Survival of Subyearling Fall Chinook Salmon in the Free-flowing Snake River and Lower Snake River Reservoirs in 2003 and from McNary Dam Tailrace to John Day Dam Tailrace in the Columbia River from 1999 to 2002

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Survival of Subyearling Fall Chinook Salmon in the Free-Flowing Snake River and Lower Snake River Reservoirs, 2003, and from McNary Dam tailrace to John Day Dam tailrace in the Columbia River, 1999-2002

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EXECUTIVE SUMMARY

We report results from an ongoing study of survival and travel time of subyearling fall Chinook salmon in the Snake River during 2003 and in the Columbia River during 1999-2002. Earlier years of the study included serial releases of PIT-tagged hatchery subyearling Chinook salmon upstream from Lower Granite Dam, but these were discontinued in 2003. Instead, we estimated survival from a large number of PIT-tagged fish released upstream from Lower Granite Dam to evaluate transportation from Snake River Dams. During late May and early June 2003, 68,572 hatchery-reared subyearling fall Chinook salmon were PIT tagged at Lyons Ferry Hatchery, trucked upstream, acclimated, and released at Couse Creek and Pittsburg Landing in the free-flowing Snake River. We estimated survival for these fish from release to Lower Granite Dam tailrace. In comparison to wild subyearling fall Chinook salmon PIT tagged and released in the free-flowing Snake River, the hatchery fish we released traveled faster and had higher survival to Lower Granite Dam, likely because of their larger size at release. For fish left in the river to migrate we estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace. Each year, a small proportion of fish released are not detected until the following spring. However, the number of fish released in 2003 that overwintered in the river and were detected as they migrated seaward as yearlings in 2004 was small (<1.0%) and had minimal effect on survival estimates.

We evaluated a prototype floating PIT-tag detector deployed upstream from Lower Granite reservoir to collect data for use in partitioning travel time and survival between free-flowing and reservoir habitats. The floating detector performed poorly, detecting only 27 PIT tags in 340 h of operation from a targeted release of 68,572; far too few to partition travel time and survival between habitats.

We collected river-run subyearling Chinook salmon (mostly wild fish from the Hanford Reach) at McNary Dam, PIT tagged them, and released them to the tailrace as part of an evaluation of transportation from McNary Dam in 2002. Estimated survival in 2002 from the tailrace of McNary Dam to the tailrace of John Day Dam was 0.746 (s.e. 0.036). For migration years 1999-2002, we found that in the reach from McNary to John Day Dam reach, travel time was shorter (migration rate was greater) and survival probabilities were greater when flow volume was greater. Survival was also correlated with water temperature: warmer water was associated with decreased survival, and there was an apparent survival threshold at about 19.3ºC (above this temperature survival decreased substantially).

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INTRODUCTION

Much is unknown about migrational characteristics of subyearling fall Chinook salmon *Oncorhynchus tshawytscha,* including the proportion that survive passage through the Snake and Columbia River dams and reservoirs, how flow volume and water temperature affect survival, and the percentage of migrants collected and transported at the dams. The Snake River fall Chinook salmon evolutionarily significant unit (ESU) was listed as threatened under the Endangered Species Act in April 1992 (NMFS 1992). Information specific to Snake River migrants is necessary to develop and assess the effects of possible restoration strategies such as supplementation, transportation of smolts, dam modification, dam breaching, flow augmentation, spill, or reservoir drawdown.

Because of low population size, conducting research with wild Snake River subyearling fall Chinook salmon has been difficult. Recent studies by using wild fish collected, PIT tagged, and released in the free-flowing Snake River upstream of Lower Granite Dam found that survival decreased coincidental in time with decreases in flow, increases in water temperature, and decreases in turbidity (Connor et al.1998, 2003a; Connor 2001). The ability to determine temporal trends within seasons was limited by the number of fish available for tagging, particularly late in the migration season (late June and early July), when few fish remain in the free-flowing Snake River.

To overcome this problem, we used subyearling fall Chinook salmon raised at Lyons Ferry Hatchery as surrogates for wild fish, ensuring that we could release sufficient fish in each group, even late in the migration season. Starting in 1995, we estimated survival and travel time using subyearling Chinook salmon reared and PIT tagged at Lyons Ferry Hatchery, and transported for release in the free-flowing Snake and Clearwater Rivers upstream of Lower Granite Dam (Muir et al. 1998, 1999; Smith et al. 1997, 2002). These studies found that survival decreased with decreases in flow, increasing water temperature, and decreasing turbidity (Smith et al. 2003).

In 2003, the National Marine Fisheries Service released Lyons Ferry Hatchery subyearling fall Chinook salmon for a study to determine the efficacy of transporting this species from Snake River dams. As part of that study, we estimated survival for a portion of PIT-tagged fish that were returned to the river at Snake River dams. Results are reported here.

Estimating travel time and survival throughout the Snake and Columbia River hydropower system is facilitated by numerous PIT-tag interrogation sites within juvenile bypass systems at dams. Estimating survival and travel time for juvenile salmon before they enter the hydropower system is more difficult. Upstream of Lower Granite Dam are two distinct habitats that juvenile fish must negotiate: the free-flowing Snake River and Lower Granite Reservoir. In an effort to partition travel time and survival of subyearling Chinook salmon between these two habitats, we deployed a prototype floating PIT-tag detector near the head of Lower Granite Reservoir, targeting fish released in the free-flowing Snake River for transportation evaluation.

Estimating survival of Snake River fall Chinook salmon downstream of the confluence with the Columbia River has not been possible due to poor survival in the Snake River and low detection rates caused by poor guidance into bypass systems. Research was conducted in the 1980s on the relationship between subyearling fall Chinook salmon travel time and environmental conditions in the Columbia River (Berggren and Filardo 1993; Giorgi et al. 1994). However, this research relied on nitrogen freeze-branded fish (the PIT tag had not yet been developed for fisheries use) so no estimates of survival were available to explore relationships between survival and environmental conditions. Furthermore, the hydropower system is operated differently today. To address this information need, we PIT tagged subyearling fall Chinook salmon (mostly wild fish from the Hanford Reach) and released them in the tailrace of McNary Dam.

Here we report results from releases of PIT-tagged hatchery subyearling fall Chinook salmon in the Snake River for 2003 and PIT-tagged river-run subyearling fall Chinook salmon in the Columbia River at McNary Dam for 2002. Study objectives were:

1) Estimate detection and passage survival probabilities of hatchery subyearling fall Chinook salmon released in the Snake River in 2003

2) Evaluate a prototype floating PIT tag detector for use in partitioning travel time and survival between free-flowing and reservoir habitats

3) Estimate detection and passage survival probabilities for river-run fall Chinook salmon PIT tagged and released at McNary Dam in 2002, and

4) Examine relationships among travel time, survival, and environmental conditions for fall Chinook salmon between the tailraces of McNary and John Day Dams for releases made from 1999-2002.

METHODS

Study Area

Subyearling fall Chinook salmon were PIT tagged at Lyons Ferry Hatchery on the Snake River (river kilometer (rkm) 95) operated by Washington Department of Fish and Wildlife, and released at Couse Creek and Pittsburg Landing (rkm 254 and 346, respectively). Tagged fish were detected at dams during their downstream migration to Bonneville Dam, the last dam on the Columbia River (rkm 234; Figure 1); the study area included a 121-km free-flowing reach of the Snake River and eight dams and reservoirs. Six of these dams were equipped with PIT-tag detection systems (Prentice et al. 1990): Lower Granite Dam (Snake rkm 173), Little Goose Dam (Snake rkm 113), Lower Monumental Dam (Snake rkm 67), McNary Dam (Columbia rkm 470), John Day Dam (Columbia rkm 347), and Bonneville Dam. The Snake River enters the Columbia River at Columbia rkm 522. We also PIT tagged river-run subyearling fall Chinook salmon at McNary Dam and released them into the tailrace at McNary Dam.

Release Groups Upstream of Lower Granite Dam

Snake River fall Chinook salmon exhibit an ocean-type life history (Healey 1991); most migrate to the ocean as subyearlings. Our goal was to release experimental (hatchery-reared) fish of approximately the same size as wild fall Chinook salmon present in the Snake River at the time of release. Target size for fish each year was 75 mm in fork length. The migration of wild subyearling Chinook salmon from rearing areas upstream of Lower Granite Dam varies annually and occurs over a protracted period (Connor et al. 2002, 2003b). Smolt passage at Lower Granite Dam typically begins in late May and continues through late summer and fall (Connor et al. 2002).

Fish for release groups were PIT tagged at Lyons Ferry Hatchery using standard techniques (Muir et al. 1999). At the hatchery, well water was supplied at a near-constant temperature averaging 12°C during tagging and loading for transportation. Fork lengths of all fish tagged were measured, and about 10% of the fish were weighed. Immediately after tagging was complete, we transported fish in truck-mounted aerated tanks to release sites (Table 1). Holding densities in the transport vehicles were kept below 8 kg fish/m^3 of water. At the release sites, fish were acclimated to ambient river temperatures (no more than 2°C warming per h) using a gasoline-powered water pump that gradually replaced the hatchery water in the tank with river water. After acclimation, fish were released directly into the Snake River via flexible hose.

Release Groups at Lower Granite Dam

To study migrational characteristics downstream from Lower Granite Dam, we used PIT-tagged subyearling fall Chinook salmon that were detected in the juvenile fish collection facility at Lower Granite Dam and returned to the tailrace. These included fish from our release groups, groups of Lyons Ferry Hatchery fish released in the Snake and Clearwater Rivers for other experiments, in the Clearwater River for experiments by the Nez Perce Tribe, and groups of wild fish released by the U.S. Fish and Wildlife Service. For analyses, fish were grouped by week of detection at Lower Granite Dam. Thus, each group consisted of actively migrating fish "released" downstream of Lower Granite Dam within the same 7-d period (a small percentage of fish that pass Lower Granite Dam might continue to rear in Little Goose Reservoir for a period of time). We estimated the survival probability from Lower Granite Dam tailrace to McNary Dam tailrace (and reaches in between) for 8 weekly groups in 2003 (Table 2). Data were not sufficient to estimate survival probabilities beyond McNary Dam for these fish.

Data Acquisition and Analysis

At each mainstem dam they encounter, juvenile migrant fish pass either via spillways or via the powerhouse. Diversion-screen systems are installed in turbine intakes so that fish entering the powerhouse are guided away from turbines and into bypass channels. Fish passing via spillways and those not guided away from turbines cannot be monitored for PIT tags. Monitoring equipment (Prentice et al. 1990) detects PIT-tagged fish that pass through fish bypass systems (Matthews et al. 1997) at Lower Granite, Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams (Figure 1). Slide gates in the bypass systems automatically route most detected PIT-tagged fish back to the river (Marsh et al. 1999), allowing multiple detections of individual tagged fish. Detection data are uploaded automatically to the Columbia Basin PIT-tag Information System (PTAGIS), a regional database (PSMFC 1996). Fish bypass and PIT-tag interrogation commences each year in late March or early April, and continues for a period that varies by dam and year. Bypass and monitoring ended at all dams by the end of October in 2003, after which we retrieved the detection data from PTAGIS for our analyses.

We used the methods described by Skalski et al. (1998) and Muir et al. (2001a) for data collection and retrieval from PTAGIS, database quality assurance/control, construction of detection histories, tests of assumptions, estimation of detection and survival probabilities, and travel time. The single-release model (SR) was used to estimate survival from PIT-tag detection history data (Cormack 1964, Jolly 1965, Seber 1965, Skalski et al. 1998; Muir et al. 2001).

