

**Postrelease Performance of Natural and Hatchery Subyearling Fall Chinook
Salmon in the Snake and Clearwater Rivers**

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2009 IMPLEMENTATION SUMMARY

In 2009, we continued a multi-year study to compare smolt-to-adult return rates (SARs) between two groups of Snake River Basin PIT-tagged fall Chinook salmon *Oncorhynchus tshawytscha* that reached the sea through a combination of either (1) transportation and inriver migration or (2) bypass and inriver migration. We captured natural subyearlings rearing along the Snake and Clearwater rivers and implanted them with passive integrated transponder (PIT) tags, but knew in advance that sample sizes of natural fish would not be large enough for precise comparisons of SARs. We supplemented the treatment groups with PIT-tagged hatchery subyearlings (Lyons Ferry Hatchery stock) raised under a surrogate rearing strategy and released them into the Snake and Clearwater rivers. The surrogate rearing strategy involved controlling incubation rate at Umatilla Hatchery and growth at Dworshak National Fish Hatchery to match natural subyearlings in size at release as closely as possible, while insuring that all of the surrogate subyearlings were large enough for tagging (i.e., 60-mm fork length). Surrogate subyearlings were released from late May to early July 2009 to coincide with the historical period of peak beach seine catch of natural parr in the Snake and Clearwater rivers. We also PIT tagged a large fairly representative sample of hatchery subyearlings reared under a production rearing strategy and released them into the Snake and Clearwater rivers in 2009 as part of research on dam passage experiences (i.e., transported from a dam, dam passage via bypass, dam passage via turbine intakes or spillways). Culturing production subyearlings is a higher priority than culturing surrogate subyearlings. It involves controlling growth incubation and growth at Lyons Ferry, Nez Perce Tribal, Umatilla, Irrigon, and Oxbow hatcheries to produce 90–95 mm fish, sometimes followed by a few weeks of acclimation at sites along the Snake and Clearwater rivers before release from May to June. In this report, we estimate the number of PIT-tagged natural, surrogate, and production subyearlings that passed Lower Granite Dam each day to illustrate the similarities and differences between the populations of PIT-tagged natural, surrogate, and production subyearlings. We also compare the postrelease performance of 2009 releases of natural subyearlings to the postrelease performance of 2009 releases of surrogate and production subyearlings. The attributes of postrelease performance we compare are: detection timing, detection during implementation of summer spill, travel time, migrant size, and the joint probability of migration and survival. This comparison provides the fisheries community with the empirical information needed to evaluate the efficacy of the surrogate release strategy and to help explain patterns in SARs. We conclude that (1) natural subyearlings have a much more diverse juvenile life history than production subyearlings and (2) postrelease performance is much more similar between natural and surrogate subyearlings than between natural and production subyearlings. Smolt-to-adult return rates are not reported here, but will be presented in future reports written after workshops and input by federal, state, and tribal researchers.

INTRODUCTION

The Snake River upper reach, Snake River lower reach, Grande Ronde River, and Clearwater River are recognized as the four major spawning areas of Snake River Basin natural fall Chinook salmon *Oncorhynchus tshawytscha* upstream of Lower Granite Reservoir (Figure 1; ICTRT 2007). Though treated as one population, temperature during incubation and early rearing fosters life history diversity among the juveniles produced in these major spawning areas (Connor et al. 2002, 2003a). Young fall Chinook salmon in the Snake River upper reach typically emerge and begin seaward movement earliest in the year followed in order by fish from the Snake River lower reach, Grande Ronde River, and finally the Clearwater River. Some fall Chinook salmon subyearlings discontinue active seaward movement, pass downstream in reservoirs throughout the Federal Columbia River Power System (FCRPS) from late fall to the following spring, and then complete their migration and enter the ocean as yearlings (Arnsberg and Statler 1995; Connor et al. 2002). This “reservoir-type” juvenile life history is important to adult returns and is more prevalent among fall Chinook salmon from the Clearwater River than in the Snake River (Arnsberg and Statler 1995; Connor et al. 2002, 2005; Marsh et al. 2007a).

Understanding how the Snake River Basin fall Chinook salmon population responds to dam passage “strategies” is critical to recovery of the population. We developed a method to evaluate the response to dam passage strategies that accommodates the diverse juvenile life history of Snake River Basin fall Chinook salmon (Marsh et al. 2007b). This method involves comparing smolt-to-adult return rates (SAR) from release upstream of Lower Granite Reservoir to adult return at Lower Granite Dam between two groups of subyearlings implanted with passive integrated transponder (PIT) tags (Prentice et al. 1990a). Both groups are released upstream of Lower Granite Reservoir, but they are treated differently at Lower Granite, Little Goose, Lower Monumental, and in some years at McNary dams (i.e., the collector dams) to represent two different dam passage strategies: (1) transportation with inriver migration and (2) bypass with inriver migration. During our study, summer spill has been implemented annually. Thus, the two passage strategies are better described as (1) transportation with summer spill and (2) bypass with summer spill. Large numbers of fish are required to precisely estimate ratios of SARs between treatment groups. Natural fall Chinook salmon subyearlings (hereafter, natural subyearlings) cannot be presently captured and tagged in these numbers. Therefore, to compare SARs of different treatment groups for this study, it was necessary to tag large numbers of hatchery-reared fall Chinook salmon subyearlings as surrogates for tagged natural fish.

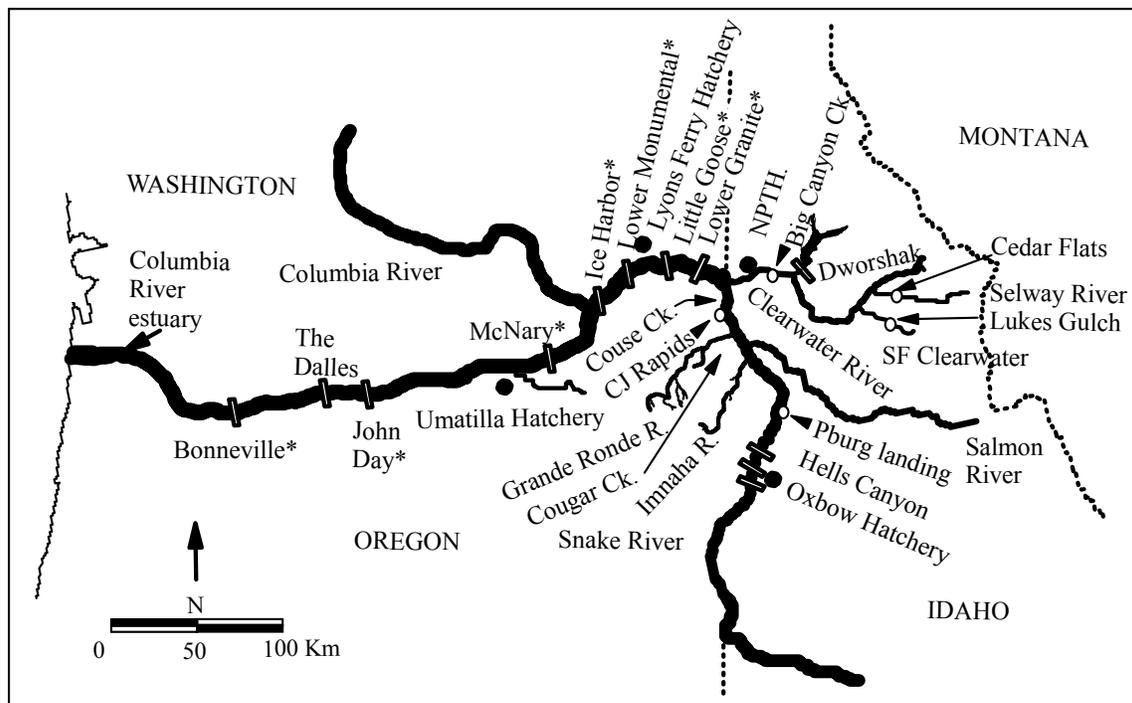


Figure 1.—The four major spawning areas of Snake River Basin fall Chinook salmon upstream of Lower Granite Reservoir are the Snake River upper reach (Hells Canyon Dam to Salmon River); Snake River lower reach (Salmon River to upper end of Lower Granite Reservoir); lower 83 km of the Grande Ronde River; and the lower 65 km of Clearwater River. Lyons Ferry Hatchery is the source of the Snake River hatchery stock of fall Chinook salmon. The Nez Perce Tribal Hatchery (NPTH), Dworshak National Fish Hatchery (DNFH), Oxbow Hatchery, and Umatilla Hatchery culture the Lyons Ferry stock of fall Chinook salmon for production or research purposes. Release points of surrogate subyearlings are the near vicinity of the mouths of Couse and Big Canyon creeks. Release points of production subyearlings are: (1) Hells Canyon Dam, (2) Pittsburg Landing acclimation facility, (3) the mouth of Cougar Creek, (4) Captain John Rapids acclimation facility, (5) the mouth of Couse Creek, (6) NPTH, (7) Big Canyon Creek acclimation facility, (8) Cedar Flats acclimation facility, and (9) Lukes Gulch acclimation facility. Lower Granite, Little Goose, Lower Monumental and McNary dams are collector dams, from which collected fish can be transported for release downstream of Bonneville Dam. Dams equipped with PIT-tag detection systems are indicated by asterisks.

Surrogate and production rearing strategies are presently available for rearing large numbers of hatchery subyearlings. The surrogate rearing strategy involves controlling incubation and growth rates of hatchery subyearlings to match the mean size of PIT-tagged natural subyearlings (70–75 mm; Connor et al. 2000) as closely as possible, while insuring that all of the surrogate subyearlings are large enough for tagging (i.e., 60-mm fork length). The surrogate rearing strategy also involves timing PIT

tagging and release of the hatchery subyearlings to coincide with rearing and PIT tagging of natural subyearlings in the Snake and Clearwater rivers (e.g., Smith et al. 2003). One production rearing strategy involves controlling growth to achieve a target fork length of 90–95 mm fork length (Connor et al. 2004), sometimes followed by a few weeks of acclimation at sites along the Snake and Clearwater rivers (Figure 1). In contrast to surrogate subyearlings, the life history timing of natural fish is not considered when scheduling release dates of production subyearlings. Release dates of production subyearlings are based on factors such as seasonal flow levels, whether or not fish have grown to the 90–95 mm target size, and the availability of acclimation facilities. Not evaluated here is the other production strategy, in which fish are reared to the yearling stage prior to release.

In the 1995 to 2000 migration years, we PIT-tagged natural, surrogate, and production subyearlings to study migrational behavior and survival, and to monitor and evaluate supplementation (e.g., Connor et al. 2002, 2003b, 2003c, 2004; Smith et al. 2003). Results indicated that migrational behavior and passage timing at dams were more similar between natural subyearlings and surrogate subyearlings than between natural subyearlings and production subyearlings. Thus, we selected the surrogate rearing strategy to provide the necessary numbers of fish to precisely estimate SAR ratios when designing and implementing our current passage strategy study. We made pilot releases of surrogate subyearlings into the Snake and Clearwater rivers in 2005 and full-scale releases in 2006 and 2008. We will wait to report SARs from these releases until after we have complete returns of full-term adults (Marsh et al. 2007b).

We made a third full-scale release of PIT-tagged surrogate subyearlings and the first full-scale release of PIT-tagged production subyearlings in 2009 (Marsh et al. 2007b). Releasing production subyearlings has been suggested as a possible alternative for making inferences regarding the effects of passage experience (see definition below) on the natural population if surrogate fish were not available. The SARs from the 2009 production subyearling releases are not intended to represent SARs of natural subyearlings, or to provide data for managing the river to increase the SARs of the natural population. As described in the consensus proposal (Marsh et al. 2007b), these releases were made to (1) calculate SARs for monitoring and evaluating supplementation and (2) understand the response of production subyearlings to dam passage “experiences” including transportation (T_0), bypass (C_1), and inriver migration without bypass (C_0).

The first objective of this report is to estimate daily passage at Lower Granite Dam for the Snake River basin PIT-tagged natural, surrogate, and production juveniles. Accomplishing this objective provides a simple illustration of the similarities and differences between natural subyearlings and the two hatchery groups. Passage timing reflects diversity in juvenile life history (or the lack thereof) and is the cumulative product of rearing environment, growth, migration rate, migrational behavior, survival, and seasonal changes in the environment (e.g., Connor et al. 2000, 2002, 2003b,c, 2004). The second objective is to compare the postrelease performance of 2009 releases of natural subyearlings to the postrelease performance of 2009 releases of surrogate and

production subyearlings. The attributes of postrelease performance we compare are: detection timing, detection during implementation of summer spill, travel time, migrant size, and the joint probability of migration and survival. This objective is completed separately for fish migrating from the Snake and Clearwater rivers. It provides the fisheries community with the empirical information needed to evaluate the efficacy of the surrogate release strategy and to better interpret eventual patterns in the SARs of surrogate and production subyearlings.

METHODS

Fish Collection, Tagging, and Release

Natural Fall Chinook Salmon Subyearlings

Snake River.—We used a beach seine to capture subyearlings at sites in the free-flowing Snake River as described by Connor et al. (1998, 2002). Sampling began at the onset of fry emergence in late March and was conducted 3 d/week. A total of 15 permanent stations from rkm 241 to 361 (rkm 0 = Snake River mouth) were sampled almost every week. During 05/18–06/05, supplemental stations were sampled to increase the number of natural subyearlings PIT tagged. Sampling ended after the week of 07/05, when catch was near zero.

Origin (hatchery or natural) of unmarked (i.e., adipose fin not clipped) and untagged fish (i.e., no coded wire or PIT tag) was determined based primarily on pupil diameter and body shape. Natural fish had smaller pupils and were more robust than their hatchery counterparts (90–100% accurate; Tiffan and Connor in press). Each natural subyearling captured was anesthetized in a 3-mL MS-222 stock solution (100 g/L) per 19 L of water buffered with a sodium bicarbonate solution, measured to fork length (FL, in mm), weighed, and a fin clip was collected for future genetic analyses. Natural subyearlings 60-mm and longer were implanted with a PIT tag and released at the collection site after a 15-min recovery period.

Clearwater River.—We used beach seines and rotary screw traps to capture subyearlings in the lower Clearwater River. Seining was conducted from 6/22 thru 8/25 along the lower Clearwater River from rkm 2 to 62 (rkm 0 = Clearwater River mouth). Permanent sampling sites were seined 5 d/wk when flow allowed. Supplemental sites were seined when time and flow allowed. Two sizes of beach seines fitted with 0.48 cm diameter mesh were used (30.5 × 1.8 m and 15.2 × 1.2 m). Both were fitted with weighted multistranded mud lines. The larger seine was set from a jet boat, and the smaller seine set by hand at less accessible and smaller sites. Two 2.4 m diameter rotary screw traps were suspended from the Spalding railroad bridge along both the north and south shorelines at rkm 20 from 6/15 to 8/12 to catch additional subyearlings. Catch neared zero the 4th week of August when open water seining transition zone between riverine and impounded habitat in the lower Clearwater River was discontinued. The fish were processed as generally described for the Snake River

Surrogate Fall Chinook Salmon Subyearlings

Snake River.—Acquisition of Lyons Ferry Hatchery fish for 2009 releases of Snake River surrogate subyearlings was coordinated under *U.S. v. Oregon*. In December 2008, roughly 245,000 eyed eggs were transferred from Lyons Ferry Hatchery to Umatilla Hatchery where they were incubated in well water. The incubation and feeding regimes were adjusted to produce 360 fish per pound (approximately 50-mm FL) for transport to Dworshak National Fish Hatchery on 04/06/2009. In March 2009, we randomly selected 60 of the Snake River surrogates at Umatilla Hatchery and examined them for *Renibacterium salmoninarum* antigen by enzyme-linked immunosorbent assay (ELISA). In addition, gill/kidney/spleen tissue was examined for viruses associated with infectious pancreatic necrosis, infectious hematopoietic necrosis, and viral hemorrhagic septicemia. The ELISA results were low (optical density less than 0.09), and viral tests were negative.

