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

William P. Connor,[1] Billy D. Arnsberg,[2] Steven G. Smith,[3] Douglas M. Marsh,[3] and William D. Muir[3]

2010 Annual Report of Research by

[1]Idaho Fisheries Resource Office, United States Fish and Wildlife Service
Post Office Box 18
Ahsahka, Idaho 83520

[2]Nez Perce Tribe Department of Fisheries Resources Management
Orofino Field Office, 3404 Highway 12
Orofino, Idaho 83544

[3]National Marine Fisheries Service, Northwest Fisheries Science Center, Fish Ecology Division, 2725 Montlake Boulevard East,
Seattle, Washington 98112-2987

to

U.S. Army Corps of Engineers
Walla Walla District
201 North 3rd
Walla Walla, Washington 99362-1876

U. S. Department of Energy
Bonneville Power Administration
Environment, Fish, and Wildlife Department
P.O. Box 3621
Portland, Oregon 97208-3621
Projects 1983350003, 199102900, and 199801004

July 29, 2011

CONTENTS

2010 IMPLEMENTATION SUMMARY

In 2010, 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 return rates. 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 2010 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 2010 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 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 2010 releases of natural subyearlings to the postrelease performance of 2010 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 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 return rates. 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. Return rates are not reported here, but will be presented in future reports written after workshops, input by federal, state, and tribal researchers, and after adult returns are complete.

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 or migration tactic is important to adult returns and is most prevalent among fall Chinook salmon from the Clearwater 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 is critical to recovery of the population. Two analytical approaches are proposed for monitoring and evaluating this response. Both approaches require implanting large numbers of subyearlings with passive integrated transponder (PIT) tags (Prentice et al. 1990a) to precisely estimate return ratios of treatment groups. Each approach has its merits and limitations. The first approach was developed specifically for Snake River Basin fall Chinook salmon (Marsh and Connor 2004). This approach involves comparing two groups of fish that are released upstream of Lower Granite Reservoir (Figure 1), but whose treatment at collector dams differs in an effort to represent two different management strategies: transportation with inriver migration (TWI) and bypass with inriver migration (BWI). Fish from the TWI group would be transported if they are detected at a collector project (Lower Granite, Little Goose, Lower Monumental and McNary dams; Figure 1) and fish from the BWI group would be bypassed if they are detected at a collector project. For both the TWI and BWI release groups, substantial numbers of fish in each group will not be detected (Prentice et al. 1990b) at any of the four collector projects due to the effectiveness of summer spill and winter passage by reservoir-type juveniles. These fish pass undetected because spillways are not equipped with PIT-tag detection systems and the juvenile fish bypass and PIT-tag detection systems are not watered up during winter. Using this approach for fall Chinook salmon populations that enter the ocean as yearlings after wintering in reservoirs or the Columbia River estuary is attractive as it requires few assumptions about their fate since they are common to both the TWI and BWI groups. However, because both groups will have adults from undetected migrants returning, their return rates will be more similar and detecting a significant difference between the TWI and BWI groups will be more difficult.

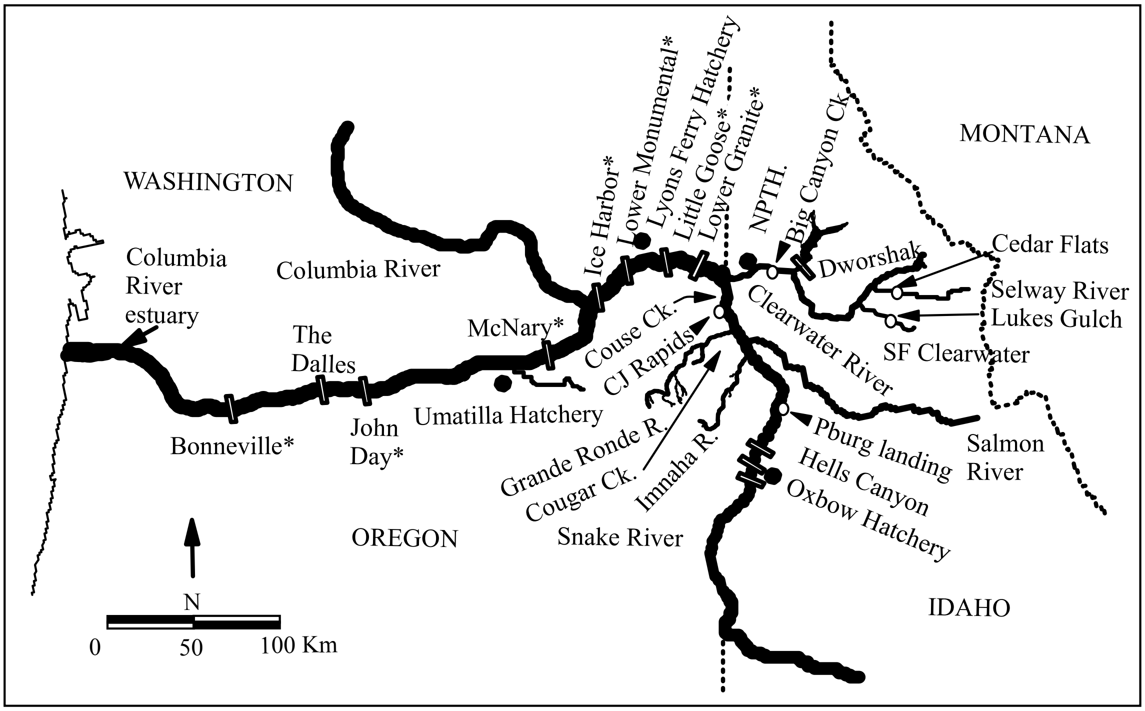

Figure 1.—The four major spawning areas of Snake River Basin fall Chinook salmon upstream of Lower Granite Reservoir are the Snake River upper reach (Hells Canyon Dam to Salmon River); Snake River lower reach (Salmon River to upper end of Lower Granite Reservoir); lower 83 km of the Grande Ronde River; 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.