A small percentage of Snake River fall Chinook salmon do not migrate in their year of emergence. Instead, they overwinter in the Snake River and resume migration as yearlings the following spring. This tendency leads to violation of assumptions of the SR model. Fish from releases to the Snake and Clearwater Rivers that immediately migrated downstream would be expected to have higher survival probabilities than their cohorts that spent the winter in the reservoir prior to migrating the following spring.

Because of the effects that overwintering fish might have on survival estimates, we based our survival analyses solely on PIT-tag detections that occurred during summer and fall 2003, and ignored detections that occurred the following spring. This approach changed the interpretation of survival probabilities in the SR model. For example, the parameter usually defined as the probability of survival within a particular reach (Skalski et al. 1998; Muir et al. 2001), 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). Detection probability at each dam was the probability of detection only for individuals that migrated as subyearlings, not for the entire group.

We estimated the proportion of our study fish that overwintered in 2003, based on both the proportion of our fish were detected the following spring and on detection probabilities for Lyons Ferry Hatchery fall Chinook salmon released into the Snake River as yearlings in 2004. We could not reliably estimate these probabilities based only on the proportion of our fish that migrated in the spring after overwintering because too few of them were detected in 2004.

Travel Time and Migration Rate

After release upstream of Lower Granite Dam, subyearling fish from Lyons Ferry Hatchery (and wild fish of comparable physiological status) spend up to several weeks feeding and growing until they are of sufficient size and physiologically ready to begin active seaward migration. While we refer to the time between release and arrival at Lower Granite Dam as “travel time,” we note that a significant portion of that time is spent rearing or dispersing downstream passively, rather than actively migrating seaward (Connor et al. 2003b).

We used travel time and migration rate as measures of seaward movement. For each fish detected at Lower Granite Dam, travel time was calculated as the number of days between release and the first detection at the dam. Between any two dams, travel time for each fish detected at both dams was calculated as the number of days between last detection at the upstream dam and first detection at the downstream dam. For each reach-specific travel time (d), we calculated the corresponding migration rate (km/d).

We calculated travel time and migration rate statistics for the following river stretches:

1) Pittsburg Landing to Lower Granite Dam (173 km)

2) Couse Creek to Lower Granite Dam (81 km)

3) Lower Granite Dam to Little Goose Dam (60 km)

4) Little Goose Dam to Lower Monumental Dam (46 km)

5) Lower Monumental Dam to McNary Dam (119 km)

6) Release to McNary Dam

For each release group, we compiled distributions of individual travel times and migration rates. We report the minimum, 20th percentile, median, 80th percentile, and maximum of the distributions for each release group. The true, complete set of travel times for a release group includes travel times of both detected and undetected fish. However, travel times cannot be determined for fish that traverse a river section but are not detected at both ends of the section. Travel time statistics are computed from travel times for detected fish only, representing a sample of the complete set.

Comparison of Wild and Hatchery Subyearling Fall Chinook Salmon

To compare characteristics of hatchery fish in our release groups with those of wild fish present in the river, we used information from wild subyearling Chinook salmon captured with a beach seine (Connor et al. 1998) in the Snake River from April to June in 2003. Wild fish were PIT tagged where they were captured (between Snake rkm 225 and 366), then released to resume rearing and seaward migration. We compared the following characteristics of wild and hatchery subyearling Chinook salmon: fork length at release, travel time to Lower Granite Dam, date of passage at Lower Granite Dam, and survival to the tailrace of Lower Granite Dam.

Evaluation of a Floating PIT-Tag Detector

Two prototype floating PIT-tag detectors were deployed in the Snake River near Asotin, Washington (rkm 236) in 2003. Both detectors were positioned on the Washington shore because of high flows and heavy debris load on the Idaho shore during the sampling period. The second detector was approximately 90 m downstream of the first detector. The detectors were operated from 29 May through 19 June 2003 during daylight hours. Additionally, we conducted three 24-h sampling efforts (6/11-6/12, 6/16-6/17, 6/18-6/19) to explore diel possible patterns in migration behavior.

Each antenna was a 134 kHz detection system, constructed of a 91 × 137-cm loop of 7.6-cm PVC conduit, containing 9 turns of 16-gauge ribbon wire and connected to a Destron-Fearing FS1001A transceiver. Each antenna was suspended perpendicular to the water surface from a modified 4-m pontoon boat, upon which was housed a transceiver, wireless data transmitter, and thermostat-regulated fan (Figure. 2).

On each pontoon boat, two net leads (1.3-cm mesh) were used to guide fish through the PIT detector. Leads were 1.5 m high at the frame attachment point. One lead was 10.7 m long and tapered to a height of 2.5 cm, where it was anchored to shore. The second lead was 12.2 m long and expanded to a height of 2.1 m, where it was anchored in the river. The anchored net leads held the pontoons and suspended antennas in place.

PIT-tagged hatchery subyearling fall Chinook salmon released from Pittsburg Landing and Couse Creek were targeted for detection with the floating detector (Table 1). We also performed a controlled release of PIT-tagged wild subyearling fall Chinook salmon within the net leads to determine if fish were actively avoiding the detection system. Some fish were anesthetized with MS-222 so that they would pass through the detection system passively. Higher rates of detection of anesthetized fish would indicate that alert fish actively avoided the detection system.

Release Groups at McNary Dam, 2002

To evaluate survival from McNary Dam tailrace to John Day Dam tailrace, we released groups of PIT-tagged subyearling fall Chinook salmon into the tailrace of McNary Dam on 17 d between 20 June and 15 August 2002. These fish also served as the reference group for a transportation evaluation at McNary Dam (see Marsh et al. 2004 for tagging details). Subyearling fall Chinook salmon were collected at the McNary Dam juvenile collection system, sorted by Smolt Monitoring Program staff, and PIT tagged.

Most were wild fish from the Hanford Reach, though origin could not be determined for every individual because not all hatchery fall Chinook salmon were fin-clipped. Fish handling methods such as water-to-water transfers and pre-anesthesia were used to minimize stress during sorting and tagging. Tagged fish were transferred through a water-filled pipe to a raceway at McNary Dam. Fish were held for an average of 12 h for recovery and determination of post-tagging mortality.

Fish were released to the tailrace at McNary Dam through the bypass outfall pipe. There were 17 groups released into the tailrace in 2002 with the number of fish per group ranging from 1,774 to 4,651 (Table 3).

Survival Between McNary and John Day Dams, 1999-2002

From 1999 through 2001, we collected, PIT tagged, and released river-run subyearling Chinook salmon (mostly wild fish from the Hanford Reach) at McNary Dam (Smith et al. 2000, 2002). Study designs and release sites varied from year to year, but a series of releases into the tailrace of McNary Dam was included each year. For this analysis, we combined individual (daily) release groups of subyearling Chinook salmon from McNary Dam into weekly groups for 1999 to 2002 (Table 3).

Travel Time and Survival Estimates

For all fish detected at John Day Dam, we calculated the time (d) from release at McNary Dam to first detection at John Day Dam. Then for each weekly group, we calculated the median travel time (d). We constructed a detection history for each fish in each weekly pooled group and used the single-release model to calculate survival estimates from release to John Day Dam.

River Environment Variables

We calculated indices of exposure between McNary and John Day Dams for the following river condition variables: river discharge ("flow") (kcfs), amount of flow over spillways (kcfs), percentage of flow that passed over spillways, water temperature (°C), and water clarity (Secchi disk reading in feet). We obtained daily values for each of these variables from the DART web site: (http://www.cbr.washington.edu/dart/river.html). In a few cases, we interpolated values for days where data were missing or obviously incorrect (e.g., a Secchi disk reading was "0" between two days that each had readings of 5 feet). For each weekly group, we calculated each index of exposure at McNary Dam as the mean of the daily values at the dam during the week of release. For John Day Dam, exposure indices were based on the group's distribution of detections at the dam. For each weekly release group we tabulated John Day detections by day, then determined the days on which the 25th and 75th percentiles of passage occurred. Each exposure index at John Day dam was the mean of the daily values at the dam between the dates of the 25th and 75th percentiles (inclusive).

We used various graphical methods, pairwise product-moment correlations, and simple and multiple linear regression modeling to explore relations among indices of exposure to selected environmental factors and survival and travel time. Because of concomitant temporal trends in river conditions, exposure indices for release groups of PIT-tagged fish were generally highly correlated with each other and with release date. Correlation of such magnitude among predictor variables generally makes it very difficult for multivariate statistical methods to distinguish the relative importance of the predictors' influence on the response variable. Nonetheless, we explored bivariate patterns and used multivariate methods to shed light on relations. Samples were of sufficient size that correlations with relatively little explanatory power (e.g., $r^2 = 0.16$) were statistically significant ($P < 0.05$). One response to this is to lower the level required to declare a correlation significant. Our approach, however, was simply to focus on the amount of variability in the response variable that is "explained" by variability in the predictor (i.e., the r^2 value).

In some regression models of data from multiple years, we used variables for "year effects" to account for differences in annual mean survival and travel time potentially not captured by the environmental variables. We also calculated "adjusted" predictor and response variables by subtracting the respective annual mean from each unadjusted variable. Correlation between adjusted predictor and adjusted response would indicate a within-season relationship between the variables that persisted despite any differences in annual means. Lack of correlation between adjusted variables could indicate either no within-season relationship, or that within-year ranges of the predictor variable did not overlap sufficiently between years to determine that differences in annual means of travel time or survival occurred because of differences in the predictor variable.

RESULTS

Release Groups At Lower Granite Dam and Upstream

Subyearling fall Chinook salmon PIT tagged at Lyons Ferry Hatchery and released upstream of Lower Granite Dam totaled 68,572 fish in 2003 (Table 1). Mortality during handling, tagging, and transport averaged less than 1.0% for these releases. PIT-tagged fish were detected at Lower Granite Dam from late May until the detection system was turned off in early November. The majority were loaded on barges for transport evaluation. Total numbers of PIT-tagged subyearling fall Chinook salmon detected at Lower Granite Dam and returned to the tailrace in 2003 were 6,741 (Table 2).

Tests of Model Assumptions

Tests of assumptions in 2003 indicated more violations than we would expect by chance (<0.10), and more than observed in previous years of the study. Significant violations for tests of homogeneity of detection distributions for previous detection histories were apparently caused by delay of previously detected fish (Table 4). For example, fish detected at Little Goose Dam that were previously detected at Lower Granite Dam took on average about 5 d longer to get to Little Goose Dam than those not detected.

There were many assumption violations indicated in tests of goodness of fit to the single-release model (Table 5), likely caused by detection systems selecting for smaller fish and by a strong relationship between fish length at tagging and survival probabilities. Further research is needed to investigate the causes of these violations, their effects on accuracy of survival estimates, and potential remedial measures. Given current knowledge of these issues, we believe that the violations of assumptions have only small effect on SR model survival estimates that are interpreted as average survival probability for the group, and we report estimates from the SR model for all release groups.

Detection and Survival Probabilities

Detection probabilities were higher at Lower Granite, Little Goose, and McNary Dams (equipped with extended bar screens) than at Lower Monumental Dam (Table 6). Estimated survival to Lower Granite Dam tailrace and sites downstream was similar among all groups released at Couse Creek (Table 7). This was not surprising, given the short time period over which the groups were released (9 d). Estimated survival was lower for groups released at Pittsburg Landing (Table 7).

For weekly passage groups, estimates of survival from Lower Granite Dam to Lower Monumental Dam tailrace were less precise than those for survival from release to Lower Granite Dam because sample sizes were typically much smaller (Table 8). Estimated survival from the tailrace of Lower Granite Dam to the tailrace of McNary Dam declined for groups in late June and July (Table 8).

