival of hatchery fish is always poorer than survival of natural fish (Anonymous 1991). The reasons for the similarity in survival estimates may be related to the biological similarities, opposed to the statistical differences, of post-release attributes of the natural and hatchery fish.

We conclude that late acquisition of hatchery subyearling fall chinook salmon in 1995 reduced the effectiveness of using hatchery fish as surrogates for natural salmon in survival analyses. We rejected eight of nine null hypotheses demonstrating statistical differences in post-release attributes of hatchery and natural salmon. These statistical differences, however, must be viewed with respect to their biological relevance. Hatchery subyearling fall chinook salmon 1) dispersed into nearshore rearing areas with natural fish prior to active emigration; 2) emigrated through Lower Granite Reservoir in the summer with their natural counterparts; 3) adapted and grew under riverine and reservoir conditions, 4) had levels of gill ATPase activity similar to natural fish, and 5) survived nearly as well as their natural counterparts. The above five tendencies were biologically similar between natural and hatchery subyearling fall chinook salmon and support the use of hatchery fish as surrogates for natural fish in survival analyses.

RECOMMENDATIONS

Survival and supplementation research will require that fish be made available soon after ponding to control fish fork length, condition, and timing of release. Hatchery fall chinook salmon are acceptable surrogates for natural fall chinook salmon in survival research. Future studies should consider 1995 findings to maximize the similarities in post-release attributes and survival between natural and hatchery subyearling fall chinook salmon. Replicate data sets, collected over a period of several years, will be required to define the relationships among fall chinook salmon survival, flow, and water temperature.

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