We transported the Snake River surrogates (roughly 240,000) to Dworshak National Fish Hatchery on 04/06/2009 in a truck equipped with a 7,500-L tank. Oxygen in the tank was kept near 100% saturation during the 4-h trip. Loading density was 0.1 kg/L, well below the recommended maximum of 0.24 kg/L for Chinook salmon (Piper et al. 1982). Upon arrival at Dworshak National Fish Hatchery, the subyearlings were piped from the tank into a 50-m³ raceway supplied with 6.0°C water at approximately 1,136 L/min. The subyearlings were 351 fish per pound (about 52-mm FL). Starting fish density in the raceway was 6.0 kg/m³. Fish were initially fed No. 1 crumb BioDiet starter. Feed size was increased to No. 2 BioDiet growth formula as the fish grew. Fish were fed 2.75% of their body weight each day. The fish were split into a second and a third raceway as they grew. Each raceway was treated with 45 kg of coarse water softening salt (NaCl) immediately after fish were transferred, after weekly cleaning, splitting, and after crowding during tagging. There were no bacterial or viral epizootics during rearing.

The subyearlings were taken off feed 24–48 h before tagging. Final rearing density in the raceways before tagging ranged from 5.0 to 6.0 kg/m³, well below densities reported to adversely affect adult returns of Chinook salmon (see Martin and Wertheimer 1989; Banks 1994; Ewing and Ewing 1995). Temperatures in the raceways during tagging ranged from 7.0 to 8.0°C. Tagging began on 5/18 and was conducted daily during three periods; 05/18–05/22, 05/25–05/29, and 06/1–06/5. These periods were selected to coincide with the historical period of peak beach seine catch of natural parr in the Snake River (Connor et al. 2002).

Each morning, the subyearlings in the raceway designated for tagging were crowded and then bucketed to a 1,893-L holding tank, which was supplied with raceway water and located inside a self-contained tagging trailer. Immediately before tagging, surrogates were transferred to a 379-L sink containing anesthetic water (45–50 mg/L MS-222). The water was recirculated through a 10-25 µm filter to remove particulate matter and then exposed to an ultraviolet light filter to prevent viral and bacterial infections. Surrogates smaller than about 60-mm FL or with obvious signs of disease or injury were

rejected for tagging and piped back to an unoccupied raceway.

Biomark, Inc. was contracted to implant the subyearlings with 12.5-mm 134.2 kHz ISO PIT tags using preloaded 12-gauge hypodermic needles fitted onto an injection device. All fish were tagged with single use needles to reduce the possibility of disease transmission and to reduce injuries caused by dull needles. After tagging, each fish was measured (FL, mm). Fish were then piped to a transport truck equipped with a 1,800-L tank constantly supplied with fresh raceway water until tagging was completed.

After tagging was completed each day, we trucked the Snake River surrogates to the mouth of Couse Creek (253 km upstream from the Snake River mouth). During each 1.5–2-h trip to the release points, oxygen in the tank was kept near 100% saturation. Loading density was 0.02 kg/L and lower. Snake River surrogates were acclimated to ambient river temperature (range, 8.0–15.0°C) using a gasoline-powered water pump to gradually replace the raceway water in the tank with river water at a maximum rate of 2°C warming per hour.

The Snake River surrogates were released directly to the river via a flexible hose when tank temperature equaled river temperature, which generally occurred from late afternoon to near dusk. We monitored mortality throughout tagging and release. The mean pre-release mortality rate was 0.1%. The tank was inspected for shed tags after fish were released. The mean shedding rate was 0.04%.

Clearwater River.—Acquisition of Lyons Ferry Hatchery subyearlings for 2009 releases of Clearwater River surrogate subyearlings was coordinated under *U.S. v. Oregon*. In December 2008, roughly 100,000 eyed eggs were transferred from Lyons Ferry Hatchery to Umatilla Hatchery where they were incubated in chilled well water. The incubation and feeding regimes were adjusted to produce 700 fish per pound (approximately 45-mm FL) for transport to Dworshak National Fish Hatchery on 04/12/2009. In March 2009, we randomly selected 60 of the Clearwater River surrogates at Umatilla Hatchery and examined them for *Renibacterium salmoninarum* antigen by ELISA. In addition, gill/kidney/spleen tissue was examined for viruses associated with infectious pancreatic necrosis, infectious hematopoietic necrosis, and viral hemorrhagic septicemia. The ELISA results were low (optical density less than 0.09), and viral tests were negative.

We transported the fry from Umatilla Hatchery to Dworshak National Fish Hatchery on 04/09/2009 using a truck equipped with a 7,500-L tank. Oxygen in the tank was kept near 100% saturation during the 4-h trip. Loading density was 0.002 kg/L. Upon arrival at Dworshak National Fish Hatchery, the subyearlings were piped from the tank into a 36-m³ raceway supplied with 6.0°C water at approximately 1,136 L/min. The number of fish per pound was 780 (about 41-mm FL). The initial rearing density was 5.1 kg/m³ and the fish were split into three raceways as they grew. The subyearlings were fed, handled, tagged, and released as described for Snake River surrogates with the following six exceptions. Clearwater River surrogate subyearlings were:

- 1) reared to final densities of 10.2–10.7 kg/m³;
- 2) tagged and released during 06/29–07/03, 07/06–07/10, and 07/13–07/17;
- 3) tagged at temperatures of 8.0–9.0°C;
- 4) transported for only 20–30 min to reach the release site downstream of Big Canyon Creek (Leaning Pine boat launch; a.k.a., Kayler’s Landing) 55 km upstream from the Clearwater River mouth;
- 5) acclimated and released at temperatures of 8.0–14.0°C;
- 6) mean pre-release mortality and shedding rates were 0.2 and 0.01%, respectively

Production Fall Chinook Salmon Subyearlings

Production subyearlings that were PIT-tagged and released in 2009 were incubated, reared, and tagged at Lyons Ferry, Oxbow, Irrigon, Umatilla, and Nez Perce Tribal hatcheries (Figure 1). In 2009, the production subyearlings were PIT tagged several weeks before release. See McCutcheon and Richmond (2009) for details on tagging methods. We estimated fork length at release assuming the fish grew 0.5 mm/d between tagging and release since the production subyearlings were not measured at release.

Rearing and release locations varied as follows. Subyearlings reared at Oxbow Hatchery were directly released at Hells Canyon Dam (Figure 1). Subyearlings reared at Umatilla Hatchery (Figure 1) were also released at Hells Canyon Dam. Subyearlings reared at Lyons Ferry Hatchery were released at Pittsburg Landing and Captain John Rapids acclimation facilities along the Snake River, the mouth of Couse Creek along the Snake River, and Big Canyon Creek acclimation facility along the Clearwater River (Figure 1). Subyearlings reared at Irrigon Hatchery were released into the Grande Ronde River at Cougar Creek (Figure 1). Subyearlings reared at the Nez Perce Tribal Hatchery were transferred for release at the Cedar Flats and Lukes Gulch acclimation facilities located along the Selway and South Fork Clearwater rivers, respectively (Figure 1). See McCleod (2006) for additional information on the Big Canyon acclimation facility and Arnsberg et al. (2010) for the upper Clearwater facilities.

Production subyearlings were PIT tagged with standard methods by both Biomark, Inc. and other agency/tribal staff. The number of production subyearlings that we PIT-tagged at given site was approximately proportional to the entire production subyearling population that was released at that site (Table A1).

Detection of PIT-Tagged Fish

At Lower Granite Dam, PIT-tagged fish that were diverted from the turbine intakes by fish guidance screens were routed to the juvenile bypass system where they were detected in flumes equipped with PIT-tag systems (Prentice et al. 1990b). Fish were routed using automated slide gates that directed fish based on PIT-tag codes (Marsh et al. 1999; Downing et al. 2001). Study fish designated for transport (50% for natural and surrogate subyearlings; 46% for production subyearlings) were routed in “monitor mode.” Fish routed in monitor mode were guided to raceways for eventual transport unless the raceways were at holding capacity or being serviced. In these situations, which did not occur in 2009, the fish would be routed back to the river. Study fish designated for inriver migration (50% for natural and surrogate subyearlings; 54% for production subyearlings) were routed back to the river. The PIT-tagged subyearlings continued migration in the river (i.e., were not transported) (1) if they were routed from the bypass system back to the river; (2) if they entered turbine intakes and passed under submersible traveling screens and through turbines; or (3) if they passed via the spillways. Those that survived downstream passage were potentially detected at Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dams. Fish were routed at Lower Granite, Little Goose, and McNary dams as described for Lower Granite Dam.

The PIT-tag detection systems at the dams are dewatered part of the year and PIT-tagged fish that pass the dams when the systems are dewatered are not detected. The PIT-tag detection systems in the juvenile fish bypass systems were dewatered during the following periods:

- 1) Lower Granite Dam 12/05/2009–03/25/2010;
- 2) Little Goose Dam 12/16/2009–03/08/2010;
- 3) Lower Monumental Dam 12/16/2009–03/23/2010;
- 4) Ice Harbor Dam year round detection depending on route;
- 5) McNary Dam 12/03/2009–04/01/2010;
- 6) John Day Dam 11/30/2009–03/30/2010; and
- 7) Bonneville Dam 12/21/2009–02/18/2010.

We downloaded detection data collected at the dams from the PIT tag Information System (PTAGIS 2009).

Downstream Recapture of Juveniles

We used the separation-by-code system at Lower Granite Dam (e.g., Downing et al. 2001) to recapture a random sample of PIT-tagged Snake River natural, surrogate, and production subyearlings during summer 2009. We did not attempt to recapture Clearwater River natural subyearlings because relatively few are detected at Lower Granite Dam as subyearlings in most years (Arnsberg et al. 2010) and past efforts have led to small sample sizes of recaptured fish.

Objective 1 Data Analyses

Passage Indices for PIT-tagged Natural and Production Juveniles at Lower Granite Dam

To construct passage indices (i.e., estimate daily passage) at Lower Granite Dam for the PIT-tagged natural and production subyearlings, we analyzed PIT-tag detection data collected during migration years 2009 and 2010. We analyzed data on fish from the Snake and Clearwater River rivers jointly. However, neither the natural or hatchery fish were tagged in direct proportion to their abundance in each river. For example, in 2008 68% of the redds counted upstream of Lower Granite Reservoir were counted in the Snake River and lower reaches of its tributaries not including the Clearwater River. The remaining 32% were counted in the Clearwater River and its tributaries. The Clearwater River is more difficult to sample than the Snake River. Of the PIT-tagged natural fish, 83% were tagged in the Snake River and 17% were tagged in the Clearwater River. We calculated weights for the detection data as follows. For the Snake River, we divided 0.68 (i.e., the proportion of redds observed) by 0.83 (the proportion of tagging observed) to calculate a weight of 0.82. For the Clearwater River, we divided 0.32 by 0.17 to calculate a weight of 1.93. We then multiplied the daily number of detections made at Lower Granite Dam for Snake River and Clearwater River natural subyearlings by 0.82 and 1.93, respectively. The sum of the two products was taken as the daily number of detections for natural subyearlings. The same steps were taken for surrogate and production subyearlings.

Plumb et al. (2010) used logistic regression to model the probability of a subyearling entering the juvenile fish bypass system. The fitted equation modeled the probability as a function of the total outflow (KCMS) at Lower Granite Dam and turbine allocation (i.e., the proportion of total outflow going into the turbines). The equation for predicting bypass probability is:

$$B_t = \frac{e^{(-4.545 + 0.3056outflow + 4.3202*turbine\ allocation)}}{1 + e^{(-4.545 + 0.3056outflow + 4.3202*turbine\ allocation)}}$$

We input the observed outflows and turbine allocations for every day of the 2009–2010 passage period into the above model to predict daily bypass probability. To

provide a daily passage index for a particular day, we divided the daily number of detections for each subyearling group for that day (weighted as described above) by the predicted daily detection probability for that day. We summed: (1) the daily passage indices for the group to calculate weekly passage indices, (2) the weekly passage indices in 2009 to calculate a migration year 2009 passage index (\hat{i}_{2009}), (3) the weekly passage indices in 2010 to calculate a migration year 2010 passage index (\hat{i}_{2010}), and (3) \hat{i}_{2009} and \hat{i}_{2010} to calculate the total passage index (\hat{I}) for each subyearling group.

Objective 2 Data Analyses

We calculated all of the postrelease attributes described hereafter separately by subyearling group and compared the attributes separately by river of release and dam when relevant. The dams were Lower Granite, Little Goose, and Lower Monumental. All hypothesis tests used significance level $\alpha = 0.05$. Given the present inability to derive accurate and unbiased estimates of detection probability for all of the subyearling groups at Little Goose and Lower Monumental dams, we analyzed unexpanded detection data. We assumed that daily variation in outflow and turbine allocation was not the sole factor for differences observed between natural subyearlings and the two hatchery subyearling groups.

Detection Timing

We tabulated daily detections at each dam throughout migration year 2009 for each group of subyearlings. At each dam, we used detection data from 05/01/2009 through the last day in 2009 on which the PIT-tag detection system was operational at the dam (hereafter, “migration year 2009 detections.” From the daily detections, we computed cumulative distribution functions (for each day, the cumulative function was equal to the percentage of the eventual total number of detections that had occurred up to that day). We used a two-sample Kolmogorov-Smirnov test (Daniel 1978) to evaluate differences in cumulative detection distributions between natural subyearlings and surrogate subyearlings and between natural subyearlings and production subyearlings. We reported the maximum daily difference in cumulative detection distributions (Kolmogorov-Smirnov D_{\max} values) in percentage points.

To evaluate differences in monthly detection, we used the migration year 2009 detection data to calculate the percentage of the detections made each month. For the Snake River analyses, we used chi-square analyses of 2×4 contingency tables (natural versus one of the other two subyearling groups; May, June, July, August–December to determine if there was significant difference in monthly detection percentages at each dam between natural and surrogate subyearlings and between natural and production subyearlings. If we found a significant difference with a 2×4 analysis, we used a chi-square analysis of 2×2 contingency table (natural versus one of the other two subyearling groups) to compare detection percentages for a given month. We analyzed monthly detection percentages for the Clearwater River subyearling groups as described above except the chi-square analysis began with a 2×7 contingency table (natural versus

one of the other two surrogate subyearling groups; June, July, August, September, October, November, and December [Lower Granite and Lower Monumental dams only]) for comparing natural and surrogate subyearlings and a 2 x 8 contingency table (natural versus production subyearlings; May, June, July, August, September, October, November, and December) for comparing natural and production subyearlings..

To provide an index of the prevalence of yearling migration in each release group of subyearlings (noting that an uncountable number of fish passed the dams undetected during the period when bypass systems were dewatered), we calculated the percentage of the total detections (i.e., migration years 2009 and 2010 combined) made in migration year 2010.

Detection Percentages during Spill Implementation

Summer spill was implemented at Lower Granite, Little Goose, and Lower Monumental Dams from 20 June to 31 August 2009. For each group of subyearlings, we calculated the percentage of the migration year 2009 detections that occurred during summer spill implementation. For statistical comparisons between natural subyearlings and the other two groups of hatchery subyearlings, we used a chi-square analysis of 2×2 contingency table to determine if there was a difference in these detection percentages at each dam.

Our 2005 analysis on spill (Connor et al. 2008a) left some readers with the impression that many natural, surrogate, and production subyearlings were not exposed to spill because we focused solely on summer spill. To provide the reader a more complete depiction of spill exposure, we also calculated the percentage of 2009 migration year detections that occurred during spring spill.

Travel Time

For each subyearling detected at one or more of the three dams studied during migration year 2009, we calculated travel time as the number of days that elapsed between release and detection. Plots of residuals from analysis of variance were skewed or bimodal even after transforming (natural logarithm) the travel times. Since we could not meet the normality assumption, we used a median test (Daniel 1978) to compare median travel time to each dam between natural subyearlings and the two groups of hatchery subyearlings.

Migrant Size

We used data collected on Snake River fish recaptured at Lower Granite Dam to characterize migrant size. We analyzed mean fork length (mm), mean weight (g) and mean condition factor K (weight divided by the cube of fork length multiplied by 10^5). We used a two-sample t test to determine if each of these indicators of size differed between natural subyearlings and the other two groups of subyearlings.