Travel Time and Migration Rate

The median travel time to Lower Granite Dam in 2003 was nearly the same for fish released from Pittsburg Landing (173 km from Lower Granite Dam) as for those released at Couse Creek (92 km from Lower Granite Dam); migration rates were about twice as great for fish released at Pittsburg Landing (Table 9). Median migration rates between each pair of dams were substantially greater between Lower Monumental and McNary Dams than between pairs of dams upstream from Lower Monumental Dam (Tables 9-13).

Comparison of Wild and Hatchery Subyearling Fall Chinook Salmon

Hatchery subyearling Chinook salmon released at Pittsburg Landing and Couse Creek in 2003 were much larger at release than their wild counterparts. Average length of hatchery fish ranged from 27 to 32 mm longer than wild fish (Table 14). Hatchery and wild fish both exhibited protracted travel times from release to Lower Granite Dam, with wild fish taking 10 to 14 d longer. Both types passed Lower Granite Dam primarily in June. Estimated survival probabilities from release to Lower Granite Dam were higher for hatchery fish than for wild fish during 2003. The faster travel time and higher survival to Lower Granite Dam for hatchery fish was likely because of their larger size at release.

PIT-Tag Detections During Spring After Overwintering

Overall, less than 1.0% of fish we released in 2003 were detected at Snake and Columbia River dams in spring 2004 (Table 15). Each spring, detections of fall Chinook salmon released the previous summer as subyearlings begin soon after the juvenile bypass systems begin operation (late March or early April). Thus, detected fish were probably near a dam when bypass operation began, perhaps having migrated from rearing areas to the lower Snake River as subyearlings and having spent the winter in a reservoir. However, because detection systems are not operational during winter months, we lack information to determine precisely where the fish spent the winter or when they resumed migration in the spring.

In spring 2004, 14,949 PIT-tagged yearling fall Chinook salmon reared at Lyons Ferry Hatchery were released from acclimation ponds at Pittsburg Landing and Captain John Rapids on the Snake River and at Big Canyon Creek on the Clearwater River. Of those that survived to Lower Granite Dam, we estimated that about 86% were detected at least once. We assumed that detection probabilities for fish that migrated out of the Snake River the spring following release were equal to those for yearlings released that spring. That is, the 68 fish (Table 15) released as subyearlings in 2003 and detected in 2004 represented 86% of the total proportion that overwintered and migrated as yearlings in spring. Thus, we estimated that 0.12% (0.10%/0.81) of the subyearlings released in 2003 actually migrated as yearlings the following spring.

Little is known about the overwinter survival probability of subyearling fall Chinook salmon. Most subyearlings that suspend migration probably remain in reservoirs, where they likely have low metabolic needs because water temperatures are low. Low temperatures also may inhibit predation rates. Assuming that overwinter survival was about 65% regardless of release date or site, we estimated that 0.19% (0.12%/0.65) of the subyearlings released in 2003 did not migrate in the year of release. Conversely, we estimated that the proportion of study fish that migrated as subyearlings was 99.81% in 2003. This is by far the highest proportion observed in the years of this study.

Floating PIT-Tag Detector

We detected 34 unique tags using the floating detector, with 24 unique detections on the upstream monitor and 10 on the downstream monitor (Table 16). Of the 14,991 tags released from Pittsburg Landing, 14 (0.09%) were detected, and of the 53,581 tags released from Couse Creek, 13 (0.02%) were detected. The 7 remaining detections were wild spring Chinook salmon released by NOAA Fisheries, wild summer Chinook salmon released by Idaho Department of Fish and Game, wild fall Chinook salmon released by U.S. Fish and Wildlife Service, and hatchery fall Chinook salmon released by Washington Department of Fish and Wildlife.

The number of PIT tags detected was too small for statistical analyses, but we can provide a summary of the behavior of the fish detected. The 14 subyearling fall Chinook salmon released from Pittsburg Landing and detected by a floating detector had a median travel time of 7 d, with a range of 1 to 14 d. The median rate of travel from the upstream release site at Pittsburg Landing was 16.3 km/d and ranged from 7.8 to 99.2 km/d. The 13 subyearling fall Chinook salmon released at Couse Creek and detected on our antennas had a median travel time of 3 d and ranged from <1 to 8 d. The median rate of travel from Couse Creek was 6.1 km/d, ranging from 2.3 to 84.4 km/d. PIT tags were most frequently detected between 1700 and 2100 PDT. Because we sampled primarily during daylight hours, our sample may be biased against nighttime detections. However, during the three 24-h sampling efforts, we detected few fish during nighttime hours.

Data from controlled releases of fish into the net leads of the detection system indicated that fish were able to avoid the antenna, and the net leads were not effective at guiding fish. Of anesthetized fish released within the net leads, 33.2% were detected. Visual examination of the lead nets after the release of anesthetized fish confirmed that the majority of fish were not passing through the antenna, but were concentrated in a part of the net that had formed a pocket behind the antenna. Fish that were not anesthetized were detected at an even lower percentage (16.6%). We observed these fish as they were released, and the majority immediately swam upstream and out of the net leads.

Survival Between McNary and John Day Dams, 1999-2002

River Conditions, 1999-2002

The study period included one year with relatively high flow, especially in late summer (1999), one year with very low flow (2001), and two years with intermediate flow (2000 and 2002; Figures 3 and 4). Water temperature was strongly correlated with flow; water was warmest in 2001, coolest in 1999, and intermediate the other two years. Flow and water temperature at McNary and John Day Dams were very highly correlated (Figures 3 and 4), but spill and water clarity differed between the two dams. At McNary Dam, there were large differences from year to year in percentage of flow that was spilled (Figure 3). Spill usually did not occur when flow was less than 175 kcfs (no spill occurred at all in 2001 after 19 June; there was no spill at McNary Dam on 44 d between 19 June and 31 August in 2000, and on 29 d–mostly August–in 2002). When flow was greater than 175 kcfs, the rate and percentage of spill were highly correlated with flow. Because the study fish were collected in the bypass system at McNary Dam and released in the tailrace, it is very unlikely that spill at McNary Dam influenced their travel time or survival to John Day Dam. Therefore, beyond the description above, we made no further use of the McNary Dam spill variable.

Spill occurred at John Day Dam on all days between 19 June and 31 August in 1999, 2000, and 2002, and on no days in 2001 (Figure 4). The percentage of total flow spilled was fairly constant in 1999, and averaged 26.6% between 19 June and 31 August. In 2000, spill was alternated between blocks of days with average a little under 30% and blocks of days with average a little over 40%. The overall average for 2000 was 34.7%. The average percentage spilled in 2002 was 29.2%. The relatively constant spill percentage within years at John Day Dam (in 2001 spill was constant at 0%) resulted in a lack of correlation between flow and percentage of flow spilled, but also resulted in a lack of contrast in spill percentage among the years 1999, 2000, and 2002.

At McNary Dam, water clarity was correlated with flow and temperature on an annual basis: water was clearest in 2001 and most turbid in 1999; 2000 and 2002 were intermediate (Figure 3). A similar pattern in annual average clarity occurred at John Day Dam (Figure 4), though with less difference among years (2001 was not nearly as different from 2000 and 2002 as it was at McNary Dam), and with more variability in the reported data within years.

Travel Time, Survival Estimates, and River Environment Indices

We calculated survival estimates, median travel times, and river condition indices for 5 weekly groups in each of 1999 and 2000, 6 weeks in 2001, and 9 weeks in 2002 (Tables 17 and 18). Exposure indices were generally highly correlated with each other (Table 19). For example, the product-moment correlation coefficients (r^2) between flow and temperature exposure were -0.84 and -0.90 for McNary Dam and John Day Dam indices, respectively. Flow indices at the two dams were very highly correlated ($r^2 = 0.94$), as were the two temperature indices ($r^2 = 0.88$). For analyses of relationships with survival and travel time, it is clearly not necessary to use indices of flow and temperature for both dams; they are giving essentially the same information. We chose to use the flow and temperature indices from John Day Dam. Similarly, the spill volume index was too highly correlated with either the flow index or the spill percentage index (or both) to provide unique information, so we did not use the spill volume index. Indices of water clarity at the two dams were not as strongly correlated; it is possible that the two separate indices could give independent information as predictor variables in models of travel time and survival.

Unadjusted for annual means, pairwise correlations were highly significant ($P<0.01$) between median travel time and all variables except the John Day clarity index (Figure 5; Table 20). Adjusted for annual means, none of the adjusted variables were significantly correlated with adjusted median travel time ($P>0.05$; Table 20).

The difference between results for adjusted and unadjusted data for travel time was caused almost exclusively by the "separation" of 2001 data from that of other years and the narrow range of indices within 2001. Particularly for the John Day flow index, it was not possible to determine from the data whether the points from 2001 belonged on the same line as those from other years, or whether there were generalized year effects that affected both the flow index and travel time. Assuming that the points are appropriately fit to a single flow/travel time function, it appears the relationship is curved (Figure 5); for a fixed difference (kcfs) in flow volume, the reduction in travel time (slope of the curve) was greater at lower flow levels than at higher flow. Because water velocity is related to flow volume, a plausible explanation for the shape of the curve is a direct link between water velocity and migration rate for subyearling Chinook salmon.

For analyses of relations between river indices and estimated survival, we omitted data from 2000 because the survival estimates were not sufficiently precise (i.e., standard errors were too large; see Table 18). Unadjusted for annual means, pairwise correlations were highly significant ($P <0.01$) between estimated survival and all variables except the

John Day clarity index (Figure 6; Table 20). Adjusted for annual means, the correlations between estimated survival and indices of temperature, clarity, and spill percentage at John Day Dam were not significant. However, there was a significant correlation between adjusted estimated survival and adjusted John Day flow index (Table 20).

Within seasons (i.e., using data from one year at a time), the correlation between John Day flow index and estimated survival was negative (greater flow related to lower survival) but not significant in 1999 and 2001. In 2002, when the range of the flow index was greater, the correlation was positive and significant. There is no indication of a curved relationship between flow and survival over the range of observed flow index (Figure 6). In the multi-year analysis, slopes of the regression lines for adjusted and unadjusted flow were nearly the same and indicated that on average, each increase of 10 kcfs in the flow index was associated with an increase in survival of 1.3 to 1.5%.

The temperature index at John Day Dam was also sufficiently correlated with the flow index to make independent assessment of these two variables impossible. Certainly, the two predictors were too correlated for multiple regression methods to separate effects of the two variables (when both are included, the flow variable is statistically significant and the temperature variable is not). However, the pairwise relationship of estimated survival with temperature deserves a closer look, as a causal mechanism is plausible.

Careful examination of the observed temperature index data indicates there was a gap in the range of temperature data; while points are fairly evenly distributed over the rest of the range, there were no data between 19.3 and 20.6°C (Figure 6). It is noteworthy that for the groups with temperature index less than 19.3°C (10 data points from 1999 and 2002) the slope between survival and temperature was nearly zero. Similarly, for groups with temperature index greater than 20.6°C (10 points from 2001 and 2002) the slope was nearly zero (Figure 6). Mean estimated survival was 0.801 for groups that migrated in cooler water (<19.3°C) and 0.600 for groups that migrated in warmer water (>20.6°C), suggesting there may be a threshold temperature around 20°C, above which survival decreases markedly.

DISCUSSION

Assumptions

An assumption of the SR model is that fish bypassed and detected at a dam and then returned to the river have the same subsequent detection and survival probability as fish that survive dam passage but are not detected (spillway and turbine passage). Although significant violations of this assumption were observed in 2003, survival estimates did not appear to be greatly affected.

For PIT-tagged fall Chinook salmon released as subyearlings, the usual survival probability parameters of the SR model must be interpreted as the joint probability of migrating before winter (when the PIT-tag interrogation system at the downstream dam is dewatered) and the probability of surviving migration. However, the small percentage of fish that did not migrate as subyearlings had minimal effect on subyearling survival estimates. To obtain a precise estimate of the proportion that overwinter would require operation of interrogation systems essentially year-round. However, the shape of the distribution of yearling detections in the spring following the year of release indicated that relatively few migrating fish passed while detection systems were dewatered. An exception might occur during winter flood events (such as the winter of 1995) under which conditions some winter passage has been documented (Connor et al. 1997; Connor 2001).

We assumed that Lyons Ferry Hatchery subyearling fall Chinook salmon would have post-release attributes and survival probabilities similar to their wild counterparts. Our rearing and release strategies were designed to produce hatchery subyearling Chinook salmon with post-release attributes and survival probabilities similar to wild fish migrating from the free-flowing Snake River. However, because hatchery fish were larger than their wild counterparts in 2003, they traveled faster and had higher survival to Lower Granite Dam. Although hatchery fish were not perfect surrogates for wild fish, they were still reasonable surrogates. Hatchery fish spent an extended period of time rearing upstream of Lower Granite Dam, migrated past Lower Granite Dam primarily during the summer, and increased their rate of seaward movement as they progressed downstream, as was observed in studies of wild subyearling fall Chinook salmon (Connor et al. 2002, 2003b).

Detection and Survival Probabilities

In this report, we provide survival and travel time estimates from the free-flowing Snake River to Lower Granite Dam and from Lower Granite Dam downstream through the impounded Snake River to McNary Dam for PIT-tagged subyearling fall Chinook salmon. Substantial losses have been documented during rearing and migration to Lower Granite Dam each year, and relationships between release date, survival, and environmental conditions have been identified (Smith et al. 2003). This information is useful to managers to help maximize survival to Lower Granite Dam. However, during the summer migration season, transportation is maximized for the untagged population of fall Chinook salmon (both wild and hatchery subyearlings) so adult return rates for the population are largely dependent on survival after collection and transport to downstream of Bonneville Dam. To date, information on smolt-to-adult return rates for barged or trucked fish is lacking because most PIT-tagged fish are returned to the Snake River by slide gates to continue their inriver migration. Information on return rates of transported PIT-tagged subyearling Chinook salmon are needed to evaluate the efficacy of this mitigation strategy.

Travel time from release to Lower Granite Dam was similar for groups released on the same date from Pittsburg Landing and from Couse Creek in 2003. Similar travel times suggest that it did not take long for fish from Pittsburg Landing to travel the 92 km to Couse Creek, and thereafter fish from the two sites may have shared rearing habitat downstream of Couse Creek, most likely in Lower Granite Reservoir.

Evaluation of Floating PIT-Tag Detector

The objective was to evaluate the effectiveness of a floating PIT-tag antenna to detect subyearling fall Chinook salmon as they migrate downriver along the shoreline. The total number of unique detections recorded from both floating PIT-tag detectors was 34 over a total of 340 h of fishing, leading us to determine the device was ineffective. There were two types of problems with the floating PIT tag detector that became evident as the trial progressed; gear design and migration behavior.

The first problem had to do with gear design. The net leads that were used to guide fish through the detectors allowed fish to escape below the lead line and adjacent to the antennas. A better design would have been to attach the net leads directly to the antenna and to have ceiling and floor mesh connecting the net leads to prevent fish from avoiding detection. The net leads also created substantial drag causing the nets to distort and the anchors to dislodge. A larger mesh size would allow more debris to pass, thus reducing drag on the nets, which would help keep the nets from billowing and reduce the likelihood of dislodging the anchors. Using longer net leads would allow sampling a greater proportion of the river, although the additional drag might be a problem. A mechanism for flushing or inverting the nets to purge the debris would also be advisable.

There were problems with detection technology as well. Excessive noise caused by interference, either within the electrical system or externally, prevented the transceiver from operating under optimally tuned conditions. This could have led to missed detections due to a reduced detection range. Part of the excessive noise problem was solved by increasing the length of the transceiver's data input cord, but an auto-tuning transceiver would be ideal. Excessive heat was also a problem. High temperature alarms occurred daily despite the ventilation fans in the electrical equipment housing on top of the pontoon boats. Possible alterations to prevent overheating would be to paint the housings white and/or install a larger ventilation fan. The wireless communication between the transceivers and the laptops on shore was not reliable. In many instances, the transceiver would record a detected tag ID on the buffer, but the wireless data transmitter would not relay the information to the laptops so that a time/date stamp could be associated with that particular detection. Had we not downloaded the buffer daily, we would have missed 16 of the 34 detected PIT tags. Using a transceiver that records the time and date of each detection on the buffer or using a better wireless communication system would solve this problem.

An additional problem had to do with migration timing and behavior of subyearling fall Chinook salmon, whose seaward migration coincides with late spring and early summer snow melt. These seasonal freshets create high flow conditions in which the floating PIT-tag detectors are difficult to operate because of the high debris load in the river during flood stages. Thus, the main pulse of smolts may proceed downriver undetected. Although we conducted three 24-h sampling sessions, we were not able to determine definitively whether smolts were mobile throughout the night or just at dusk. We did not observe an increase in detections as night progressed, but cannot say that fish were not moving during this time because the longer the nets were in the water the more debris would accumulate in them, increasing drag and distorting the nets, which provided further opportunities for fish to avoid detection.

The migrational behavior of subyearling fall Chinook salmon may be the overriding factor explaining why our detection levels were so low. Data recently published by Connor et al. (2003b) suggests that subyearling fall Chinook salmon use the river shoreline as rearing habitat and remain in one rearing area until they are ready to migrate downriver, at which time they move out into the main river channel. If the majority of subyearling fall Chinook salmon were moving in the deeper, faster-flowing part of the Snake River, then shoreline-oriented floating PIT-tag detectors would not detect large numbers of subyearling smolts even with modifications. To increase our detections, we would have to modify our net leads and move the floating PIT tag detectors to the middle of the river. This, however, is not feasible because of the large volume of boat traffic, higher flows, and large woody debris found mid-river.

With the limited data collected, we can say little concerning travel time partitioned between the free-flowing Snake River and Lower Granite Reservoir, and survival estimates are not possible. An interrogation site near the head of Lower Granite Reservoir would allow partitioning travel time through free-flowing and reservoir habitats and in estimating how much mortality occurs upstream of the hydropower system. However, the device we tested does not appear sufficient to gather the type of information required to properly estimate survival and travel time in this environment.

This detection system will be subsequently tested in an estuarine environment where subyearling Chinook salmon are known to migrate along the shoreline. The lead nets will be longer and will be changed to a trawl-body net to help improve the sampling and guidance of fish through the detection antenna.

Subyearling Chinook Salmon Survival, McNary Dam to John Day Dam

Data available from river-run subyearling Chinook salmon from 1999 through 2002 are not sufficient to make definitive statements regarding potentially complex dynamics among travel time, survival, and environmental (river) conditions between McNary Dam and John Day Dam. For example, strong correlations among river conditions (flow, spill, temperature) made it impossible to determine which variable had the strongest influence on response variables. Further, because within most years there was a relatively narrow range in river condition values, with little overlap between years in some cases, it was not possible to separate processes and relations that occur within migration seasons from potential annual differences due to generalized "year effects."

We provide the following conclusions (tempered with the above caveats):

1) Travel time (migration rate) between McNary and John Day Dams likely depended on water velocity. Increasing flow had more effect on reducing travel time when flow was low than when it was high.

2) Before adjusting for differences in annual means, estimated survival was significantly correlated with flow, temperature, and spill percentage at John Day Dam. After adjusting for annual means, only the correlation with flow remained significant. This result apparently occurred because there was not sufficient within-year variation in temperature or spill percentage indices to distinguish between generalized year effects and direct influence of temperature or spill percentage (e.g., lower mean survival in 2001 may have been due to the lack of spill at John Day Dam or due to some other difference between years; lacking periods of 0% spill in the other years, we cannot determine which is the case).

3) Travel time may affect survival, as faster travel means less exposure to predators in John Day reservoir.

4) Average survival was nearly constant at water temperatures below 19.3°C, and nearly constant, but considerably lower at water temperature above 20.6°C. A threshold may exist at which temperature will lead to increased mortality in this reach.

Previous studies on travel time of subyearling fall Chinook salmon in the McNary to John Day reach of the Columbia River found a weak relationship between increased flow and faster travel time (Berggren and Filardo 1993; Tiffan et al. 2000), while Giorgi et al. (1994) found no consistent relationship in this reach between the two variables. In the reach upstream (Rock Island Dam to McNary Dam), Giorgi et al. (1997) found that only fish fork length showed a significant relationship with travel time of subyearling fall Chinook salmon.

The relationships identified here among flow, temperature, travel time, and survival of subyearling fall Chinook salmon between McNary and John Day dams are consistent with those found in the Snake River (Connor et al. 2003a,b; Smith et al. 2003). In both locations, the effects of flow and temperature were confounded, making it difficult to confidently predict the effect of either variable independently. In laboratory studies, Marine et al. (2004) found that exposure of Sacramento River fall Chinook salmon fry to water temperatures above 20°C resulted in decreased growth, increased osmoregulatory impairment, and increased vulnerability to predation. That temperature value was near the same temperature threshold found to affect survival for fall Chinook salmon migrants in the McNary to John Day Dam reach.

Increased water temperature exposure for subyearling fall Chinook salmon increases metabolic costs of rearing and migration (Groot et al. 1995). In addition, warmer water could result in increased predation rates due to increased metabolic needs of predators (Vigg and Burley 1991; Vigg et al. 1991; Curet 1993).

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Table 1. Information for groups of PIT-tagged hatchery subyearling fall Chinook salmon released into the free-flowing Snake River in 2003. Water temperatures were measured at release sites. Mortality is total for tagging and transportation.

Release site	Release date	Number released	Water temp. (°C)	Mean length (mm)	Mortality	
					N	%
Pittsburg Landing	29 May	7,491	16.0	102.6	6	0.08
	4 Jun	7,500	16.0	99.6	0	0.00
Couse Creek	28 May	8,726	14.0	100.1	3	0.03
	30 May	8,708	14.0	98.0	5	0.06
	2 Jun	11,544	14.0	100.9	6	0.05
	3 Jun	8,596	14.0	99.4	2	0.02
	5 Jun	16,007	14.0	100.2	4	0.02

Table 2. Numbers of PIT-tagged subyearling fall Chinook salmon detected at Lower Granite Dam and routed to the tailrace each week, 2003. Includes wild fish and fish reared at Lyons Ferry Hatchery. Bold type indicates weeks for which survival estimates were possible; data were not sufficient in other weeks.

Lower Granite Dam passage dates	2003
18-24 May	1
25-31 May	**42**
1-7 Jun	**292**
8-14 Jun	**1,394**
15-21 Jun	**2,604**
22-28 Jun	**1,508**
29 Jun-5 Jul	**536**
6-12 Jul	**226**
13-19 Jul	**82**
20-26 Jul	15
27 Jul-2 Aug	9
3-9 Aug	16
10-16 Aug	6
17-23 Aug	3
24-30 Aug	3
31 Aug.-6 Sep	0
7-13 Sep	0
14-20 Sep	0
21-27 Sep	0
28 Sep.-5 Oct	0
6-12 Oct	1
13-19 Oct	2
20-26 Oct	1
27 Oct.-2 Nov	0
Total	6,741
Total used for survival estimation	6,684

Table 3. Number of subyearling fall Chinook salmon PIT tagged and released in McNary Dam tailrace, number of groups released, and average survival between the tailrace of McNary and John Day Dams (standard errors in parentheses), 1999-2002.