Joint Probability of Migration and Survival

Because of the reservoir-type juvenile life history, detection data did not always conform to the classic single-release recapture model described by Cormack (1964) and Skalski et al. (1998). Lowther and Skalski (1998) attempted to develop a model to deal with data of this nature. However, the possibility that tagged fish can pass dams during periods when detection is impossible (during periods that PIT-tag detection systems are dewatered during late fall and winter results in violation of a critical assumption of both the single-release and Lowther/Skalski (1998) models.

One option for dealing with this situation was to use only detections of subyearlings made in migration year 2009. This results in data more likely to fit assumptions of the single-release model, but requires a reinterpretation of model parameters. When information collected on reservoir-type juveniles in migration year 2010 is ignored, there can be no distinction between cessation of “directed” or “active” migration until the year after release and mortality during the year of release. Consequently, the parameter that is usually interpreted as the probability of survival must instead be interpreted as the joint probability of survival and migration in migration year 2009.

Natural fall Chinook salmon from the Snake River upper reach rarely exhibit the reservoir-type juvenile life history (e.g., 2% and less; Connor et al. 2002). Thus, we can assume that the majority of these fish pass during year t (e.g., migration year 2009) and few of these fish pass dams undetected from late fall to winter, when the PIT-tag detection systems are dewatered. Ignoring detections of reservoir-type juveniles in year $t + 1$ (e.g., migration year 2010) after the PIT-tag detection systems are supplied with water, a hypothetical single-release model “survival” estimate to the tailrace of Lower Granite Dam for upper Snake River reach fish might be 69%. In reality, this estimate is the product of the probability of migrating as a subyearling smolt and passing Lower Granite Dam in year t while the PIT-tag detection system is supplied with water (e.g., 98%) and the probability of surviving to the tailrace of Lower Granite Dam as a subyearling (e.g., 70%). That is, $69\% = 98\% \times 70\%$. Thus, the estimate of the joint probability of migration and survival is only one percentage point lower than the probability of survival alone. Therefore, the joint probability estimate has relatively little bias as an estimate of actual survival probability.

However, natural fall Chinook salmon from the Clearwater River exhibit the reservoir-type juvenile life history more frequently (e.g., 6–85%; Connor et al. 2002) than those from the Snake River upstream of the Salmon River confluence. The prevalence of late fall passage, as well as empirical observations (Tiffan and Connor 2005), suggest that these reservoir-type juveniles commonly pass dams undetected during the winter, when PIT-tag detection systems are dewatered. Ignoring detections of reservoir-type juveniles that occur in the spring following release, a hypothetical single-release model “survival” estimate to the tailrace of Lower Granite Dam for Clearwater fish might be 16%. Again,

this quantity actually estimates the probability of migrating as a subyearling in year t while the PIT-tag detection system is supplied with water (e.g., 40%) and the probability of surviving to the tailrace of Lower Granite Dam (e.g., 40%; i.e., $40\% \times 40\% = 16\%$). In this case, the joint probability estimate of migration and survival is 24 percentage points lower than actual survival probability.

We estimated the joint probability of migration and survival (\pm SE) from release to the tailrace of Lower Granite Dam, from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam, from the tailrace of Little Goose Dam to the tailrace of Lower Monumental Dam for the subgroups of subyearlings as described by Cormack (1964) and Skalski et al. (1998). We multiplied the SE for each estimate by 2 to calculate an approximate 95% confidence interval. The natural subyearling group was divided into subgroups using the cohort approach ($n = 2$ per river; hereafter, cohorts 1 and 2; e.g., Connor et al. 2003b). For Snake and Clearwater River surrogate subyearlings, the subgroups were defined by tagging week ($n = 3$ in the Snake River; $n = 3$ in the Clearwater River). Production fish were kept in their original release groups by release location ($n = 6$ in the Snake River; $n = 3$ release in the Clearwater River).

We concluded that an estimate of the joint probability of migration and survival that exceeded 100% lacked accuracy, that had 95% C.I.s wider than $\pm 20\%$ lacked precision, or that exceeded 100% and had wide confidence intervals lacked both accuracy and precision. We did not base analyses on estimates that lacked accuracy or precision. This limited possible 2009 Snake and Clearwater River analyses to comparisons between estimates of the joint probability of migration and survival from release to the tailrace of Lower Granite Dam. We tested for significant differences between joint probability of migration and survival for the subgroups using likelihood ratio tests.

Overall Comparisons of Attributes

The preceding methods described formal statistical hypothesis tests made to compare postrelease attributes between natural and surrogate subyearlings and between natural and production subyearlings. By themselves, the results (significance or non-significance of differences) of the tests do not completely answer the question of whether surrogate subyearlings were more similar to natural subyearlings than their hatchery counterparts cultured under the production rearing strategy. In some tests, we expected to reject the null hypotheses even with very small actual differences because statistical power was high. In other tests, failure to find a significant difference did not rule out the existence of a biologically meaningful difference.

To provide a more informative series of comparisons, we calculated indices to determine which of the two hatchery subyearling groups was more similar to natural subyearlings. To calculate each index for a pair of groups, the higher value of an attribute was always divided by the lower value. For example, if median travel time to Lower Monumental Dam was 35 d for natural subyearlings and 31 d for surrogates, the index for natural versus surrogate comparison would be 1.1 (35/31). Likewise, if median

travel time was 35 d for natural subyearlings and 14 d for production subyearlings the index for natural versus production subyearlings would be 2.5 (35/14). For this example, we would report a 1.1-fold or 10% difference between the mean travel times of natural and surrogate subyearlings and a 2.5-fold or 150% difference between the mean travel times of natural and production subyearlings. We would conclude that travel time was more similar (closer to 1.0) between natural and surrogate subyearlings than between natural and production subyearlings.

Values used to calculate the indices follow. For cumulative detection date distributions, we used the cumulative percentage of the detections observed at D_{\max} . For monthly detection percentages, we used the peak monthly detection percentage of natural subyearlings. When comparing D_{\max} and peak monthly detection percentages between Clearwater River natural and production subyearlings, we sometimes had to analyze data other than the actual D_{\max} or peak monthly detection percentage because the detection timing differed so greatly between these two groups of subyearlings. For example, at Little Goose Dam D_{\max} between Clearwater River natural and production subyearlings was observed on 07/24, by which date 94.1% of the total detections of production subyearlings had occurred, but no detections of natural subyearlings had yet occurred. The peak month of detection at Lower Granite Dam for Clearwater River natural subyearlings was in November, but no Clearwater River production subyearlings were detected at this dam in November. So, we had to go back to September to find a month when both groups of subyearlings were detected. For age at migration, we calculated the proportion of the total detections (2009 and 2010 combined) that occurred in 2009. We used the percentage of the migration year 2009 detections made during summer spill implementation to calculate the indices for this postrelease attribute. Similarity indices for travel time were described in the preceding paragraph. We calculated indices for migrant size using fork length measurements taken at Lower Granite Dam for the Snake River comparisons. We calculated a total of six similarity indices for comparing the joint probability of migration and survival to the tailrace of Lower Granite Dam of the two Snake River natural subgroups and the three Snake River surrogate subgroups (i.e., cohort 1 versus weekly releases 1, 2, 3; cohort 2 versus weekly releases 1, 2, and 3). We then averaged the six indices to produce one index for final comparison. We followed the same procedure for comparisons made between Snake River natural and production subyearlings and for the Clearwater River subyearlings. We reported both the overall means and medians of the similarity indices for the comparisons made between natural and surrogate subyearlings and natural and production subyearlings. We reported the medians because some of the individual indices were very large. We focused the remainder of the analyses on the means, however, because the large differences in individual indices were biologically meaningful and needed to be given weight in our conclusions.

RESULTS

Fish Collection, Tagging, and Release

The number of subyearlings PIT tagged and released into the Snake River during 2009 was lowest for natural fish and highest for surrogates (Table 1). Natural subyearlings were released in the Snake River over a more protracted period than surrogate or production subyearlings. Fifty-one percent of the Snake River natural subyearling group was tagged and released during the 05/18–06/05 period in which 100% of the Snake River surrogate subyearlings were released. Tagged Snake River natural subyearlings averaged 2 mm smaller in fork length at tagging than surrogate subyearlings and 19–33 mm smaller than production subyearlings.

The number of subyearlings PIT tagged and released into the Clearwater River in 2009 was lowest for natural fish and highest for surrogates (Table 1). Natural subyearlings were released in the Clearwater River over a more protracted period than surrogate or production subyearlings. Fifty-four percent of the Clearwater River natural subyearling group was tagged and released during the 06/29–07/17 period in which 100% of the Clearwater River surrogate subyearlings were released. Natural Clearwater River subyearlings were the same average size as surrogate subyearlings and 17–26 mm smaller than production subyearlings.

Table 1.—The number (*N*), range of release dates, and mean fork length (mm ± SD) of PIT-tagged Snake River and Clearwater River natural, surrogate, and production subyearlings released in 2009. Production subyearlings were measured at tagging but not at release.

Group	Subgroup	<i>N</i>	Release dates	Fork length
Snake River				
Natural		3,332	04/29–07/07	67 ± 7
Surrogates		237,741	05/18–06/05	69 ± 6
Production	Hells Canyon Dam	70,332	05/08–05/14	87 ± 6
	Pittsburg Landing	13,777	05/24	95 ± 6
	Captain John Rapids	13,831	05/26	100 ± 6
	Couse Creek	13,740	05/26	96 ± 6
	Cougar Creek	27,764	05/28–06/03	91 ± 5
Clearwater River				
Natural		664	06/22–08/18	74 ± 12
Surrogates		90,039	06/29–07/17	74 ± 6
Production	Big Canyon Creek	13,763	05/26	100 ± 7
	Lukes Gulch	14,006	06/10	96 ± 6
	Cedar Flats	13,941	06/09	91 ± 7
Total				
Natural		3,996		
Surrogates		327,780		
Production		181,154		

Objective 1: Passage Indices for PIT-tagged Natural, Surrogate, and Production Juveniles at Lower Granite Dam

Passage of PIT-tagged natural and surrogate juveniles at Lower Granite Dam began in spring 2009, peaked in early summer 2009, continued throughout fall 2009, was still in progress when the PIT-tag detection system was dewatered in 2009, and resumed shortly after the system was watered back up in spring 2010 (Figure 2; top and middle panels). Passage of PIT-tagged production subyearlings peaked in mid spring 2009 and was nearly complete by the early August 2009 (Figure 2; bottom panel). Of the natural subyearlings that made up the passage index for 2009 (i.e., \hat{i}_{2009}); 81% passed by 07/31/2009, 1% passed during August, and the remaining 18% passed from September to 12/05/09 when the PIT-tag detection system was dewatered. The percentages for surrogate subyearlings were 69% by 07/31/2009, 4% during August, and 27% from September to 12/05/2009. The percentages for production subyearlings were 99.3% by 07/31/2009, 0.5% during August, and 0.2% from September to 12/05/2009.

For natural juveniles, 2.14% of the total passage index for 2009-2010 (\hat{I}) at Lower Granite Dam occurred in 2010, after the PIT-tag detection systems were watered up for the season. That is, an estimated 2.14% of natural juveniles were confirmed reservoir-type juveniles. The estimated percentage of reservoir-type juveniles was 0.83% for the surrogate group and 0.01% for the production group.

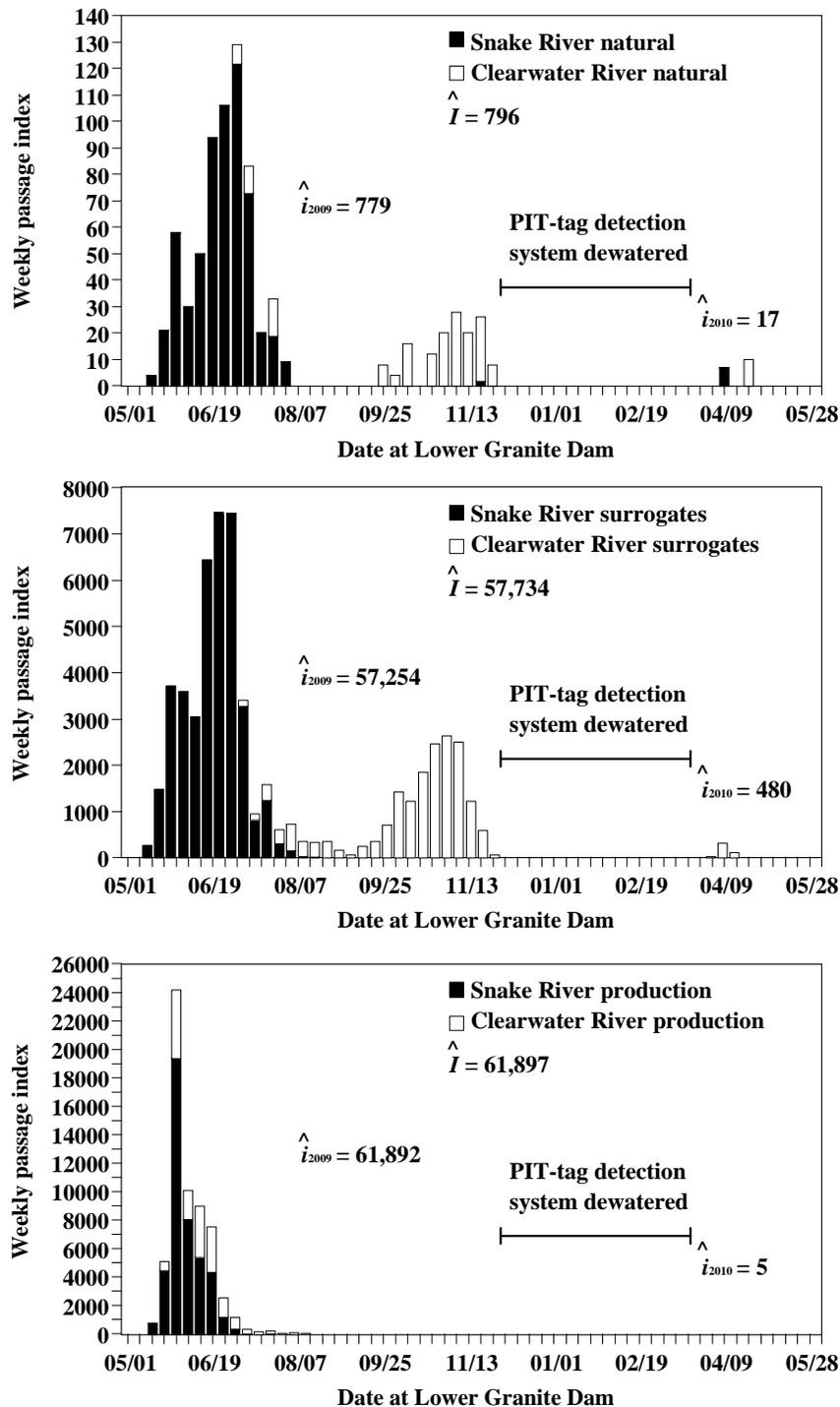


Figure 2.—Weekly passage indices at Lower Granite Dam during migration years 2009 and 2010 for Snake River and Clearwater River natural (top panel), surrogate (middle panel) and production (bottom panel) fall Chinook salmon juveniles based on fish that were PIT tagged and released in 2009. The weekly indices were summed across migration years 2009 and 2010 (\hat{I}) and within each migration year 2009 (\hat{i}_{2009}) and 2010 (\hat{i}_{2010}).

Objective 2: Snake River Comparisons

Detection Timing

The cumulative detection distributions at Lower Granite Dam for Snake River natural and surrogate subyearlings were nearly indistinguishable (Figure 3). On the dates of maximum difference in the cumulative detection distributions (i.e., D_{\max}) at Little Goose and Lower Monumental dams, the detection of Snake River natural subyearlings was closer to completion than the detection of surrogate subyearlings (Figure 3). On 06/14, when D_{\max} (5.9 percentage points) was observed at Lower Granite Dam, 25.7% of the eventual total detections of natural subyearlings had occurred, compared to 31.5% for surrogate subyearlings. On 06/27, when D_{\max} (13.7 percentage points) was observed at Little Goose Dam, 50.0% of the eventual total detections of natural subyearlings had occurred, compared to 36.3% for surrogate subyearlings. On 06/29, when D_{\max} (19.7 percentage points) was observed at Lower Monumental Dam, 47.7% of the eventual total detections of natural subyearlings had occurred, compared to 28.0% for surrogate subyearlings.