Year	Release dates	Number of fish released	Number of release groups	Estimated survival
1999	6/23-7/20	33,004	26	0.775 (0.019)
2000	6/20-7/19	23,423	14	0.744 (0.205)
2001	6/20-7/28	38,546	15	0.581 (0.016)
2002	6/20-8/15	56,310	18	0.746 (0.036)

Table 4. Tests of homogeneity for detection distributions at Little Goose, Lower Monumental, and McNary Dams for subgroups of groups released from Pittsburg Landing (PL) and Couse Creek (CC) in the Snake River, 2003. Subgroups were defined by detection histories at previous dams. *P* values calculated using Monte Carlo approximation of the exact method. Shaded cells indicate *P* values less than 0.10.

	Little Goose Dam			Lower Monumental Dam			McNary Dam		
Release	χ^2	d.f.	*P* value	χ^2	d.f.	*P* value	χ^2	d.f.	*P* value
PL 1	181.2	56	<0.001	254.0	180	<0.001	661.4	406	<0.001
PL 2	129.8	55	<0.001	246.1	174	0.004	1104.1	315	<0.001
CC 1	200.5	55	<0.001	302.8	165	0.002	429.8	392	0.219
CC 2	176.0	56	<0.001	305.4	183	<0.001	577.9	385	0.034
CC 3	223.5	67	<0.001	304.8	204	0.002	708.9	399	0.024
CC 4	240.1	62	<0.001	251.4	204	0.040	686.5	392	0.002
CC 5	274.4	70	<0.001	373.4	219	<0.001	674.5	469	0.029

Table 5. Results of tests of goodness of fit to the single-release model for release groups of subyearling fall Chinook salmon from Pittsburg Landing (PL) and Couse Creek (CC) in the Snake River, 2003. Shaded cells indicate *P* values less than 0.10.

	Overall		Test 2		Test 2.C2		Test 2.C3		Test 3		Test 3.SR3		Test 3.Sm3		Test 3.SR4	
Release	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value
PL 1	19.022	0.004	14.385	0.002	4.964	0.084	9.421	0.002	4.637	0.200	1.606	0.205	0.101	0.751	2.931	0.087
PL 2	12.771	0.047	12.303	0.006	5.107	0.078	7.196	0.007	0.468	0.926	0.152	0.696	0.171	0.680	0.145	0.703
CC 1	1.967	0.923	1.950	0.583	1.535	0.464	0.415	0.520	0.018	0.999	0.005	0.943	0.012	0.912	0.000	0.989
CC 2	19.019	0.004	17.659	0.001	5.115	0.078	12.545	<0.001	1.359	0.715	0.075	0.785	1.116	0.291	0.168	0.682
CC 3	38.939	<0.001	30.922	<0.001	21.915	<0.001	9.007	0.003	8.016	0.046	5.109	0.024	1.403	0.236	1.505	0.220
CC 4	34.783	<0.001	25.656	<0.001	20.412	<0.001	5.244	0.022	9.127	0.028	0.851	0.356	7.679	0.006	0.597	0.440
CC 5	30.713	<0.001	28.777	<0.001	23.507	<0.001	5.270	0.022	1.936	0.586	1.566	0.211	0.001	0.979	0.370	0.543

Table 6. Estimated detection probabilities for subyearling fall Chinook salmon PIT tagged at Lyons Ferry Hatchery and released in free-flowing sections of the Snake River, 2003. Estimates based on the single-release model. Standard errors in parentheses.

Release Site	Release Date	Number released	Lower Granite Dam		Little Goose Dam		Lower Monumental Dam		McNary Dam	
Couse Creek	28 May	8,726	0.360	(0.008)	0.430	(0.012)	0.295	(0.017)	0.563	(0.027)
Pittsburg Landing	29 May	7,491	0.429	(0.009)	0.479	(0.013)	0.320	(0.017)	0.597	(0.031)
Couse Creek	30 May	8,708	0.419	(0.009)	0.446	(0.013)	0.306	(0.017)	0.658	(0.031)
Couse Creek	2 Jun	11,544	0.474	(0.008)	0.483	(0.012)	0.360	(0.017)	0.686	(0.029)
Couse Creek	3 Jun	8,596	0.490	(0.008)	0.519	(0.013)	0.369	(0.020)	0.673	(0.036)
Pittsburg Landing	4 Jun	7,500	0.547	(0.010)	0.526	(0.016)	0.334	(0.027)	0.605	(0.053)
Couse Creek	5 Jun	16,007	0.527	(0.007)	0.521	(0.011)	0.372	(0.016)	0.596	(0.033)

Table 7. Estimated survival probabilities for subyearling fall Chinook salmon PIT tagged at Lyons Ferry Hatchery and released in free-flowing sections of the Snake River, 2003. Estimates based on the single-release model. Standard errors in parentheses.

Release Site	Release Date	Number released	Release to Lower Granite Dam		Lower Granite Dam to Little Goose Dam		Little Goose Dam to Lower Monumental		Lower Monumental to McNary Dam	
Couse Creek	28 May	8,726	0.828	(0.015)	0.941	(0.032)	0.871	(0.053)	0.831	(0.065)
Pittsburg Landing	29 May	7,491	0.758	(0.012)	0.880	(0.026)	0.887	(0.045)	0.823	(0.058)
Couse Creek	30 May	8,708	0.820	(0.014)	0.892	(0.030)	0.893	(0.053)	0.790	(0.060)
Couse Creek	2 Jun	11,544	0.809	(0.011)	0.870	(0.025)	0.837	(0.042)	0.804	(0.053)
Couse Creek	3 Jun	8,596	0.838	(0.011)	0.889	(0.025)	0.830	(0.047)	0.828	(0.068)
Pittsburg Landing	4 Jun	7,500	0.685	(0.010)	0.885	(0.030)	0.957	(0.080)	0.729	(0.095)
Couse Creek	5 Jun	16,007	0.823	(0.008)	0.868	(0.020)	0.809	(0.038)	0.853	(0.063)

Table 8. Estimated survival and detection probabilities for Lower Granite Dam weekly passage groups of PIT-tagged subyearling fall Chinook salmon, 2003. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Lower Granite Dam passage dates	N	Survival				Detection		
		LGR to LGO	LGO to LMO	LMO to MCN	LGR to MCN	LGO	LMO	MCN
25-31 May	42	0.595 (0.093)	0.986 (0.249)	0.825 (0.383)	0.484 (0.202)	0.640 (0.112)	0.507 (0.162)	0.538 (0.246)
1-7 Jun	292	0.885 (0.060)	0.831 (0.128)	0.777 (0.160)	0.571 (0.092)	0.511 (0.045)	0.333 (0.055)	0.580 (0.098)
8-14 Jun	1,394	0.954 (0.041)	0.799 (0.063)	0.989 (0.092)	0.754 (0.053)	0.356 (0.020)	0.268 (0.021)	0.623 (0.045)
15-21 Jun	2,604	0.884 (0.021)	0.833 (0.050)	0.736 (0.070)	0.542 (0.040)	0.540 (0.016)	0.433 (0.025)	0.669 (0.048)
22-28 Jun	1,508	0.835 (0.021)	0.750 (0.065)	0.633 (0.088)	0.396 (0.043)	0.696 (0.020)	0.414 (0.037)	0.707 (0.072)
29 Jun-5 Jul	536	0.703 (0.032)	0.786 (0.109)	0.548 (0.118)	0.303 (0.051)	0.716 (0.035)	0.367 (0.057)	0.600 (0.102)
6-12 Jul	226	0.768 (0.060)	0.757 (0.203)	0.380 (0.139)	0.221 (0.055)	0.674 (0.059)	0.324 (0.093)	0.632 (0.149)
13-19 Jul	82	0.626 (0.080)	1.042 (0.439)	0.359 (0.226)	0.234 (0.113)	0.701 (0.092)	0.350 (0.160)	0.500 (0.250)

Table 9. Travel times and migration rates between the point of release and Lower Granite Dam for hatchery subyearling fall Chinook salmon released at Pittsburg Landing (PL, 173 km) and Couse Creek (CC, 81 km) in the Snake River, 2003.

			Travel time (d)					Migration rate (km/d)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
PL1	29 May	2,438	1.6	11.5	17.5	23.1	72.5	2.4	7.4	9.8	14.9	106.2
PL2	4 Jun	2,814	3.2	13.3	16.8	20.4	72.8	2.3	8.4	10.2	12.9	53.3
CC1	28 May	2,598	1.8	11.2	15.9	22.5	123.9	0.7	3.6	5.1	7.2	44.0
CC2	30 May	2,988	1.3	10.4	15.9	21.6	135.3	0.6	3.8	5.1	7.8	61.4
CC3	2 Jun	4,426	1.6	12.2	17.6	20.5	135.1	0.6	3.9	4.6	6.6	50.3
CC4	3 Jun	3,529	2.1	12.3	17.4	20.4	116.0	0.7	4.0	4.7	6.6	38.6
CC5	5 Jun	6,940	2.3	11.8	15.6	19.3	139.4	0.6	4.2	5.2	6.9	35.4

Table 10. Travel times and migration rates between Lower Granite Dam and Little Goose Dam (60 km) for hatchery subyearling fall Chinook salmon released at Pittsburg Landing (PL) and Couse Creek (CC) in the Snake River, 2003.

			Travel time (d)					Migration rate (km/d)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
PL1	29 May	319	1.8	2.5	4.0	7.0	30.5	2.0	8.5	15.2	23.9	33.9
PL2	4 Jun	299	1.5	2.6	4.0	7.1	43.8	1.4	8.4	15.2	23.1	41.1
CC1	28 May	238	1.6	2.7	3.5	6.5	39.5	1.5	9.3	17.4	22.6	38.5
CC2	30 May	261	1.7	3.0	4.0	6.6	34.7	1.7	9.0	15.0	20.3	34.7
CC3	2 Jun	435	1.7	2.8	4.1	8.1	51.9	1.2	7.4	14.8	21.8	34.9
CC4	3 Jun	416	1.7	2.8	4.4	8.4	64.4	0.9	7.2	13.6	21.1	35.7
CC5	5 Jun	706	1.7	2.9	4.6	8.6	57.8	1.0	7.0	13.1	20.7	35.5

Table 11. Travel times and migration rates between Little Goose Dam and Lower Monumental Dam (46 km) for hatchery subyearling fall Chinook salmon released at Pittsburg Landing (PL) and Couse Creek (CC) in the Snake River, 2003.

			Travel time (d)					Migration rate (km/d)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
PL1	29 May	189	1.0	2.0	3.2	8.9	38.1	1.2	5.2	14.6	22.8	45.5
PL2	4 Jun	113	1.2	2.2	4.1	11.2	48.1	1.0	4.1	11.3	20.7	37.4
CC1	28 May	119	1.1	2.0	3.0	7.3	62.4	0.7	6.3	15.5	22.5	42.6
CC2	30 May	139	0.9	2.0	3.2	8.0	58.9	0.8	5.7	14.5	23.5	50.0
CC3	2 Jun	169	1.0	2.3	4.5	12.4	57.4	0.8	3.7	10.3	20.1	46.5
CC4	3 Jun	156	1.4	2.3	4.7	10.7	49.7	0.9	4.3	9.9	20.4	32.9
CC5	5 Jun	239	1.1	2.6	4.9	13.8	62.6	0.7	3.3	9.4	18.0	42.2

Table 12. Travel times and migration rates between Lower Monumental Dam and McNary Dam (119 km) for hatchery subyearling fall Chinook salmon released at Pittsburg Landing (PL) and Couse Creek (CC) in the Snake River, 2003.

			Travel time (d)					Migration rate (km/d)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
PL1	29 May	135	2.7	3.6	4.5	6.9	27.5	4.3	17.1	26.2	33.1	44.6
PL2	4 Jun	44	2.9	3.9	5.4	7.2	21.6	5.5	16.5	22.1	30.4	41.6
CC1	28 May	90	2.6	3.5	4.5	6.8	27.6	4.3	17.6	26.4	33.6	46.3
CC2	30 May	95	2.8	3.5	4.5	6.6	27.7	4.3	18.1	26.5	34.5	42.7
CC3	2 Jun	119	2.8	3.4	4.5	7.1	19.3	6.2	16.8	26.3	34.8	43.1
CC4	3 Jun	85	2.8	3.7	5.0	6.8	18.4	6.5	17.4	23.7	32.2	43.3
CC5	5 Jun	135	2.5	3.5	4.6	6.2	19.6	6.1	19.1	25.9	33.9	48.2

Table 13. Travel times and migration rates between the point of release and McNary Dam for hatchery subyearling fall Chinook salmon released at Pittsburg Landing (PL, 398 km) and Couse Creek (CC, 306 km) in the Snake River, 2003.

			Travel time (d)					Migration rate (km/d)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
PL1	29 May	850	10.9	21.5	25.2	32.9	76.6	5.2	12.1	15.8	18.5	36.6
PL2	4 Jun	475	11.9	18.9	24.6	35.5	87.2	4.6	11.2	16.2	21.0	33.5
CC1	28 May	1,040	9.4	20.3	24.5	28.6	75.8	4.0	10.7	12.5	15.1	32.5
CC2	30 May	999	9.1	20.3	23.5	30.6	94.5	3.2	10.0	13.0	15.1	33.5
CC3	2 Jun	1,031	11.5	19.2	22.6	31.6	79.7	3.8	9.7	13.5	16.0	26.5
CC4	3 Jun	773	10.8	18.4	22.1	31.9	83.6	3.7	9.6	13.8	16.7	28.4
CC5	5 Jun	1,136	10.4	17.3	23.0	35.1	105.2	2.9	8.7	13.3	17.7	29.4

Table 14. Comparison of hatchery and wild subyearling Chinook salmon released in the free-flowing Snake River above Lower Granite Dam, 2003. LGR = Lower Granite Dam. Numbers shown are means (length and survival) or medians (travel time and passage date).

Release date	Length (mm)		Travel time (d)		Passage date at LGR		Percent survival (s.e.)	
	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild
30 Apr	-	64	-	45	-	13 Jun	-	52.8 (8.3)
1 May	-	64	-	44	-	14 Jun	-	25.7 (5.8)
6 May	-	64	-	45	-	20 Jun	-	62.8 (6.4)
7 May	-	64	-	45	-	20 Jun	-	48.3 (7.0)
8 May	-	64	-	41	-	18 Jun	-	24.9 (2.8)
13 May	-	64	-	40	-	22 Jun	-	63.0 (5.2)
14 May	-	65	-	43	-	26 Jun	-	60.8 (6.1)
15 May	-	65	-	40	-	24 Jun	-	29.9 (3.0)
20 May	-	67	-	41	-	30 Jun	-	66.3 (3.8)
21 May	-	67	-	39	-	30 Jun	-	58.6 (2.8)
22 May	-	69	-	33	-	24 Jun	-	51.1 (3.4)
27 May	-	70	-	32	-	28 Jun	-	69.3 (5.4)
28 May	100	68	16	30	13 Jun	27 Jun	82.8 (1.5)	50.0 (9.7)
29 May	103	73	18	28	16 Jun	26 Jun	75.8 (1.2)	61.3 (4.6)
30 May	98	-	16	-	15 Jun	-	82.0 (1.4)	-
2 Jun	101	-	18	-	20 Jun	-	80.9 (1.1)	-
3 Jun	99	70	17	28	21 Jun	1 Jul	83.8 (1.1)	59.0 (6.0)
4 Jun	100	70	17	27	21 Jun	30 Jun	68.5 (1.0)	61.9 (8.7)
5 Jun	100	73	16	28	21 Jun	3 Jul	82.3 (0.8)	32.2 (4.7)
10 Jun	-	70	-	25	-	5 Jul		38.5 (4.2)
11 Jun	-	79	-	28	-	9 Jul		61.0 (11.1)
12 Jun	-	83	-	20	-	2 Jul		42.1 (8.8)
17 Jun	-	80	-	17	-	4 Jul		48.5 (5.9)

Table 15. Number of detections during spring 2004 (and percentage of total number released) from hatchery fall Chinook salmon released in the Snake River as subyearlings in2003.

Release date	Pittsburg Landing	Couse Creek
28 May	---	3 (0.03%)
29 May	3 (0.04%)	---
30 May	---	6 (0.07%)
2 Jun	---	10 (0.09%)
3 Jun	---	9 (0.10%)
4 Jun	10 (0.13%)	---
5 Jun	---	27 (0.17%)
All dates	13 (0.09%)	55 (0.10%)

Table 16. PIT tag codes detected near Asotin, Washington in the Snake River by the floating PIT tag detector, 2003.

Tag ID	Release location	First observation	Number of detections	Last observation
3D9.1BF11AC20A	Snake River	05/29/03	1	05/29/03
3D9.1BF15F0103	Big Creek	05/29/03	1	05/29/03
3D9.1BF1B0FF32	Couse Creek	06/02/03	1	06/02/03
3D9.1BF1BBC222	Pittsburg Landing	06/02/03	1	06/02/03
3D9.1BF1BBC823	Couse Creek	06/02/03	1	06/02/03
3D9.1BF1BBE45C	Pittsburg Landing	06/02/03	1	06/02/03
3D9.1BF1C33839	Couse Creek	06/02/03	8	06/04/03
3D9.1BF1C33C96	Pittsburg Landing	06/02/03	4	06/05/03
3D9.1BF1C6F4FC	Couse Creek	06/02/03	1	06/02/03
3D9.1BF11EAE46	Snake River	06/03/03	2	06/12/03
3D9.1BF1B12BB7	Couse Creek	06/03/03	1	06/03/03
3D9.1BF1B33F57	Couse Creek	06/03/03	1	06/03/03
3D9.1BF1BC5301	Pittsburg Landing	06/03/03	1	06/03/03
3D9.1BF1BC855E	Couse Creek	06/03/03	1	06/03/03
3D9.1BF1BCD02C	Pittsburg Landing	06/03/03	1	06/03/03
3D9.1BF1C5CE48	Pittsburg Landing	06/03/03	1	06/03/03
3D9.1BF1C4F0FC	Couse Creek	06/04/03	1	06/04/03
3D9.1BF12396A6	Snake River	06/05/03	1	06/05/03
3D9.1BF1BA9AFE	Couse Creek	06/05/03	1	06/05/03
3D9.1BF1BBB0F7	Couse Creek	06/05/03	1	06/05/03
3D9.1BF1BBDA5A	Couse Creek	06/05/03	4	06/05/03
3D9.1BF1BD5ABF	Pittsburg Landing	06/05/03	1	06/05/03
3D9.1BF1BBAF29	Pittsburg Landing	06/09/03	3	06/10/03
3D9.1BF1BCE366	Snake River	06/09/03	1	06/09/03

Table 16. Continued.

Tag ID	Release location	First observation	Number of detections	Last observation
3D9.1BF1B192AC	Couse Creek	06/10/03	1	06/10/03
3D9.1BF1BC16BB	Pittsburg Landing	06/10/03	1	06/10/03
3D9.1BF1C4FC57	Pittsburg Landing	06/10/03	1	06/10/03
3D9.1BF1BBA91A	Pittsburg Landing	06/11/03	1	06/11/03
3D9.1BF1BCB536	Pittsburg Landing	06/11/03	1	06/11/03
3D9.1BF1C3AE38	Couse Creek	06/11/03	1	06/11/03
3D9.1BF1B49119	Pahsimeroi River Trap	06/12/03	1	06/12/03
3D9.1BF1BCCF41	Pittsburg Landing	06/12/03	1	06/12/03
3D9.1BF1BEE455	Snake River	06/12/03	1	06/12/03
3D9.1BF1C50BB7	Pittsburg Landing	06/12/03	1	06/12/03

Table 17. Weekly totals of run-of-river subyearling Chinook salmon (mostly wild fish from the Hanford Reach) collected and tagged at McNary Dam and released in the tailrace of McNary Dam, 1999-2002.

Release dates	1999	2000	2001	2002
19-25 Jun	3,704	5,102	6,089	4,156
26 Jun-02 Jul	8,146	5,045	7,511	5,468
03-09 Jul	6,267	5,138	3,814	5,655
10-16 Jul	9,195	5,038	6,935	3,703
17-23 Jul	5,692	3,100	5,703	9,710
24-30 Jul	–	–	8,494	10,675
31 Jul-06 Aug	–	–	–	5,328
07-13 Aug	–	–	–	8,001
14-20 Aug	–	–	–	3,664

Table 18. Survival estimates and median travel times from McNary Dam to John Day Dam, and indices of exposure to river conditions for weekly groups of run-of-river subyearling Chinook salmon released in the tailrace of McNary Dam, 1999-2002.

					McNary Dam Indices			John Day Dam Indices				
Year	Dates at McNary Dam	Estimated Survival to John Day Dam	(std. err.)	Median Travel Time (d)	Flow (kcfs)	Temp. (°C)	Clarity (Secchi) (ft)	Flow (kcfs)	Spill (kcfs)	Spill (%)	Temp. (°C)	Clarity (Secchi) (ft)
1999	19-25 Jun	0.788	(0.042)	4.3	333.4	16.0	2.5	302.8	33.5	11.1	16.0	2.6
1999	26 Jun-02 Jul	0.746	(0.032)	3.8	305.1	15.7	2.5	287.7	56.6	19.4	16.4	2.3
1999	03-09 Jul	0.765	(0.059)	5.5	255.3	16.3	3.1	265.4	83.4	31.5	18.0	3.1
1999	10-16 Jul	0.770	(0.053)	5.2	267.6	18.0	3.1	242.8	63.5	26.2	18.9	3.2
1999	17-23 Jul	1.026	(0.162)	6.4	238.6	18.2	3.2	230.4	61.0	26.5	19.2	3.4
2000	19-25 Jun	0.593	(0.195)	4.4	197.6	17.2	4.1	198.0	66.3	34.1	19.1	4.8
2000	26 Jun-02 Jul	0.547	(0.228)	5.3	188.8	18.1	4.0	170.7	61.0	35.6	18.5	4.2
2000	03-09 Jul	0.675	(0.256)	6.5	173.6	18.2	4.2	173.1	56.5	33.2	19.4	4.7
2000	10-16 Jul	1.974	(1.108)	11.2	172.5	19.1	3.9	162.3	56.0	34.3	20.4	4.8
2000	17-23 Jul	0.616	(0.233)	8.8	162.6	19.9	3.8	160.4	49.9	31.1	20.9	4.6

Table 18. Continued.