Cumulative detection distributions did not differ significantly between Snake River natural and surrogate subyearlings at Lower Granite ($P = 0.4$), but were significantly different between these two subyearling groups at Little Goose ($P < 0.0001$) and Lower Monumental ($P < 0.0001$) dams.

On the dates that D_{\max} was observed for Snake River natural and production subyearlings at Lower Granite, Little Goose, and Lower Monumental dams, the detection of natural subyearlings was further from completion than the detection of production subyearlings (Figure 3). On 06/18, when D_{\max} (52.0 percentage points) was observed at Lower Granite Dam, 34.0% of the eventual total detections of natural subyearlings had occurred, compared to 86.0% for production subyearlings. On 06/18, when D_{\max} (64.1 percentage points) was observed at Little Goose Dam, 27.2% of the eventual total detections of natural subyearlings had occurred, compared to 91.3% for production subyearlings. On 06/17, when D_{\max} (67.0 percentage points) was observed at Lower Monumental Dam, 20.0% of the eventual total detections of natural subyearlings had occurred, compared to 87.0% for production subyearlings.

Cumulative detection distributions differed significantly between Snake River natural and production subyearlings at Lower Granite ($P < 0.0001$), Little Goose ($P < 0.0001$), and Lower Monumental ($P < 0.0001$) dams.

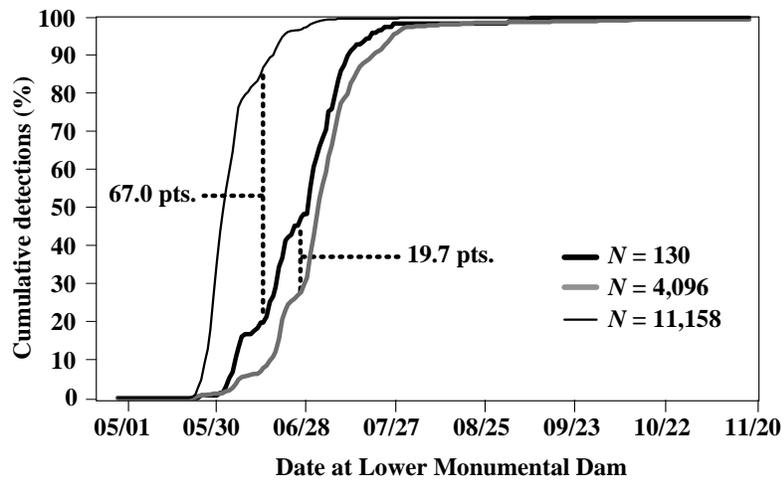
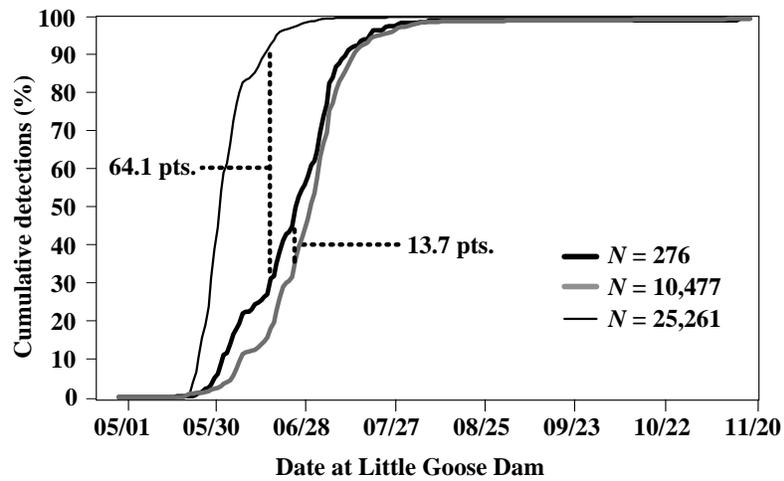
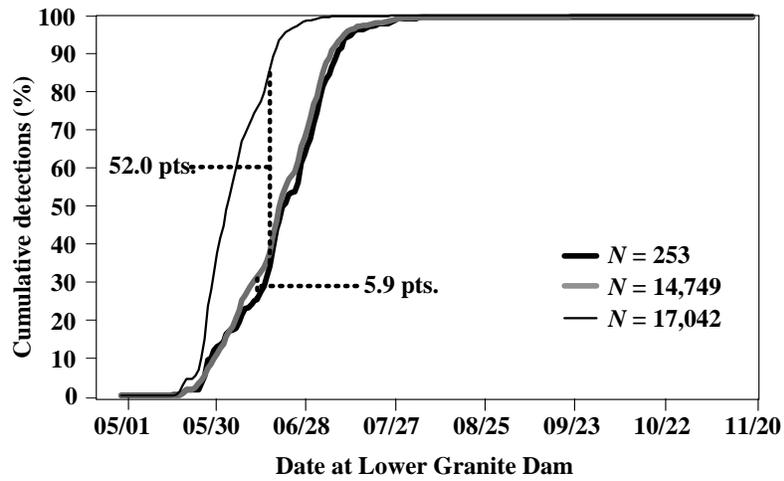


Figure 3.—Cumulative detection distributions at Lower Granite, Little Goose, and Lower Monumental dams for PIT-tagged Snake River natural (thick black line), surrogate (thick gray line), and production (thin black line) fall Chinook salmon subyearlings in migration year 2009. Percentage points (pts) and dotted lines indicate D_{max} values calculated as the maximum daily difference between cumulative detection distributions of natural and surrogate subyearlings, and between natural and production fall Chinook salmon subyearlings.

The monthly percentages of detections at Lower Granite, Little Goose, and Lower Monumental dams in migration year 2009 were similar between Snake River natural and surrogate subyearlings (Figure 4). June was the peak month of detection at Lower Granite Dam for both natural (53.8%) and surrogate (60.4%) subyearlings. June was the peak month of detection at Little Goose Dam for natural subyearlings (52.5%). During June, 42.2% of the total detections of surrogate subyearlings at Little Goose Dam occurred. July was the peak month of detection at Lower Monumental Dam for both natural (50.0%) and surrogate (67.2%) subyearlings.

Monthly detections percentages in migration year 2009 between Snake River natural and surrogate subyearlings were not significantly different (2 x 3 contingency table; $P = 0.2$) at Lower Granite Dam, but they did differ significantly at Little Goose ($P = 0.001$) and Lower Monumental dams. Monthly detections differed significantly between the two groups of subyearlings at Little Goose Dam because of significant differences (2 x 2 contingency tables) in June ($P = 0.001$) and July ($P = 0.001$). Monthly detections differed significantly between the two groups of subyearlings at Lower Monumental Dam because of significant differences in June ($P = 0.0001$) and July ($P < 0.0001$). See Figure 4 for an illustration of the differences in these monthly detections.

Detections of both Snake River natural and production subyearlings during migration year 2009 increased were greater in June than in May at the three dams studied, but monthly detections of natural subyearlings remained high in July, while detections of production subyearlings decreased in July (Figure 4). June was the peak month of detection at Lower Granite Dam for natural (53.8%) and production subyearlings (66.7%). June was also the peak month of detection at Little Goose Dam for natural (52.5%) and production (67.0%) subyearlings. July was the peak month of detection at Lower Monumental Dam for natural subyearlings (50.0%). During July, 2.6% of the total detections of production subyearlings at Lower Monumental Dam occurred.

There were significant differences in monthly detections between Snake River natural and production subyearlings at all three dams in migration year 2009 (2 x 3 contingency tables; all P values < 0.0001). There were significant differences (all P values < 0.0001) in detection for every month. See Figure 5 for an illustration of the differences in these monthly detections.

Of the Snake River natural, surrogate and production juveniles detected during 2009–2010 at Lower Granite Dam; 0.4% of the natural, 0.0% of the surrogate, and 0.0% of the production juveniles were detected in 2010. These percentages at Little Goose Dam were 0.0% for natural juveniles, 0.2% for surrogate juveniles, and 0.0% for production juveniles. At Lower Monumental Dam, the percentages were 0.0% for natural juveniles, 0.4% for surrogate juveniles, and 0.01% for production juveniles.

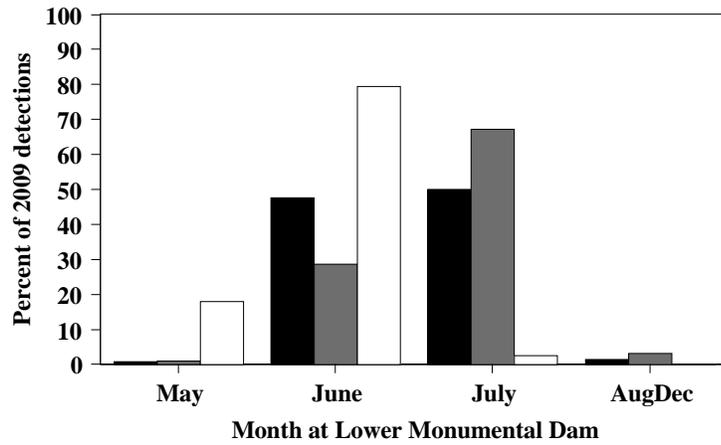
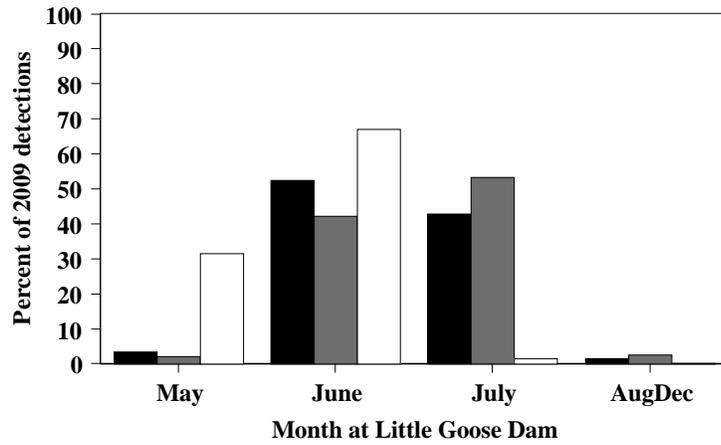
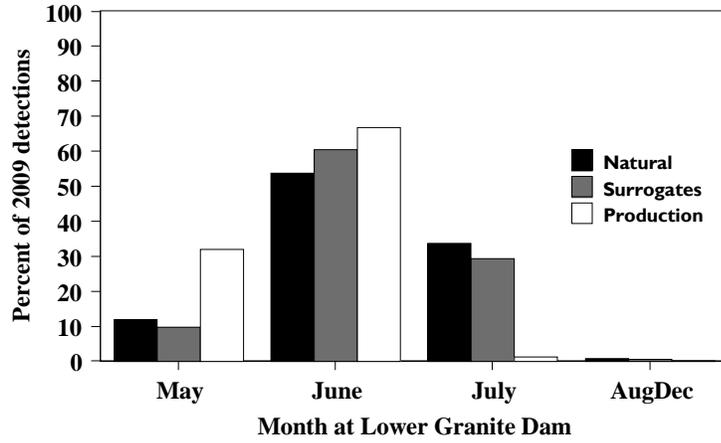


Figure 4.—Monthly percentages of the total detections made during migration year 2009 for PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings. The number of detections for each subyearling group at each dam is given in Figure 3.

Detection Percentages during Spill Implementation

The percentage of migration year 2009 detections made at Lower Granite Dam during summer spill implementation was 60.5% for Snake River natural subyearlings and 57.0% for Snake River surrogate subyearlings (Figure 5). The percentage of the migration year 2009 detections made at Little Goose Dam during summer spill implementation was 68.1% for natural subyearlings and 88.0% for surrogate subyearlings. The percentage of the migration year 2009 detections made at Lower Monumental Dam during summer spill implementation was 73.1% for natural subyearlings and 88.9% for surrogate subyearlings. Thus, there was a 3.5–15.9 percentage point difference between the migration year 2009 detection percentages made during summer spill implementation for natural and surrogate subyearlings.

Percentage of migration year 2009 detections made during summer spill implementation at Lower Granite Dam were not significantly different between Snake River natural and surrogate subyearlings ($P = 0.3$), but did differ significantly between the two groups of subyearlings at Little Goose ($P < 0.0001$) and Lower Monumental ($P < 0.0001$) dams.

The percentages of migration year 2009 detections of Snake River production subyearlings made at Lower Granite, Little Goose, and Lower Monumental dams during summer spill implementation were 10.5, 7.1, and 10.4%, respectively (Figure 5). Thus, there was a 50.0–62.7 percentage point difference between the migration year 2009 detection percentages made during summer spill implementation for natural and production subyearlings.

The percentage of the migration year 2009 detections made during implementation of summer spill was significantly higher for Snake River natural subyearlings than for Snake River production subyearlings at all three dams (all P values < 0.0001).

Nearly all (98.5–100%) of the Snake River natural, surrogate, and production subyearlings that were detected at Lower Granite, Little Goose, and Lower Monumental dams in migration year 2009 were detected during the implementation of either spring or summer spill (Figure 5).

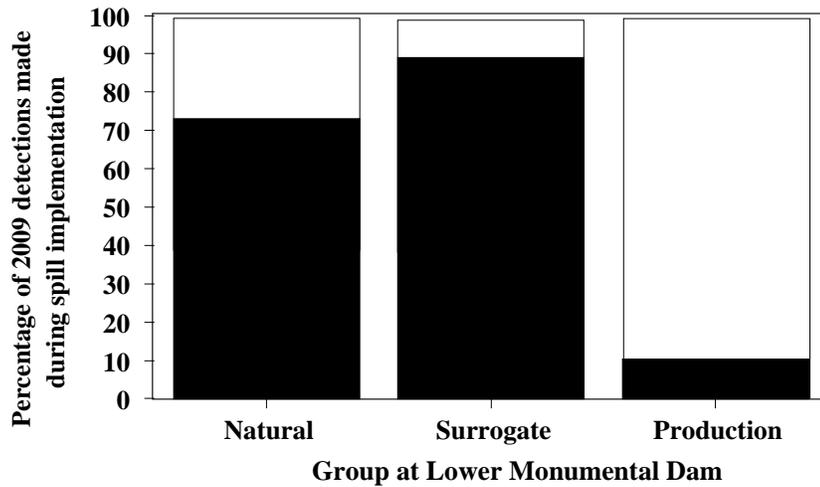
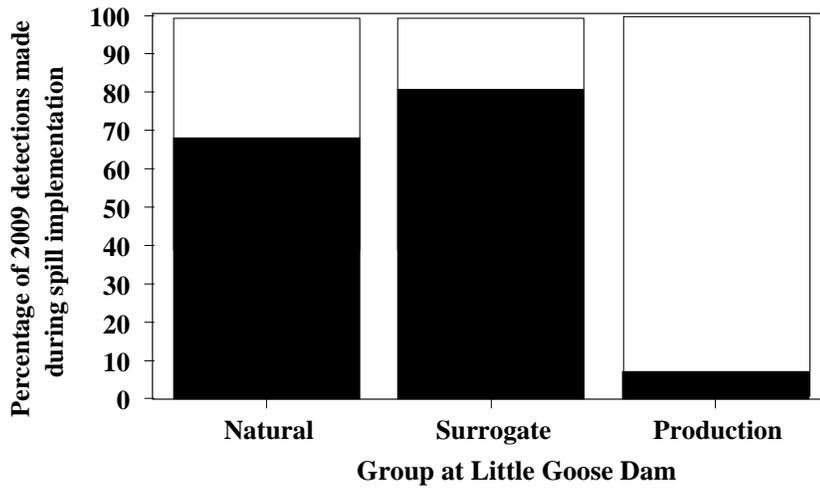
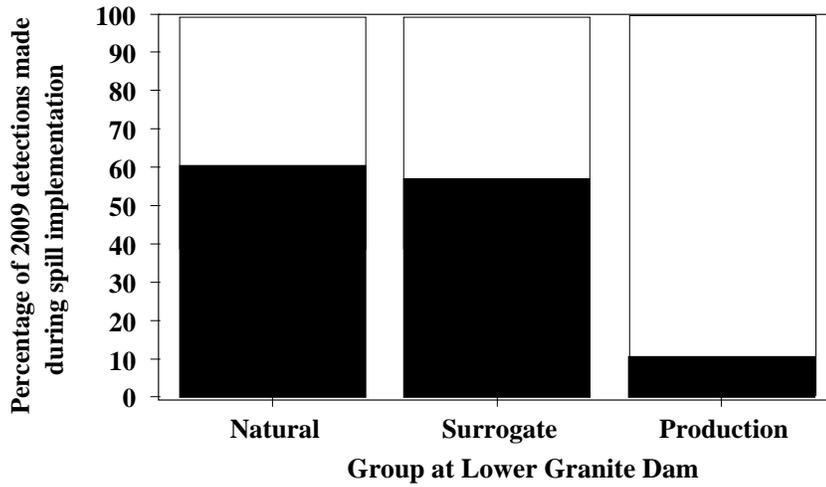


Figure 5.—The percentages of migration year 2009 detections of PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings made during summer (black portion of bar) or spring (white portion of bar) spill implementation at Lower Granite (top panel), Little Goose (middle panel), and Lower Monumental (bottom panel) dams. The number of detections for each subyearling group is given in Figure 3.