Year	Dates at McNary Dam	Estimated Survival to John Day Dam (std. err.)		Median Travel Time (d)	McNary Dam Indices			John Day Dam Indices				
					Flow (kcfs)	Temp. (°C)	Clarity (Secchi) (ft)	Flow (kcfs)	Spill (kcfs)	Spill (%)	Temp. (°C)	Clarity (Secchi) (ft)
2001	19-25 Jun	0.572	(0.026)	13.8	125.0	16.9	4.9	89.0	0.0	0.0	19.3	4.2
2001	26 Jun-02 Jul	0.560	(0.036)	27.6	117.3	17.6	5.7	79.7	0.0	0.0	20.6	4.3
2001	03-09 Jul	0.520	(0.077)	26.9	92.1	19.2	5.8	84.9	0.0	0.0	21.1	4.4
2001	10-16 Jul	0.655	(0.054)	16.6	80.8	20.5	6.0	79.1	0.0	0.0	20.7	4.2
2001	17-23 Jul	0.586	(0.048)	13.7	82.2	20.4	6.0	84.1	0.0	0.0	21.0	4.1
2001	24-30 Jul	0.597	(0.049)	13.3	81.5	21.4	6.0	90.5	0.0	0.0	21.5	4.7
2002	19-25 Jun	0.888	(0.079)	3.8	325.9	15.7	4.5	308.7	100.7	32.3	16.9	4.3
2002	26 Jun-02 Jul	0.964	(0.086)	4.6	322.1	17.0	4.5	271.2	90.9	32.9	17.6	4.2
2002	03-09 Jul	0.679	(0.033)	5.2	262.4	16.8	4.2	252.3	69.8	27.6	18.2	4.0
2002	10-16 Jul	0.814	(0.078)	5.0	239.8	18.7	4.2	225.5	60.9	26.9	19.0	4.7
2002	17-23 Jul	0.598	(0.069)	4.8	228.7	19.7	4.8	185.6	50.5	27.5	20.7	4.5
2002	24-30 Jul	0.655	(0.076)	7.7	173.0	20.1	4.6	160.5	46.9	29.3	20.7	4.6
2002	31 Jul-06 Aug	0.811	(0.231)	8.7	159.3	20.2	4.6	152.9	40.6	26.4	21.3	5.3
2002	07-13 Aug	0.448	(0.078)	5.6	156.5	20.1	4.6	145.8	40.5	27.7	21.1	5.0
2002	14-20 Aug	0.571	(0.131)	4.9	144.3	20.9	5.3	149.9	43.4	29.0	20.9	5.0

Table 19. Product-moment correlation coefficients (r) among river condition exposure indices for groups of subyearling Chinook salmon released in McNary Dam tailrace, 1999-2002. Each variable was adjusted by subtracting respective annual mean.

		McNary Dam Indices			John Day Dam Indices				
		Flow (kcfs)	Temp. (°C)	Clarity (Secchi) (ft)	Flow (kcfs)	Spill (kcfs)	Spill (%)	Temp. (°C)	Clarity (Secchi) (ft)
McNary Dam indices	Flow								
	Temp.	-0.84[a]							
	Clarity	-0.53	0.61						
John Day Dam indices	Flow	0.94[a]	-0.79[b]	-0.43					
	Spill	0.64[b]	-0.60	-0.04	0.72[b]				
	%Spill	-0.05	-0.06	0.39	0.01	0.70[b]			
	Temp.	-0.90[a]	0.88[a]	0.56	-0.90[a]	-0.55	0.10		
	Clarity	-0.73[b]	0.63[b]	0.48	-0.69[b]	-0.35	0.19	0.78[b]	

a $r^2 > 0.65$
b $0.40 < r^2 < 0.65$

Table 20. Product-moment correlation coefficients (r) between river condition exposure indices and median travel time and estimated survival between McNary Dam tailrace and John Day Dam tailrace for run-of-river subyearling Chinook salmon, 1999-2002. Correlations and corresponding P values are given for unadjusted variables and for variables adjusted for annual means. P values are for two-sided test of null hypothesis of zero correlation.

	Median Travel Time (1999-2002)				Estimated Survival (excludes 2000)			
	Unadjusted		Adjusted		Unadjusted		Adjusted	
Index	*r*	*P* value	*r*	*P* value	*r*	*P* value	*r*	*P* value
Flow at John Day	-0.747	<0.001	-0.256	0.250	0.714	<0.001	0.506	0.032
Temp. at John Day	0.518	0.008	0.297	0.179	-0.610	0.004	-0.384	0.116
%Spill at John Day	-0.756	<0.001	0.011	0.962	0.501	0.024	0.260	0.297
Clarity at McNary	0.651	<0.001	0.040	0.861	-0.584	0.007	-0.118	0.641
Clarity at John Day	0.188	0.367	0.225	0.314	-0.381	0.097	-0.107	0.674

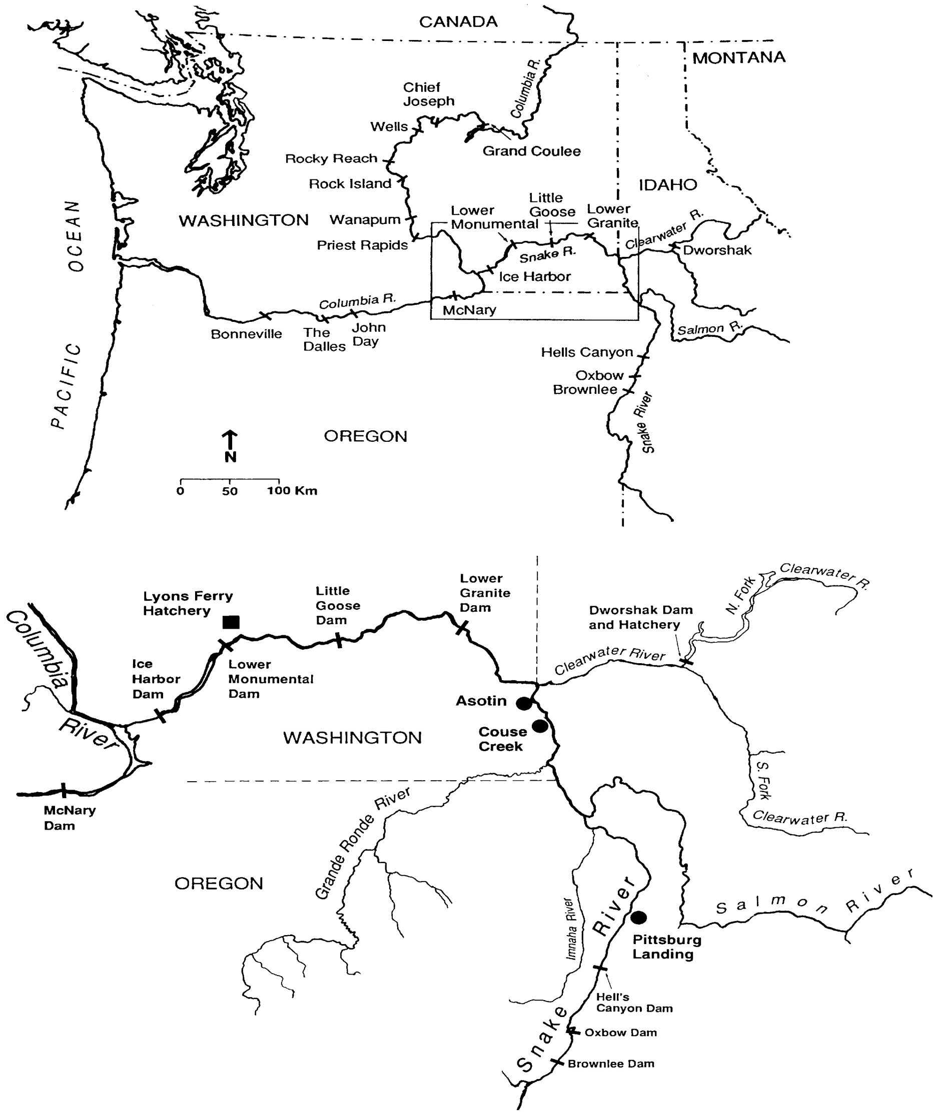

Figure 1. Study area showing location of Lyons Ferry Hatchery; release sites at Pittsburg Landing, Couse Creek, and McNary Dam; Asotin PIT-tag detector site; and dams with PIT-tag detection capabilities for hatchery fall Chinook Salmon studies, 1999-2003.

Figure 2. Floating PIT-tag detector antenna (top) and unit deployed in the free-flowing Snake River, 2003.

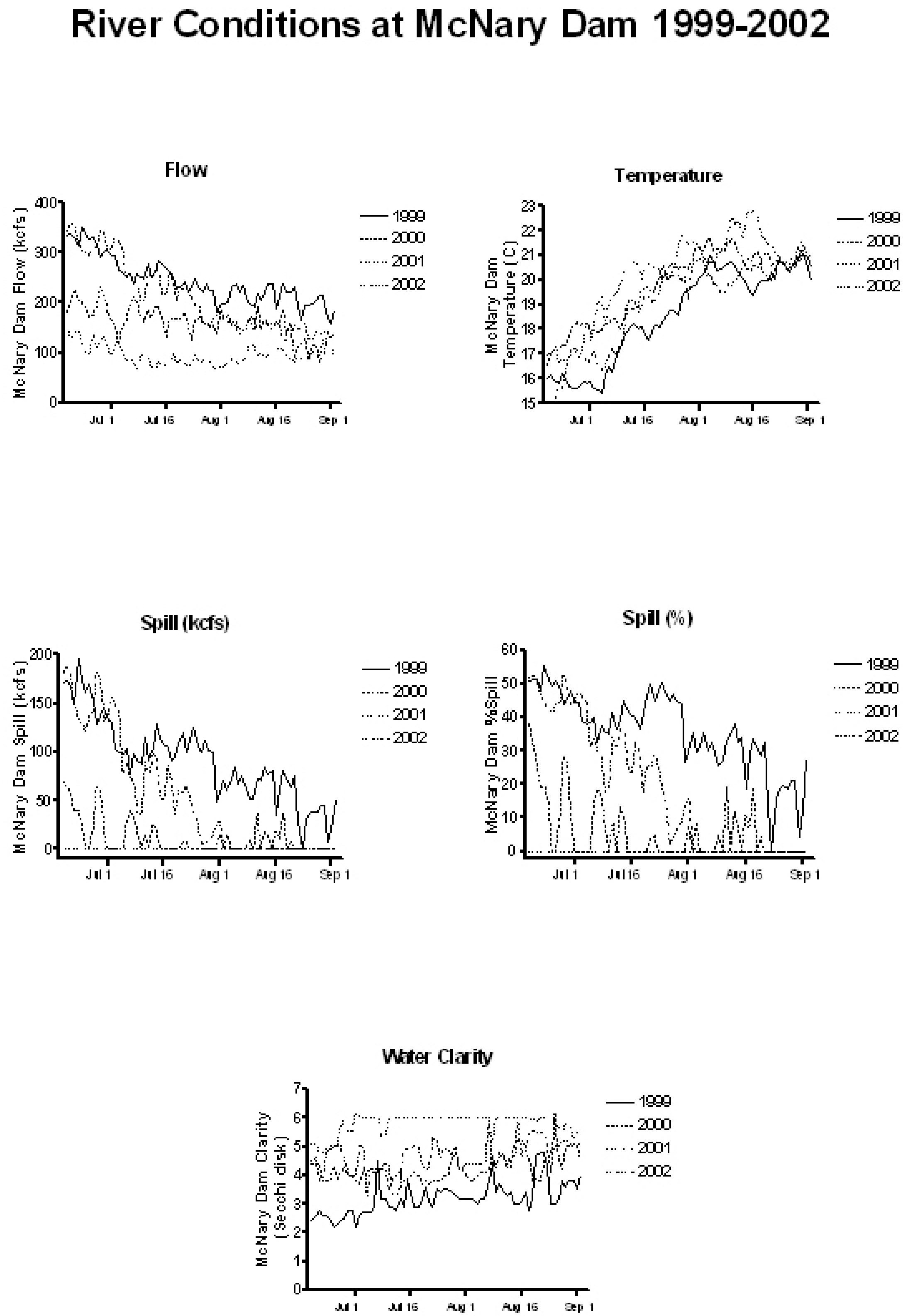

Figure 3. River conditions at McNary Dam, June 19-August 31, 1999-2002.

River Conditions at John Day Dam 1999-2002

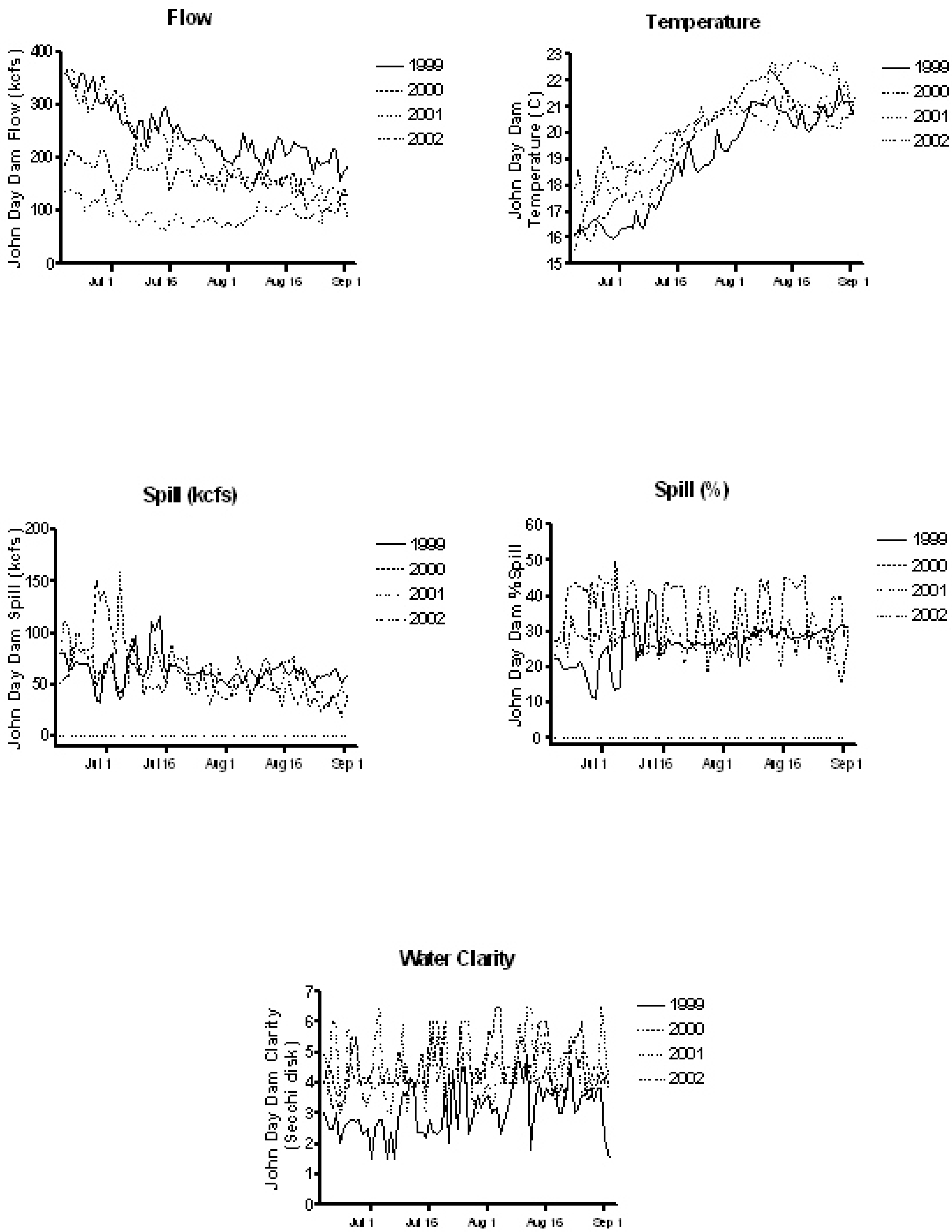

Figure 4. River conditions at John Day Dam, June 19-August 31, 1999-2002.

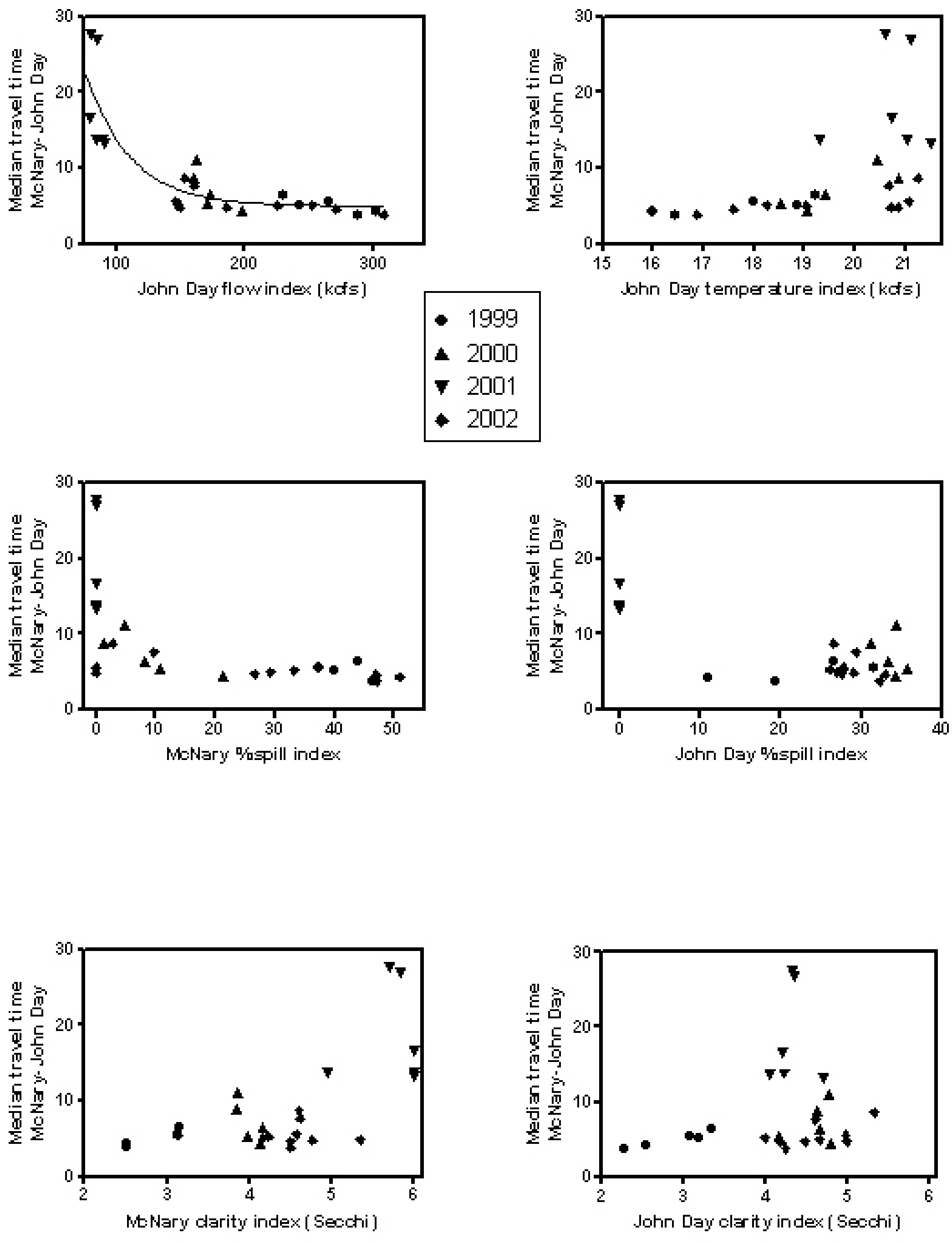

Figure 5. Median travel time between McNary and John Day Dams plotted against various river condition indices for run-of-river subyearling Chinook salmon released in tailrace of McNary Dam, 1999-2002. Flow index panel illustrates exponential-decay curve fit to data.

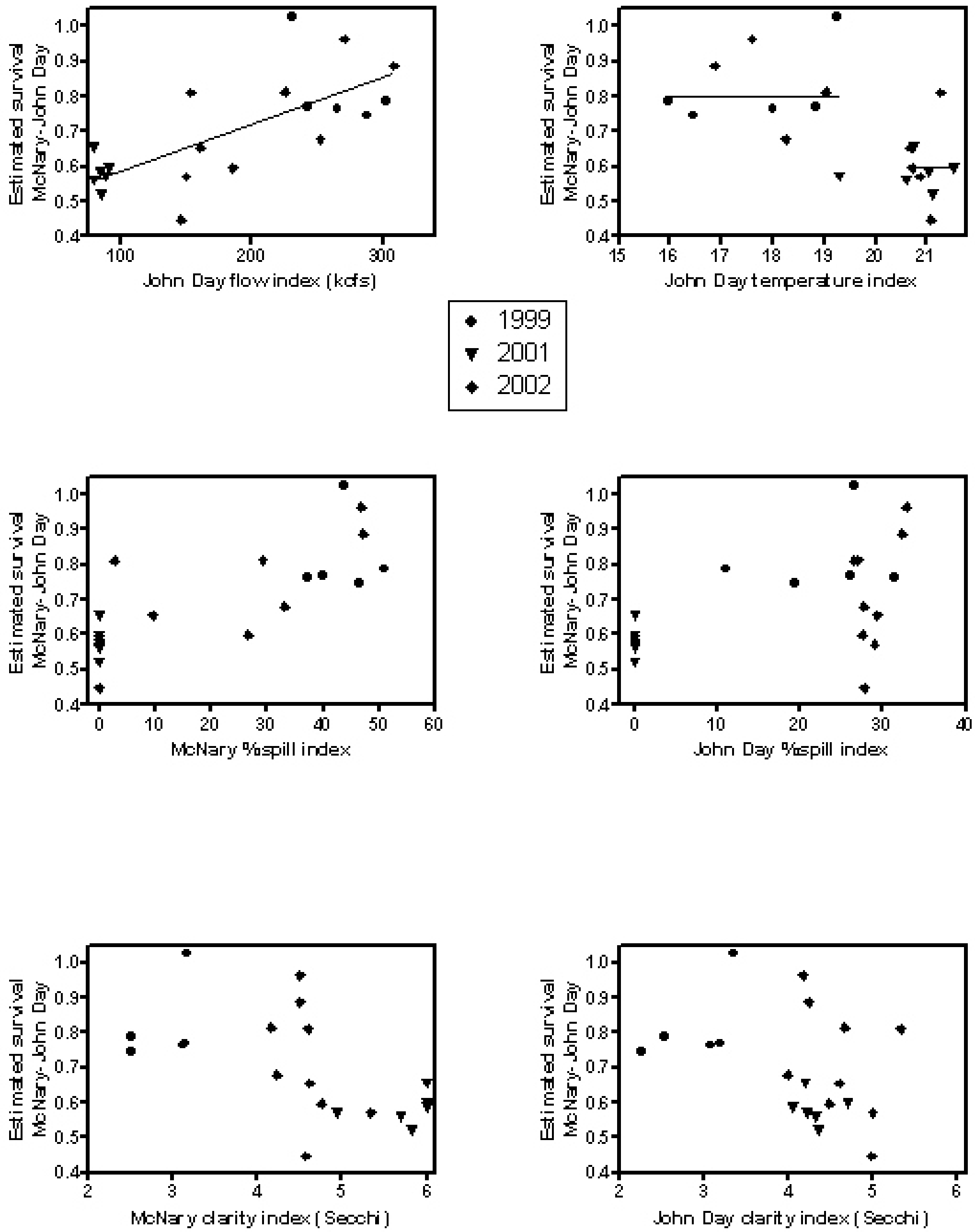

Figure 6. Estimated survival between McNary Dam tailrace and John Day Dam tailrace plotted against various river condition indices for run-of-river subyearling Chinook salmon released in tailrace of McNary Dam, 1999, 2001, and 2002. Flow index panel illustrates simple linear regression line without year effects. Temperature index panel illustrates constant mean survival above and below 20 degrees.