Travel Time

There was a 2-d difference in median travel time to Lower Granite Dam between Snake River natural and surrogate subyearlings in migration year 2009 (Table 2). The differences in median travel times between these two groups of subyearlings to Little Goose and Lower Monumental dams were 1 d and 0 d, respectively.

Median travel time of Snake River natural and surrogate subyearlings to Lower Granite ($P = 0.3$), Little Goose ($P = 0.5$), and Lower Monumental ($P = 0.3$) dams did not differ significantly in migration year 2009.

There was an 11-d difference in median travel time to Lower Granite Dam between Snake River natural and production subyearlings in migration year 2009 (Table 2). There were 16-d and 19-d difference in travel times between these two groups of subyearlings at Little Goose and Lower Monumental dams, respectively.

Median travel times of Snake River natural and production subyearlings to Lower Granite, Little Goose, and Lower Monumental dams differed significantly (all P values < 0.0001) in migration year 2009.

Table 2.—Number detected (*N*), median, minimum, and maximum travel time (days) from release to Lower Granite, Little Goose, and Lower Monumental dams for PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2009.

Dam	Group	<i>N</i>	Travel time		
			Median	Minimum	Maximum
Lower Granite	Natural	253	28	2	189
	Surrogate	14,749	26	1	189
	Production	17,042	17	1	129
Little Goose	Natural	276	34	5	175
	Surrogate	10,477	35	3	208
	Prods	25,261	18	1	192
Lower Monumental	Natural	130	39	9	115
	Surrogate	4,096	39	4	202
	Production	11,158	20	4	98

Migrant Size

For Snake River fish recaptured at Lower Granite Dam in migration year 2009, natural subyearlings averaged 9 mm larger in fork length than surrogates and 7 mm smaller in fork length than production subyearlings (Table 3). Natural subyearlings averaged 2 g heavier than surrogates and 1.2 g lighter than production subyearlings. Natural and surrogate subyearlings were more robustly shaped than production subyearlings when recaptured at Lower Granite Dam, but condition factor was higher for surrogate subyearlings than for natural subyearlings.

Mean fork length ($P = 0.001$) and mean weight ($P = 0.01$) differed significantly between Snake River natural and surrogate subyearlings. Condition factor did not differ significantly ($P = 0.07$) between these two groups of subyearlings. Mean fork length ($P < 0.0001$), mean weight ($P = 0.01$), and condition factor ($P = 0.01$) differed significantly between Snake River natural and production subyearlings.

Table 3.—Mean fork length (mm \pm SD), weight (g \pm SD), and condition factor ($K \pm$ SD) of PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings released in migration year 2009 and recaptured at Lower Granite Dam in migration year 2009.

Group	<i>N</i>	Recapture dates		Fork length	Weight	<i>K</i>
		Min	Max			
Natural	59	05/19	07/08	94 \pm 14	9.1 \pm 3.8	1.02 \pm 0.09
Surrogates	60	05/26	07/09	85 \pm 14	7.1 \pm 3.5	1.05 \pm 0.10
Production	160	05/27	07/09	101 \pm 8	10.3 \pm 2.4	0.98 \pm 0.09

Joint Probability of Migration and Survival

Estimates of the joint probability of migration and survival of Snake River natural subyearlings from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam, and from the tailrace of Little Goose Dam to the tailrace of Lower Monumental Dam, were imprecise (Table 4).

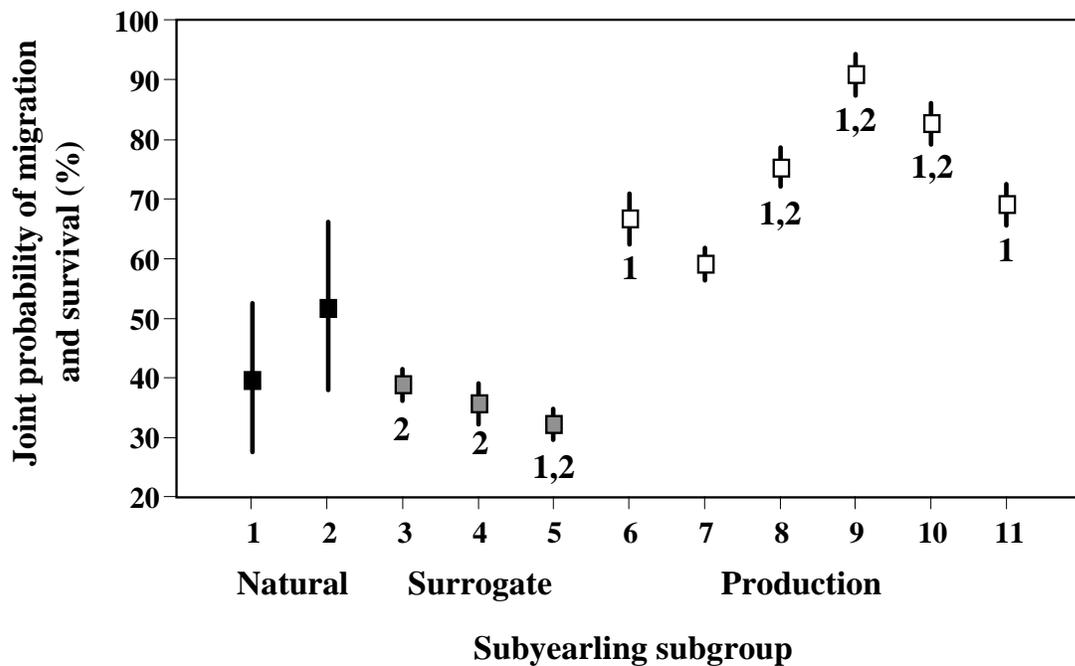
Estimated joint probability of migration and survival to the tailrace of Lower Granite Dam averaged 45.7% for natural subyearlings, 36.0% for surrogate subyearlings, and 74.1% for production subyearlings (Table 4).

Natural cohort 1 had a significantly higher joint probability of migration and survival to the tailrace of Lower Granite Dam than surrogate release 3 and natural cohort 2 had a significantly lower joint probability of migration and survival than all 3 surrogate releases (Figure 6).

The joint probability of migration and survival to the tailrace of Lower Granite Dam for all the production releases except for the Hells Canyon Dam (Umatilla hatchery) releases was significantly higher than for natural cohort 1 (Figure 6). The joint probability of migration and survival to the tailrace of Lower Granite Dam for the Pittsburg Landing, Captain John Rapids, and Couse Creek releases of production subyearlings was significantly higher than for natural cohort 2, whereas this joint probability of migration and survival was not significantly different between natural cohort 2 and the production releases made from Hells Canyon Dam (Oxbow Hatchery), Hells Canyon Dam (Umatilla Hatchery) and Cougar Creek along the Grande Ronde River.

Table 4.—Estimated joint probability of migration and survival (% ± 95% C.I.) from release to the tailrace of Lower Granite Dam (LGR), from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam (LGS), and from the tailrace of Little Goose Dam to the tailrace of Lower Monumental Dam (LMN) for PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2009. Estimates that lack accuracy, precision, or both are indicated in bold (see page 16 for criteria). The means (% ± 95% C.I.) of the individual estimates made for the period from release to the tailrace of Lower Granite Dam are also given.

Group	Subgroup	Joint probability of migration and survival		
		Release to LGR	LGR to LGS	LGS to LMN
Natural	Cohort 1	39.7 ± 12.6	78.9 ± 32.12	98.0 ± 43.7
	Cohort 2	51.8 ± 14.3	94.4 ± 37.32	70.6 ± 29.0
	Mean	45.7 ± 76.9		
Surrogate	Release 1	39.0 ± 2.0	78.1 ± 6.4	76.5 ± 9.1
	Release 2	36.1 ± 1.8	73.5 ± 6.2	84.0 ± 10.6
	Release 3	32.9 ± 1.7	75.1 ± 6.7	85.7 ± 11.9
	Mean	36.0 ± 7.5		
Production	Hells Canyon Dam (Oxbow)	66.9 ± 3.4	90.7 ± 5.8	96.6 ± 7.9
	Hells Canyon Dam (Umatilla)	59.4 ± 1.7	94.1 ± 3.6	91.1 ± 4.7
	Pittsburg Landing	75.6 ± 3.0	103.8 ± 6.1	92.7 ± 8.1
	Captain John Rapids	91.0 ± 3.4	96.7 ± 5.4	96.0 ± 8.6
	Couse Creek	82.8 ± 3.8	90.5 ± 6.5	102.0 ± 11.4
	Cougar Creek	69.2 ± 3.2	91.5 ± 7.0	83.2 ± 9.2
	Mean	74.1 ± 12.0		



Cohort 1 = 1, Cohort 2 = 2, first weekly release = 3, second weekly release = 4, third weekly release = 5, Hells Canyon Dam (Oxbow Hatchery) = 6, Hells Canyon Dam (Umatilla Hatchery) = 7, Pittsburg Landing acclimation facility = 8, Captain John Rapids = 9, Couse Creek = 10, Cougar Creek = 11

Figure 6.—Estimated joint probability of migration and survival (\pm 95% C.I.) from release to the tailrace of Lower Granite Dam for subgroups of PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2009. A “1” below an estimate for a hatchery subgroup indicates a significant difference between the subgroup and the natural subyearling subgroup cohort 1; whereas, a “2” indicates a significant difference between the hatchery subgroup and the natural subyearling subgroup cohort 2.

Overall Comparison of Attributes

The indices for Snake River fish showed greater similarity between natural and surrogate subyearlings than between natural and production subyearlings (Table 5). The largest similarity index for natural and surrogate subyearlings (a 70% difference) was for cumulative detection at Lower Monumental Dam. The largest similarity index for natural and production subyearlings was for the percentage of the PIT-tagged fish that passed during implementation of summer spill at Little Goose Dam (an 857% percent difference). Based on mean and median similarity indices calculated by dam, the level of similarity in the attributes of natural and surrogate subyearlings changed slightly as fish moved downstream (Lower Granite Dam, mean 1.1, median 1.1; Little Goose Dam, mean 1.2, median 1.2; Lower Monumental Dam, mean 1.3, median 1.2); whereas, the attributes of natural and production subyearlings became increasingly dissimilar as the fish moved downstream (Lower Granite Dam, mean 2.1, median 1.4; Little Goose Dam, mean 3.4, median 1.9; Lower Monumental Dam, mean 6.8, median 4.4). Overall, there was a 20% difference in the postrelease attributes of natural and surrogate subyearlings compared to a 290% difference between natural and production subyearlings.

Table 5.—Similarity indices (higher value divided by lower value of the attribute) for each comparison between 2009 releases of PIT-tagged Snake River natural and the two groups of hatchery fall Chinook salmon subyearlings. An index value of 1.0 would indicate no difference, while a value of 2.0 would indicate a two-fold difference. The attribute values are proportions except for migrant size (mm) and travel time (days). See page 16 for attribute descriptions.

Attribute	Attribute values		Similarity indices	Attribute values		Similarity indices
	Natural	Surrogates		Natural	Production	
Lower Granite Dam						
Cumulative detection	0.257	0.315	1.2	0.340	0.860	2.5
Peak monthly detection	0.538	0.604	1.1	0.538	0.667	1.2
2009 detection	0.996	1.000	1.0	0.996	1.000	1
Summer spill detection	0.605	0.570	1.1	0.605	0.105	5.8
Travel time	28	26	1.1	28	17	1.6
Migrant size	94	85	1.1	94	101	1.1
Migration/survival	See Table A2		1.3	See Table A2		1.6
Little Goose Dam						
Cumulative detection	0.500	0.363	1.4	0.272	0.913	3.4
Peak monthly detection	0.525	0.422	1.2	0.525	0.670	1.3
2009 detection	1.000	0.998	1.0	1.000	1.000	1.0
Summer spill detection	0.681	0.808	1.2	0.681	0.071	9.6
Travel time	34	35	1.0	34	18	1.9
Lower Monumental Dam						
Cumulative detection	0.477	0.280	1.7	0.200	0.870	4.4
Peak monthly detection	0.500	0.672	1.3	0.500	0.026	19.5
2009 detection	1.000	0.996	1.0	1.000	1.000	1.0
Summer spill detection	0.731	0.889	1.2	0.731	0.104	7.0
Travel time	39	39	1.0	39	20	2.0
Overall mean			1.2			3.9
Overall median			1.1			1.9

Objective 2: Clearwater River Comparisons

Detection Timing

On the dates of maximum differences in the migration year 2009 cumulative detection distributions (i.e., D_{\max}), the detection of Clearwater River natural subyearlings was further from completion than the detection of surrogate subyearlings at Lower Granite and Little Goose dams (Figure 7). On 11/06, when D_{\max} (11.3 percentage points) was observed at Lower Granite Dam, 47.4% of the eventual total detections of natural subyearlings had occurred, compared to 58.6% for surrogate subyearlings. On 12/05, when D_{\max} (18.2 percentage points) was observed at Little Goose Dam, 45.0% of the eventual total detections of natural subyearlings had occurred, compared to 63.2% for surrogate subyearlings. No statistical analyses were conducted with detection data collected at Lower Monumental Dam in the remainder of this report because only four Clearwater River natural subyearlings were detected at the dam 2009. Cumulative detection distributions were not significantly different between Clearwater River natural and surrogate subyearlings at Lower Granite Dam ($P = 0.7$) or Little Goose Dam ($P = 0.5$).

On the dates that D_{\max} was observed at Lower Granite and Little Goose dams, the detection of Clearwater River natural subyearlings was just beginning or had yet to begin, while the detection of production subyearlings was nearly complete (Figure 7). On 07/15, when D_{\max} (94.7 percentage points) was observed at Lower Granite Dam, 2.6% of the eventual total detections of natural subyearlings had occurred, compared to 97.3% for production subyearlings. On 07/29, when D_{\max} (98.5 percentage points) was observed at Little Goose Dam, no natural subyearlings had yet been detected, compared to 98.5% of eventual total detections for production subyearlings.

Cumulative detection distributions differed significantly between Clearwater River natural and production subyearlings at Lower Granite ($P < 0.0001$) and Little Goose ($P < 0.0001$) dams.

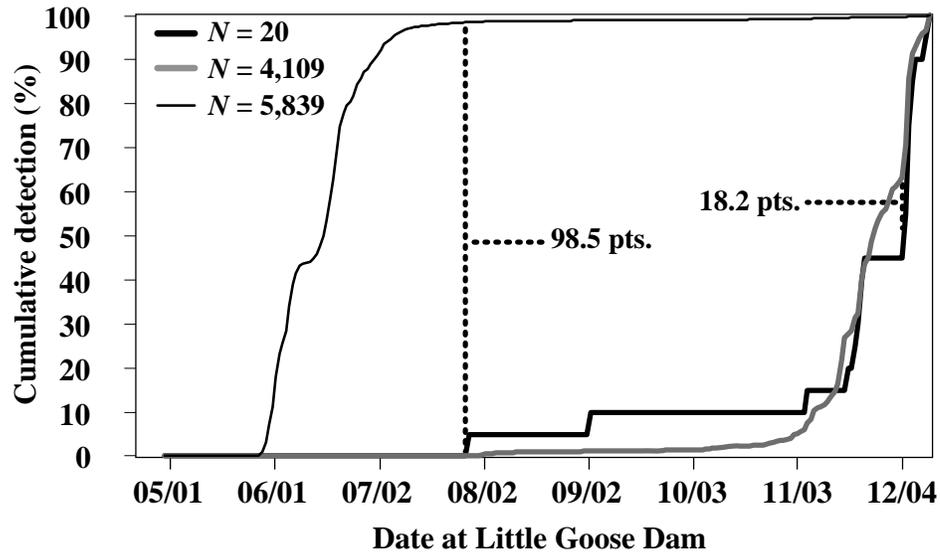
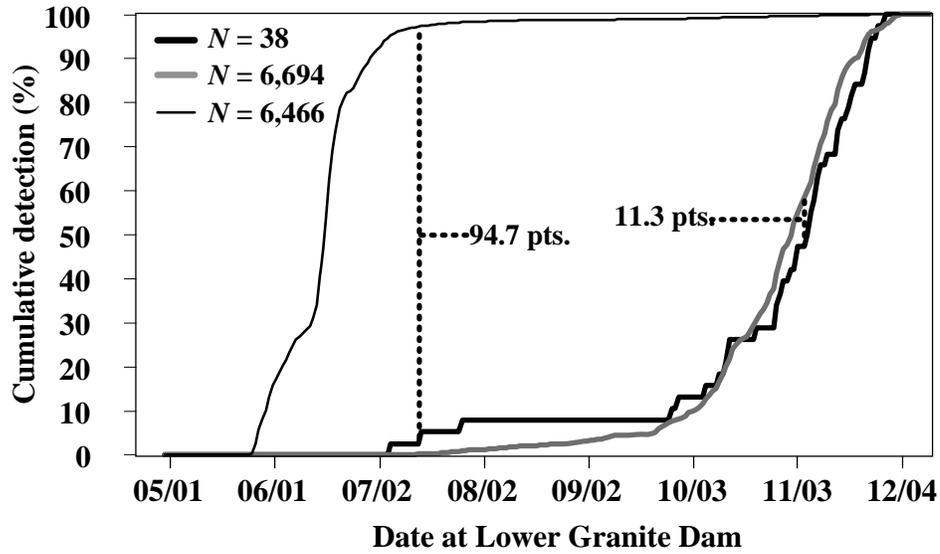


Figure 7.—Cumulative detection distributions at Lower Granite, Little Goose, and Lower Monumental dams for PIT-tagged Clearwater River natural (thick black line), surrogate (thick gray line), and production (thin black line) fall Chinook salmon subyearlings in migration year 2009. Percentage points (pts) and dotted lines indicate D_{max} values calculated as the maximum daily difference between cumulative detection distributions of natural and surrogate subyearlings, and between natural and production subyearlings.

Monthly percentages of detections at Lower Granite and Little Goose dams in migration year 2009 were generally similar between Clearwater River natural and surrogate subyearlings (Figure 8). The peak month of detection for natural (60.5%) and surrogate (51.1%) subyearlings at Lower Granite Dam was November. The peak month of detection for natural subyearlings at Little Goose Dam was December (55.0%). During December, 43.9% of the total migration year 2009 detections of surrogate subyearlings at Little Goose Dam occurred.

There were significant differences in monthly detections in migration year 2009 between Clearwater River natural and surrogate subyearlings at Lower Granite Dam (2 x 7 contingency table; P value = 0.003) and Little Goose ($P < 0.0001$) dams. Monthly detections differed significantly between the two groups of subyearlings because of significant differences (2 x 2 contingency tables) in July ($P < 0.0001$) at Lower Granite Dam and in July ($P < 0.0001$) and September ($P = 0.001$) at Little Goose Dam. Very few fish were detected during these months. See Figure 8 for an illustration of the differences in these monthly detections.

Monthly percentages of detections differed between Clearwater River natural and production subyearlings during migration year 2009 at Lower Granite and Little Goose dams (Figure 8). The peak month of detection for natural subyearlings was November (60.5%) at Lower Granite and December at Little Goose Dam (55.0%). The corresponding detection percentages for these two months and dams for production subyearlings were both 0.3%.

There were significant differences in monthly detections between Clearwater River natural and production subyearlings at both Lower Granite and Little Goose dams (2 x 7 contingency tables; both P values < 0.0001). Monthly detections differed significantly between these two groups of subyearlings primarily because of significant differences (2 x 2 contingency tables; all P values < 0.0001) in June, October, and November at Lower Granite Dam and in June, November, and December at Little Goose Dam. See Figure 8 for an illustration of the differences in these monthly detections.

Of the Clearwater River natural, surrogate and production juveniles detected during 2009–2010 at Lower Granite Dam; 2.6% of the natural, 1.2% of the surrogate, and 0.03% of the production juveniles were detected in 2010. The percentages at Little Goose Dam were 9.1% for natural juveniles, 9.2% for surrogate juveniles, and 0.17% for production juveniles. At Lower Monumental Dam, the percentages were 25.0% for natural juveniles, 25.5% for surrogate juveniles, and 0.15% for production juveniles.

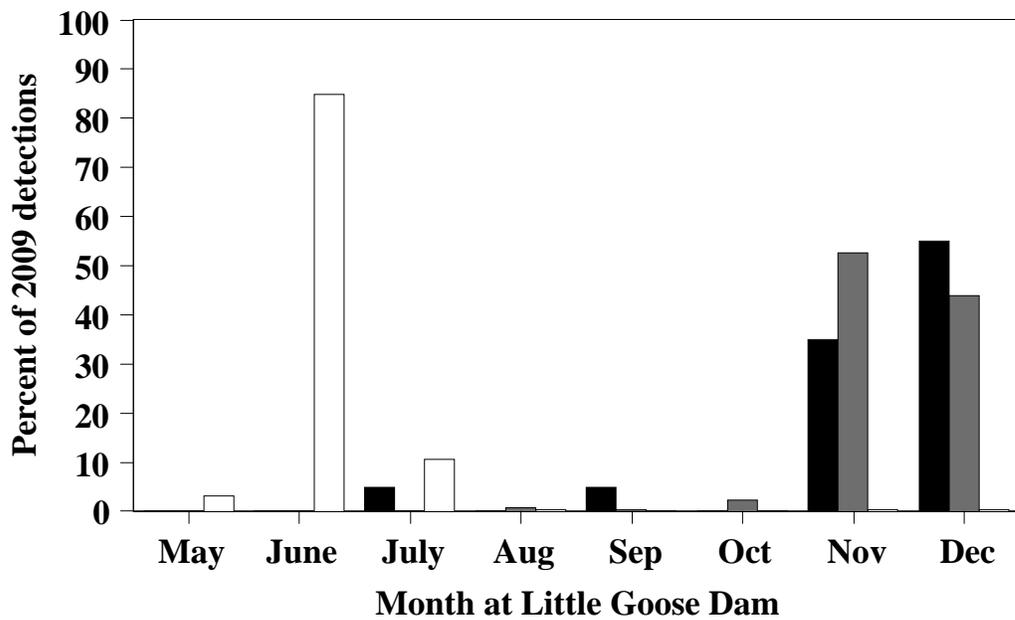
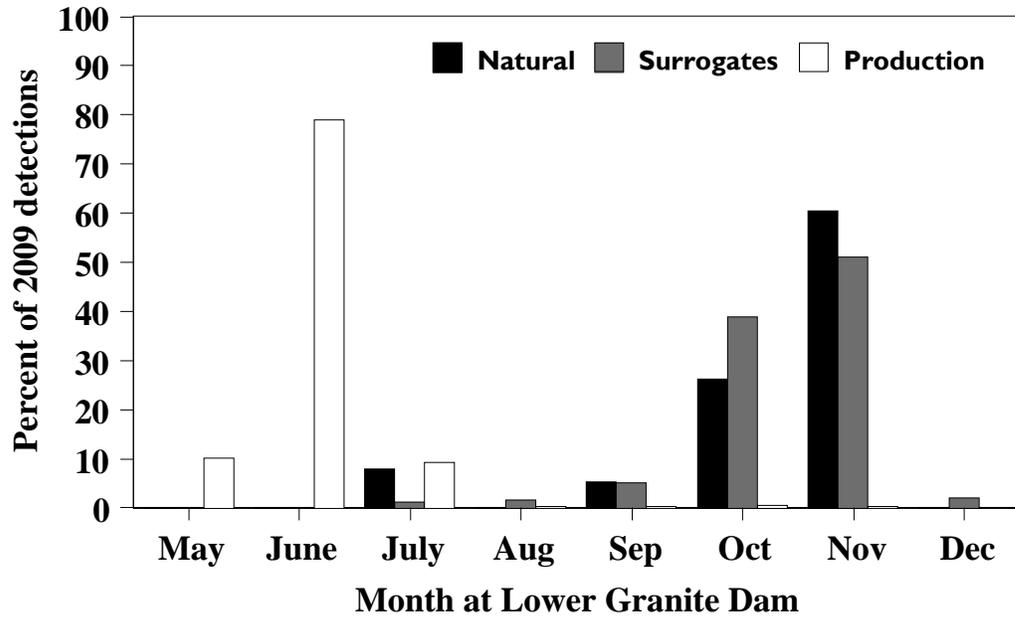


Figure 8.—Monthly percentages of the total detections made during migration year 2009 for PIT-tagged Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings. The number of detections for each subyearling group at each dam is given in Figure 7.

Detection Percentages during Spill Implementation

The percentage of the migration year 2009 detections made at Lower Granite Dam during summer spill implementation was 7.9% for Clearwater River natural subyearlings and 2.9% for Clearwater River surrogate subyearlings (Figure 9). The percentage of the migration year 2009 detections made at Little Goose Dam during summer spill implementation was 5.0% for natural subyearlings and 1.0% for surrogate subyearlings. Thus, there was a 0.08–4.0 percentage point difference between the migration year 2009 detection percentages of natural and surrogate subyearlings made during summer spill implementation.

The percentage of the migration year 2009 detections made during summer spill implementation did not differ significantly between Clearwater River natural and surrogate subyearlings at Lower Granite Dam ($P = 0.06$) or Little Goose Dam ($P = 0.07$).

The percentages of the migration year 2009 detections of Clearwater River production subyearlings made at Lower Granite and Little Goose dams during summer spill implementation were 33.8 and 40.2, respectively (Figure 9). Thus, there was a 25.9–35.2 percentage point difference between the migration year 2009 detection percentages made during summer spill implementation for natural and production subyearlings.

The percentage of the migration year 2009 detections made during implementation of summer spill was significantly lower for Clearwater River natural subyearlings than for Clearwater River production subyearlings at Lower Granite and Little Goose dams (both P values < 0.0001).

There were no detections of Clearwater River natural and surrogate subyearlings at the two dams studied during the implementation of spring spill, compared to 58.8% of detections at Lower Granite Dam and 65.0% of detections at Little Goose Dam for Clearwater River production subyearlings (Figure 9).

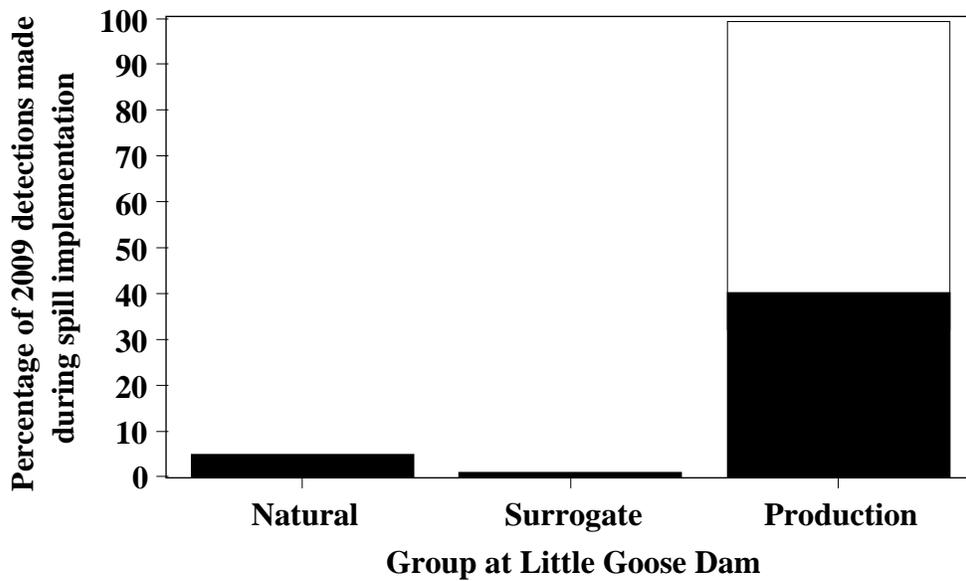
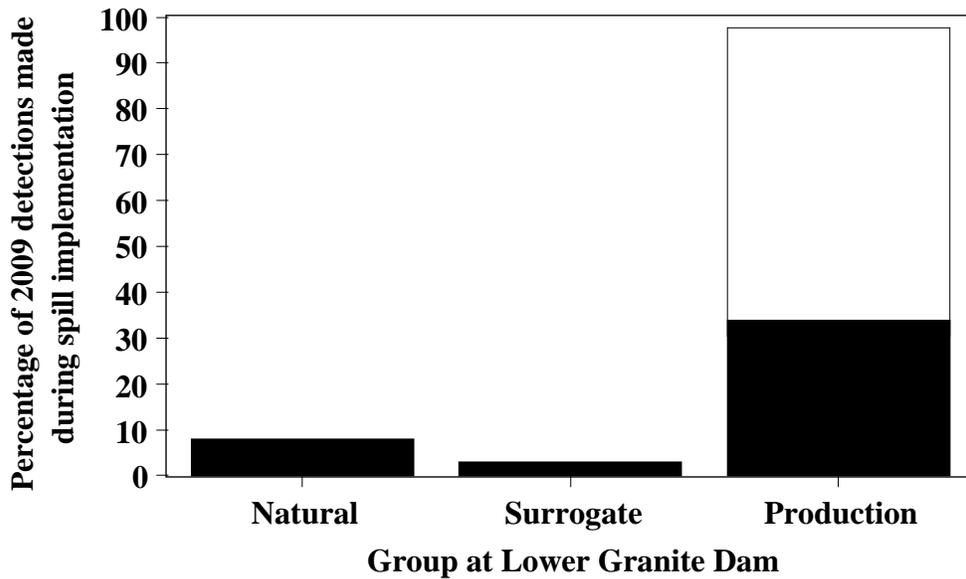


Figure 9.—The percentages of migration year 2009 detections of PIT-tagged Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings that occurred during implementation of summer spill (black portion of bar) or spring spill (white portion of bar) at Lower Granite (top panel) and Little Goose (bottom panel) dams. The number of detections for each subyearling group at each dam is given in Figure 7.

Travel Time

There was a 6-d difference in median travel time to Lower Granite Dam between Clearwater River natural and surrogate subyearlings in migration year 2009 (Table 6). The difference in travel time between these two groups of subyearlings to Little Goose Dams was 2 d.

Median travel time of Clearwater River natural and surrogate subyearlings to Lower Granite ($P = 0.2$) and Little Goose ($P = 0.7$) dams did not differ significantly in migration year 2009.

There was a 99-d difference in median travel time to Lower Granite Dam between Clearwater River natural and production subyearlings in migration year 2009 (Table 6). The difference in travel time between these two groups of subyearlings to Little Goose Dam was 127 d.

Median travel time of Clearwater River natural and production subyearlings to Lower Granite and Little Goose dams differed significantly (both P values < 0.0001) in migration year 2009.

Table 6.— Number detected (*N*) and median, minimum, and maximum travel time (days) from release to Lower Granite and Little Goose dams for PIT-tagged Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2009.

Dam	Group	<i>N</i>	Travel time		
			Median	Minimum	Maximum
Lower Granite	Natural	38	110	7	149
	Surrogate	6,694	116	7	157
	Production	4,147 ^a	11	1	179
Little Goose	Natural	20	139	35	166
	Surrogate	4,109	141	23	169
	Production	4,246 ^b	12	3	189

^aA total of 2,299 detections of production subyearlings acclimated at Lukes Gulch was removed because some fish escaped from the facility prior to forced release, thus their actual release dates are not known.

^bA total of 1,593 detections of production subyearlings acclimated at Lukes Gulch was removed because some fish escaped from the facility prior to forced release, thus their actual release dates are not known.

Joint Probability of Migration and Survival

There were too few detections downstream of Lower Granite Dam to estimate the joint probability of migration and survival of Clearwater River natural subyearlings from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam, or from the tailrace of Little Goose Dam to the tailrace of Lower Monumental Dam (Table 7). There were also problems involving sample size or precision in the estimates of the joint probability of migration and survival downstream of Lower Granite Dam for surrogate subyearlings. The estimates of the joint probability of migration and survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam for production subyearlings released at Big Canyon Creek and Lukes Gulch acclimation facilities were inaccurate.

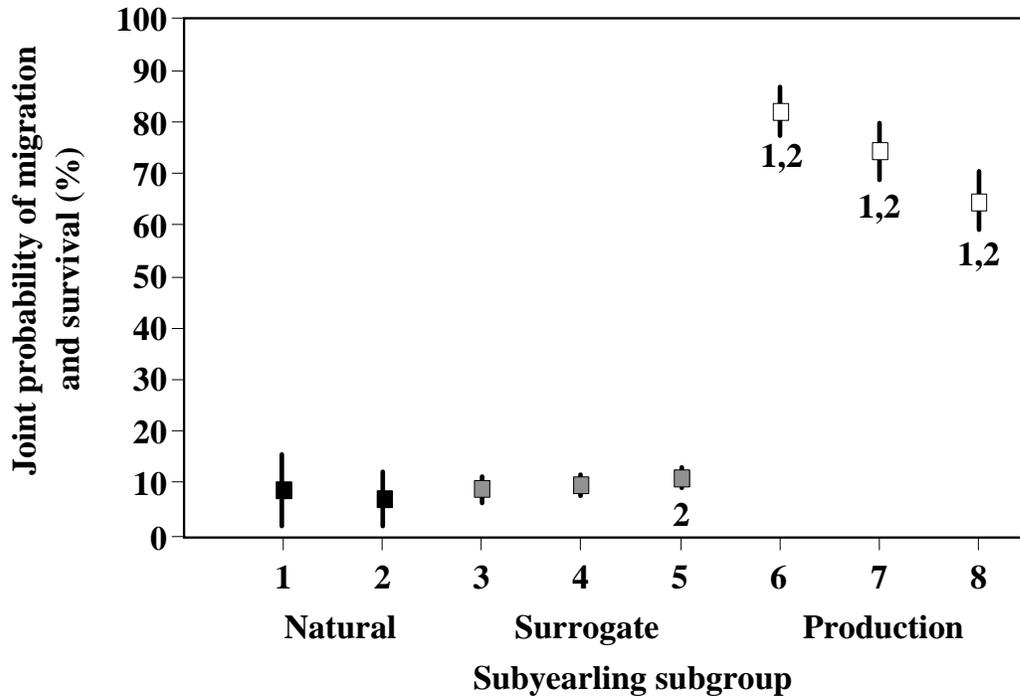
Estimated joint probability of migration and survival to the tailrace of Lower Granite Dam averaged 8.3% for natural subyearlings, 10.7% for surrogate subyearlings, and 73.7% for production subyearlings (Table 7).

Natural cohort 2 had a significantly lower joint probability of migration and survival than surrogate release 3 (Figure 10). No other comparison between natural cohorts and surrogate releases was significant.

The joint probability of migration and survival to the tailrace of Lower Granite Dam for all three production releases was significantly higher than for natural cohorts 1 and 2 (Figure 10).

Table 7.—Estimated joint probability of migration and survival ($\% \pm 95\%$ C.I.) from release to the tailrace of Lower Granite Dam (LGR), from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam (LGS), and from the tailrace of Little Goose Dam to the tailrace of Lower Monumental Dam (LMN) for PIT-tagged Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2009. Estimates that lack accuracy, precision, or both are indicated in bold (see page 16 for criteria). The means ($\% \pm 95\%$ C.I.) of the individual estimates made for the period from release to the tailrace of Lower Granite Dam are also given.

Group	Subgroup	Joint probability of migration and survival		
		Release to LGR	LGR to LGS	LGS to LMN
Natural	Cohort 1	9.3 \pm 5.1		
	Cohort 2	7.3 \pm 3.2		
	Mean	8.3 \pm 12.7		
Surrogate	Release 1	9.8 \pm 0.5	77.5 \pm 34.2	34.8 \pm 53.7
	Release 2	10.5 \pm 0.4	61.9 \pm 13.9	72.2 \pm 138.8
	Release 3	11.7 \pm 0.4		
	Mean	10.7 \pm 2.4		
Production	Big Canyon Creek	82.9 \pm 3.6	104.4 \pm 7.0	88.2 \pm 8.9
	Lukes Gulch	74.2 \pm 4.1	102.6 \pm 10.8	85.8 \pm 13.7
	Cedar Flats	63.9 \pm 4.0	89.1 \pm 10.1	88.7 \pm 15.5
	Mean	73.7 \pm 23.7		



Cohort 1 = 1, Cohort 2 = 2, first weekly release = 3, second weekly release = 4, third weekly release = 5, Big Canyon Creek = 6, Lukes Gulch = 7, Cedar Flats = 8

Figure 10.— Estimated joint probability of migration and survival from release to the tailrace of Lower Granite Dam for subgroups of PIT-tagged Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2009. A “1” below a point for a hatchery subgroup indicates a significant difference between the subgroup and the natural subyearling subgroup cohort 1; a “2” indicates a significant difference between the hatchery subgroup and the natural subyearling subgroup cohort 2.

Overall Comparison of Attributes

Similarity indices for Clearwater River fish showed greater similarity between natural and surrogate subyearlings than between natural and production subyearlings (Table 8). The lowest level of similarity between natural and surrogate subyearlings was observed for percent detection during summer spill at Little Goose Dam (a 400% difference). The lowest level of similarity between natural and production subyearlings was for peak monthly detection at Lower Granite Dam (over a 17,000% difference). Based on mean and median similarity indices calculated by dam, the level of similarity in the attributes of natural and surrogate subyearlings decreased as fish moved downstream (Lower Granite Dam, mean 1.4, median 1.2; Little Goose Dam, mean 1.9, median 1.9). Based on mean and median similarity indices calculated by dam, the level of similarity in the attributes of natural and production subyearlings also decreased as fish moved downstream (Lower Granite Dam, mean 39.8, median 9.6; Little Goose Dam, mean 41.9, median 11.6). Overall, there was a 65% difference in the postrelease attributes of natural and surrogate subyearlings compared to a 3,976% difference between natural and production subyearlings.

Table 8.—Similarity indices (higher value divided by lower value of the attribute) for each comparison between 2009 releases of PIT-tagged Clearwater River natural and the two groups of hatchery fall Chinook salmon subyearlings. An index value of 1.0 would indicate no difference, while a value of 2.0 would indicate a two-fold difference. The attribute values are proportions except for migrant size (mm) and travel time (days). See page 19 for attribute descriptions.

Attribute	Attribute values		Similarity indices	Attribute values		Similarity indices
	Natural	Surrogates		Natural	Production	
Lower Granite Dam						
Cumulative detection	0.474	0.586	1.2	0.026	0.973	37.0
Peak monthly detection	0.605	0.511	1.2	0.605	0.003	177.3
2009 detection	0.974	0.988	1.0	0.974	1.000	1.0
Summer spill detection	0.079	0.029	2.8	0.079	0.338	4.3
Travel time	110	116	1.1	110	11	10.0
Migration/survival	See Table A2		1.3	See Table A2		9.3
Little Goose Dam						
Cumulative detection	0.450	0.632	1.4	0.050	0.985	19.7 ^a
Peak monthly detection	0.550	0.439	1.3	0.550	0.003	169.0
2009 detection	0.909	0.908	1.0	0.909	0.998	1.1
Summer spill detection	0.050	0.010	5.0	0.050	0.402	8.0
Travel time	139	141	1.0	139	12	11.6
Overall mean			1.7			40.8
Overall median			1.2			10.0

^aThe day after Dmax was observed provided the data for this calculation because no natural fish were detected the day Dmax was observed.

DISCUSSION

Assumptions and Limitations

We beach seine and PIT tag natural subyearlings in the Snake and Clearwater rivers that are members of “open” populations, thus it is difficult to tell if changes in catch are related to changes in sampling efficiency or fish presence. For example, peak seine catch in the Snake River sometimes (but not always) precedes a high flow event. It is not possible to determine if such changes in catch are the result of changes in sampling efficiency, fish movement, or a combination of the two. Thus, we simply acknowledge the tag data generally represents the population rather than adjusting tagging dates with statistical models fraught with un-testable assumptions. We have also been limited in the past to tagging fish larger than 59-mm fork length. Thus, our tagging does not represent fish that disperse into the lower Snake River reservoirs at fork lengths less than 60 mm. We began tagging 50–59 mm subyearlings in the Snake and Clearwater rivers with 8.5 mm tags in 2008. We also began seining subyearlings and tagging fish ≥ 50 mm in Lower Granite Reservoir in 2009. We initiated a large-scale seining and tagging effort in Lower Granite and Little Goose reservoirs in 2010. Future analyses of these data will be informative, but were beyond the time constraints for this report.

Another limitation on our study is that we tag some natural spring Chinook subyearlings (e.g., 4% juveniles genetically sampled in 2005, 17% in 2006, 4% in 2007, and 8% in 2008; Connor, unpublished) that cannot be distinguished morphologically from natural fall Chinook salmon subyearlings. When publishing Connor et al. (2002), a reviewer suggested calling all of the fish sampled fall Chinook salmon subyearlings for the sake of simplicity because the differences in the post-release attributes of natural fall and spring lineage subyearlings were not large. Though spring lineage subyearlings migrate on an overlapping time schedule with natural subyearling fall Chinook salmon, in some years they can make up most of the larger earlier migrants that pass Lower Granite Dam in late spring (Connor et al. 2001). Thus, the presence of natural spring Chinook salmon subyearlings in the data set increases the similarity between natural and production subyearlings. Testing for differences in life history timing between natural fall and spring Chinook subyearlings will be an interesting future effort.

The potential also exists to mistakenly tag production subyearlings in the seine catch that are not externally marked or PIT tagged (e.g., 42% of the 4,000,000 released in 2009), but we do not believe this was a factor for our results for three reasons. The first reason is natural subyearlings have smaller pupils and eyes, shorter snouts, smaller head measures, deeper bodies, longer peduncles, and more posterior caudal fin insertion points on the peduncles than hatchery subyearlings even when there is no difference in size between fish of the two origins (Figure 11). We conducted blind field tests in the Snake River and our field staff correctly identified origin of inriver fish with 94% accuracy in 2001, 99% accuracy in 2002, 100% accuracy in 2003, 100% accuracy in 2004, 98% accuracy in 2005, 99% accuracy in 2006, 100% accuracy in 2007, and 96% accuracy in 2008 (Tiffan and Connor in press). The second reason is related to the spatial and

temporal nature of our sampling in the Snake River. About 1/3 of our permanent Snake River seining stations are upstream of the release points of unmarked hatchery fish and we sample these and the other permanent stations on eight separate occasions (i.e., once a week for eight weeks) prior to the release of unmarked production subyearlings. In addition, about 2/3 of the supplemental sampling is also done prior to the release of unmarked production subyearlings. Thus, we tag a large portion of the natural subyearlings destined to be tagged in a given year at locations or at times when hatchery fish are not present (2001–2008 inter-annual mean, $59 \pm 13\%$). After the hatchery releases begin, we seine and tag natural subyearlings at each supplemental stations once and the permanent stations five times (again, once per week for five weeks). In contrast to the Snake River, we begin to seine and tag natural subyearlings in the Clearwater River about the time the first releases of Clearwater River production subyearlings are made. This brings us to the third reason we do not believe our results are largely affected by incidental tagging of unmarked production subyearlings. That is, most hatchery subyearlings disperse downstream of our seining stations rapidly after release (see Smith et al. 2003 for a supporting travel time analysis). In the Snake River, known hatchery subyearlings (i.e., PIT-tagged prior to release) are only present in the catch for an average of less than 12 d (Tiffan and Connor in press) and these fish are likely stragglers based on observed travel times to Lower Granite Dam (e.g., 17 d in 2009). In the Clearwater River, Tiffan et al. (2008) found that 90-mm production subyearlings released on 05/23 near Big Canyon Creek took an average of only 0.9 ± 0.6 d to pass all of the Clearwater River seining stations and enter Lower Granite Reservoir. The fourth reason that we do not believe our results are largely affected by incidental tagging of unmarked production subyearlings is that production subyearlings are an average of at least 20-mm longer than the natural subyearlings we tag in the Snake River. In the Clearwater River, fish from the earliest production subyearlings release average over 90-mm fork length when natural fry are still emerging from the gravel and the latest production releases are made when natural parr average approximately 55 mm during this time period (Arnsberg et al. 2010).

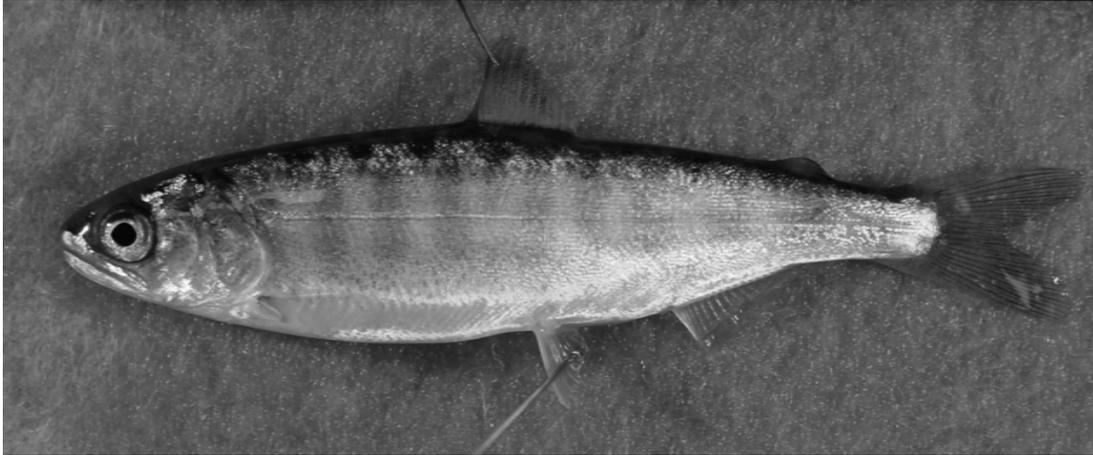


Figure 11.—An example of some of the morphological differences between rearing subyearling fall Chinook salmon of natural origin (top panel) and hatchery origin (bottom panel). Both fish were 70 mm fork length. From Tiffan and Connor (in press).

When estimating daily passage for each PIT-tagged group of subyearlings, we assumed that the bypass probability model fitted with data collected on 95–157 mm radio-tagged subyearlings could be used to predict bypass probability for 60–125-mm PIT tagged subyearlings. Plumb et al. (2010) compared daily passage estimates of PIT-tagged subyearlings made with their model to daily passage estimates made for the same PIT-tagged subyearlings with the Sandford and Smith (2002) model. The differences in daily passage estimates made with the two models could not be traced to fish size. However, the correlation coefficient between estimated bypass probabilities from the two models was only 0.71, and others have found that fish size can affect bypass probability depending on year (for yearling Chinook salmon and steelhead *O. mykiss* at Little Goose and Lower Monumental dams; Zabel et al. 2008). Thus, fish size might account for some of the difference between the two models. In past reports, we stopped reporting passage indices for the PIT-tagged groups of subyearlings at Little Goose and Lower Monumental dams because supplying PIT-tag detection systems with water for only part of each year biased the detection probability estimates. We have suggested that supplying water to the PIT-tag detection systems in the lower Snake River, or at least synchronizing when the water is supplied, would improve the ability to estimate detection probability. The Corps maintained water supplies in the PIT-tag detection systems of Lower Granite Dam through 12/05/2009, Little Goose and Lower Monumental dams through 12/16/2009, and through the winter at Ice Harbor Dam. Evaluating the efficacy of extended water up of the PIT-tag detection systems is beyond the scope of this report. However, the 2009 data set will help to identify, test, and select the most accurate and precise methods for estimating bypass probability for future evaluations of dam passage experiences.

When comparing postrelease attributes, we used the unexpanded detection data. We assumed that daily change in percent spill at the dams was not the sole factor for differences observed between natural subyearlings and the two hatchery subyearling groups. We believe the detection data met this assumption. Given two groups of subyearlings with similar or identical passage timing, a violation of this assumption would require some variation of this unlikely example: (1) during time t natural subyearlings passed the dams via the juvenile bypass and PIT-tag detection systems and production subyearlings passed under the submersible traveling screens or over the spillways and (2) during time $t + 1$ production subyearlings passed the dams via the juvenile bypass and PIT-tag detection systems and natural subyearlings passed under the submersible traveling screens or over the spillways. The large decrease in percent spill observed after 08/31/2009 undoubtedly exaggerated the difference between the postrelease attributes of Clearwater River natural and production subyearlings. However, large differences in the postrelease attributes of Clearwater River natural and production subyearlings were inevitable because Clearwater River production subyearlings were released at fork lengths averaging over 90 mm when natural fish usually average around 55 mm during this time period (Arnsberg et al. 2010).

Objectives 1 and 2

The first objective of this report was to construct estimates of total daily passage (passage indices) at Lower Granite Dam for PIT-tagged natural, surrogate, and production juveniles. We found that many PIT-tagged natural, surrogate, and production subyearlings passed Lower Granite Dam in June, but natural and surrogate subyearlings passed later in June than production subyearlings. Moreover, passage of PIT-tagged natural and surrogate juveniles at Lower Granite Dam extended from spring 2009 to spring 2010, while passage of production subyearlings was essentially complete by the end of July 2009. This difference in passage timing reflects differences in juvenile life history and is the cumulative product of differences in rearing environment, growth, migration rate, migrational behavior, survival, and seasonal changes in the environment.

The second objective of this report was to compare the postrelease performance of 2009 releases of natural subyearlings to the postrelease performance of 2009 releases of surrogate and production subyearlings for fish from the Snake River and for fish from the Clearwater River. This objective further illuminated differences and similarities observed at Lower Granite Dam between natural subyearlings and the two hatchery subyearling groups. We found that there was an overall difference of 20% in the postrelease attributes of Snake River natural and surrogate subyearlings compared to a 290% difference between Snake River natural and production subyearlings. We also found that there was an overall difference of 65% in the postrelease attributes of Clearwater River natural and surrogate subyearlings compared to a 3,976% difference between Clearwater River natural and production subyearlings.

Consistent with our 2005, 2006, and 2008 findings (Connor et al. 2008a,b, 2009) (the study was not conducted in 2007), we conclude the postrelease attributes measured on 2009 releases were more similar between Snake River and Clearwater River natural and surrogate subyearlings than between natural and production subyearlings from these two rivers. Consistent with the consensus proposal of Marsh et al. (2007b), we recommend providing (1) surrogate subyearlings for five release years to evaluate the response of natural subyearlings to dam passage strategies and (2) production subyearlings for five release years to evaluate the response of production subyearlings to dam passage experiences and to evaluate supplementation. As of the writing of this report in 2010, we have made one pilot release of surrogate subyearlings in 2005, four full-scale releases of surrogate subyearlings (2006, 2008, 2009, 2010), one pilot release of production subyearlings in 2006, and three full-scale releases of production subyearlings (2008, 2009, 2010). The consensus study design (Marsh et al 2007), considers 2006 as the first official release year. As such, one more release year of surrogate and production subyearlings (2011) remains to be implemented. Future consideration for additional releases in 2012 through 2016 will be based on preliminary results of 2005 to 2009 releases.

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Table A1.—Approximate number of production fall Chinook salmon subyearlings released at each site (*N*), percent of total release, number PIT tagged (*n*), and percent of PIT-tagged release in 2009. * = PIT tagged as part of a separate study.

River	Site	Total release		PIT-tagged release	
		<i>N</i>	%	<i>n</i>	%
Snake	Hells Canyon Dam	1,006,324	21%	70,332	38%
	Pittsburg Landing	415,991	9%	13,777	7%
	Captain John Rapids	524,910	11%	13,831	7%
	Couse Creek	200,744	4%	13,740	7%
	Cougar Creek	622,450	13%	27,764	15%
Clearwater	Big Canyon Creek	474,868	10%	13,763	7%
	Lukes Gulch	209,878	4%	14,006	7%
	Cedar Flats	200,098	4%	13,941	7%
	NPTH*	628,815	13%	2,963	2%
	North Lapwai Valley*	495,569	10%	2,983	2%
Totals		4,779,647		187,100	

Table A2.—Calculating similarity indices for comparing the joint probability of migration and survival (%) from release to the tailrace of Lower Granite Dam between PIT-tagged Snake and Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2009. The mean index was used in Tables 5 and 8.

Group	Subgroup	Joint probability of migration and survival	Similarity indices		Mean index
			vs. cohort 1	vs. cohort 2	
Snake River					
Natural	Cohort 1	39.7			
	Cohort 2	51.8			
Surrogate	Release 1	39.0	1.0	1.3	1.3
	Release 2	36.1	1.1	1.4	
	Release 3	32.9	1.2	1.6	
Production	Hells Canyon	66.9	1.7	1.3	1.6
	Hells Canyon	59.4	1.5	1.1	
	Pittsburg Landing	75.6	1.9	1.5	
	Captain John Rapids	91.0	2.3	1.8	
	Couse Creek	82.8	2.1	1.6	
	Cougar Creek	69.2	1.7	1.3	
Clearwater River					
Natural	Cohort 1	9.3			
	Cohort 2	7.3			
Surrogate	Release 1	9.8	1.0	1.3	1.3
	Release 2	10.5	1.1	1.4	
	Release 3	11.7	1.2	1.6	
Production	Big Canyon	83.7	9.0	11.4	9.3
	Lukes Gulch	74.7	8.0	10.2	
	Cedar Flats	70.4	7.5	9.6	

REFERENCES

- Arnsberg, B. D., and D. P. Statler. 1995. Assessing summer and fall Chinook salmon restoration in the Upper Clearwater River and principal tributaries. Nez Perce Tribe Department of Fisheries Resources Management 1994 Annual Report to the U.S. Department of Energy, Bonneville Power Administration, Project No. 94-034, 67 electronic pages (BPA Report DOE/BP-12873-1).
- Arnsberg, B.D., D.S. Kellar, and M.A. Tuell. 2010. Nez Perce Tribal Hatchery monitoring and evaluation of fall Chinook salmon supplementation in the Clearwater River Subbasin. 2008 Annual Report to the U.S. Department of Energy, Bonneville Power Administration, Project No. 1983-350-003.
- Banks, J. L. 1994. Raceway density and water flow as factors affecting spring Chinook salmon (*Oncorhynchus tshawytscha*) during rearing and after release. *Aquaculture* 119:201-217.
- Connor, W. P., H. L. Burge, and D. H. Bennett. 1998. Detection of subyearling Chinook salmon at a Snake River dam: Implications for summer flow augmentation. *North American Journal of Fisheries Management* 18:530-536.
- Connor, W. P., R. K. Steinhorst, and H. L. Burge. 2000. Forecasting survival and passage for migratory juvenile salmonids. *North American Journal of Fisheries Management* 20:650-659.
- Connor, W.P., T. C. Bjornn, H. L. Burge, A. R. Marshall, H. L. Blankenship, R. K. Steinhorst, and K. F. Tiffan. 2001. Early life history attributes and run composition and of wild subyearling Chinook salmon recaptured after migrating downstream past Lower Granite Dam. *Northwest Science* 75:254-261.
- Connor, W. P., H. L. Burge, R. Waite, and T. C. Bjornn. 2002. Juvenile life history of wild fall Chinook salmon in the Snake and Clearwater rivers. *North American Journal of Fisheries Management* 22:703-712.
- Connor, W. P., C. E. Piston, and A. P. Garcia. 2003a. Temperature during incubation as one factor affecting the distribution of Snake River fall Chinook salmon spawning areas. *Transactions of the American Fisheries Society* 132:1236-1243.

- Connor, W. P., H. L. Burge, J. R. Yearsley, and T. C. Bjornn. 2003b. The influence of flow and temperature on survival of wild subyearling fall Chinook salmon in the Snake River. *North American Journal of Fisheries Management* 23:362-375.
- Connor, W. P., R. K. Steinhorst, and H. L. Burge. 2003c. Migrational behavior and seaward movement of wild subyearling fall Chinook salmon in the Snake River. *North American Journal of Fisheries Management* 23:414-430.
- Connor, W. P., S. G. Smith, T. Andersen, S. M. Bradbury, D. C. Burum, E. E. Hockersmith, M. L. Schuck, G. W. Mendel, and R. M. Bugert. 2004. Post release performance of hatchery yearling and subyearling fall Chinook salmon released into the Snake River. *North American Journal of Fisheries Management* 24:545-560.
- Connor, W. P., J. G. Sneva, K. F. Tiffan, R. K. Steinhorst, D. Ross. 2005. Two alternative juvenile life histories for fall Chinook salmon in the Snake River basin. *Transactions of the American Fisheries Society* 134:291-304.
- Connor, W. P. B. D. Arnsberg, S. G. Smith, D. M. Marsh, and W. D. Muir. 2008a. 2005 Post-release performance of natural and hatchery subyearling fall Chinook salmon in the Snake and Clearwater rivers. Report of the U. S. Fish and Wildlife Service, Nez Perce Tribe, and National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.
- Connor, W. P. B. D. Arnsberg, S. G. Smith, D. M. Marsh, and W. D. Muir. 2008b. 2006 Post-release performance of natural and hatchery subyearling fall Chinook salmon in the Snake and Clearwater rivers. Report of the U. S. Fish and Wildlife Service, Nez Perce Tribe, and National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.
- Connor, W. P. B. D. Arnsberg, S. G. Smith, D. M. Marsh, and W. D. Muir. 2009. 2008 Post-release performance of natural and hatchery subyearling fall Chinook salmon in the Snake and Clearwater rivers. Report of the U. S. Fish and Wildlife Service, Nez Perce Tribe, and National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.
- Cormack, R. M. 1964. Estimates of survival from the sightings of marked animals. *Biometrika* 51:429-438.
- Daniel, W. W. 1978. *Applied non-parametric statistics*. Houghton Mifflin Company. Boston, Massachusetts.

- Downing, S. L., E. F. Prentice, R. W. Frazier, J. E. Simonson, E. P. Nunnallee. 2001. Technology developed for diverting passive integrated transponder (PIT) tagged fish at hydroelectric dams in the Columbia River Basin. *Aquacultural Engineering* 25:149-164.
- Ewing, R. D., and S. K. Ewing. 1995. Review of the effects of rearing density on survival to adulthood for Pacific Salmon. *Progressive Fish-Culturist* 57:1-25.
- ICTRT (Interior Columbia River Basin Technical Recovery Team). 2007. Review draft: Viability criteria for application to interior Columbia Basin ESUs. Available at www.nwfsc.noaa.gov/trt/trt_documents/ictrt_viability_criteria_reviewdraft_2007_complete.pdf
- Lowther, A. B., and J. R. Skalski. 1998. A multinomial likelihood model for estimating survival probabilities and overwintering for fall Chinook salmon using release-recapture methods. *Journal of Agricultural, Biological, and Environmental Statistics* 3:223-236.
- McCutcheon, S. and R. Richmond. 2008. PIT-tagging subyearling production and surrogate groups of Snake River fall Chinook salmon to evaluate the responses of Snake and Columbia River basin fall Chinook salmon to dam passage strategies and experiences. Report of BioMark to the U.S. Army Corps of Engineers, Walla Walla, Washington.
- McLeod, B. 2006. Fall Chinook acclimation project; Pittsburg Landing, Captain John Rapids, and Big Canyon. Nez Perce Tribe Department of Fisheries Resources Management 2005 Annual Report to the U.S. Department of Energy, Bonneville Power Administration, Project No. 199801005, 41 electronic pages (BPA Report DOE/BP-00004235-7).
- Marsh, D. M., G. M. Matthews, S. Achord, T. E. Ruehle, and B. P. Sandford. 1999. Diversion of salmonid smolts tagged with passive integrated transponders from an untagged population passing through a juvenile collection system. *North American Journal of Fisheries Management* 19:1142-1146.
- Marsh D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, W. D. Muir, and W. P. Connor. 2007a. A study to understand the early life history of Snake River Basin fall Chinook salmon. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

- Marsh, D. M., W. D. Muir, W. P. Connor, J.A. Hesse, and S. L. Haeseker. 2007b. Evaluating the responses of Snake and Columbia River Basin fall Chinook salmon to Dam passage strategies and experiences. A consensus proposal available from william_connor@fws.gov.
- Martin, R. M., and A. Wertheimer. 1989. Adult production of Chinook salmon reared at different densities and released at two smolt sizes. *Progressive Fish-Culturist* 51:194-200.
- Plumb, J. M., C. M. Moffitt¹, W. P. Connor, K. F. Tiffan, R. W. Perry, N. S. Adams, and D. W. Rondorf. 2010. Modeling detection probability of juvenile salmon at a dam to improve abundance and run-timing estimation. Chapter 1 *in* K. F. Tiffan and W. P. Connor, editors. Project 199102900 2008 annual report to the Bonneville Power Administration.
- Piper, R. G., I. B. McElwain, L. E. Orme, J. P. McCraren, L. B. Fowler, and J. R. Leonard. 1982. *Fish Hatchery Management*. U.S. Department of the Interior Fish and Wildlife Service, Washington D. C.
- Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990a. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. *American Fisheries Society Symposium* 7:317-322.
- Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. *American Fisheries Society Symposium* 7:323-334.
- PTAGIS (Columbia Basin PIT Tag Information System). 2008. Pacific States Marine Fisheries Commission, Portland, Oregon. Available: www.ptagis.org. (June 2008).
- Sandford, B.P., and S.G. Smith. 2002. Estimation of Smolt-to-Adult Return Percentages for Snake River Basin Anadromous Salmonids, 1990-1997. *Journal of Agricultural, Biological, and Environmental Statistics* 7:243-263.
- Skalski, J. R., S. G. Smith, R. N. Iwamoto, J. G. Williams, and A. Hoffman. 1998. Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia rivers. *Canadian Journal of Fisheries and Aquatic Sciences* 55:1484-1493.
- Smith, S. G., W. D. Muir, E. E. Hockersmith, R.W. Zabel, R. J. Graves, C. V. Ross, W. P. Connor, and B. D. Arnsberg. 2003. Influence of river conditions on survival and travel time of Snake River subyearling fall Chinook salmon. *North American Journal of Fisheries Management* 23: 939-961.

Tiffan, K. F., and W. P. Connor. 2005. Investigating passage of ESA-listed juvenile fall Chinook salmon at Lower Granite Dam during winter when the fish bypass system is not operated. 2004 Annual report to the Bonneville Power Administration for project 200203200.

Tiffan, K. F., and W. P. Connor. In press. Distinguishing between natural and hatchery Snake River fall Chinook salmon subyearlings in the field using body morphology. Accepted for publication in Transactions of the American Fisheries Society, September 2010.

Zabel, R. W., T. Wagner, J. L. Congleton, S. G. Smith and J. G. Williams. 2008. Survival and Selection of migrating Salmon from Capture-Recapture models with individual traits. *Ecological Applications*, 15(4), 2005, pp. 1427-1439