The second analytical approach proposed for monitoring and evaluating Snake River Basin fall Chinook salmon was developed by Schaller et al. (2007) for spring/summer Chinook salmon and steelhead (*O. mykiss*). This approach also involves PIT-tagged fish released upstream of Lower Granite Reservoir, but compares groups of juvenile migrants based on their passage experience at the dams. The three possible passage experiences for these fish are determined from the PIT-tag detection data and include: transportation from a collector dam ("T0" group); passage undetected through spillways and turbines, but not through juvenile collection and bypass systems at all four collector dams ("C0" group); and collection and bypass back to the river at one or more juvenile fish bypass systems at collector dams ("C1" group). The merit of this approach is that it provides unbiased estimates of the number of smolts in the C0, C1, and T0 study groups provided the fish are active seaward migrants. However, the ability to apply this approach to groups of PIT-tagged fish that include individuals that pass upstream dams during late fall as the PIT-tag detection systems at downstream dams are being dewatered (causing problems estimating essential model parameters) and the winter (when essential detection data is missing) is currently the subject of debate.

The Nez Perce Tribe, National Oceanographic and Atmospheric Administration Fisheries, and the U.S. Fish and Wildlife Service in cooperation with parties throughout the Pacific Northwest developed the consensus research proposal: Evaluating the Responses of Snake and Columbia River Basin Fall Chinook Salmon to Dam Passage Strategies and Experiences (Marsh et al. 2007b). This consensus proposal outlines the release of surrogate subyearlings to evaluate the TWI and BWI management strategies. The surrogate rearing strategy involves controlling incubation rate of hatchery fish at Irrigon Hatchery and growth at Dworshak National Fish Hatchery (Figure 1) to match natural subyearlings in size at release as closely as possible (70-75 mm fork length), while insuring that all of the surrogate subyearlings are large enough for tagging (i.e., 60-mm fork length). Surrogate subyearlings are PIT tagged and then trucked for release late May to early July at Couse Creek and Big Canyon Creek (Figure 1) to coincide with the historical period of peak beach seine catch of natural parr in the Snake and Clearwater rivers. The consensus proposal also outlines the release of PIT-tagged production subyearlings to evaluate the C0, C1, and T0 passage experiences. Culturing production subyearlings involves controlling 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 (Figure 1) before release from May to June. Production subyearlings share the migrational and survival characteristics of yearling spring Chinook salmon for which the second analytical approach to evaluate passage experience was developed.

We made pilot releases of surrogate subyearlings into the Snake and Clearwater rivers in 2005 and full-scale releases in 2006, 2008, and 2009. We made pilot releases of production subyearlings in 2006 and full-scale releases in 2008 and 2009. We will wait to report return rates from these releases until after we have complete returns of full-term adults (Marsh et al. 2007b). In 2010, we made the fourth full-scale release of PIT-tagged surrogate subyearlings and the third full-scale release of PIT-tagged production subyearlings. Though the consensus research proposal aligned study designs with specific subyearling groups, more information on life history of the surrogate and production subyearlings was needed to develop and select the final methods for data analysis.

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 2010 releases of natural subyearlings to the postrelease performance of 2010 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 apparent juvenile reach 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 return rates of surrogate and production subyearlings. The overall premise of this work was the data collected on a particular group of surrogate subyearlings might fit the passage experience modeling approach if the group was not present in reservoirs during late fall with few fish passing dams during winter when the PIT-tag detection systems at dams were not supplied with water.

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 the week of 03/21 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. No fish were captured the week of 07/27 and sampling was discontinued.

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 2011). 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 50–59-mm and 60-mm and longer were implanted with 8.5 and 12.5-mm PIT tags, respectively, 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 6/28 thru 8/17 along the lower Clearwater River from rkm 2 to 53 (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. One 2.4 m diameter rotary screw trap was suspended from the Spalding railroad bridge along the north shoreline at rkm 20 from 6/21 to 8/2 to catch additional subyearlings. Catch neared zero the third 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 2010 releases of Snake River surrogate subyearlings was coordinated under *U.S. v. Oregon*. In December 2009, roughly 215,000 eyed eggs were transferred from Lyons Ferry Hatchery to Irrigon Hatchery where they were incubated in well water. The incubation and feeding regimes were adjusted to produce fish that were about 300 per pound for transport to Dworshak National Fish Hatchery on 04/03/2010. In March 2010, siblings of the fish transferred to Irrigon Hatchery that remained at Lyons Ferry Hatchery were randomly selected and examined them for *Renibacterium salmoninarum* antigen by enzyme-linked immunosorbent assay (ELISA). In addition, 60 fish were randomly sampled at Irrigon Hatchery and 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.

Trucking was delayed due to a scheduling problem. We transported the Snake River surrogates (roughly 213,000) to Dworshak National Fish Hatchery on 04/14/2010 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-m^3 raceway supplied with 6.0°C water at approximately 1,136 L/min. The subyearlings were 282 fish per pound (about 54-mm FL). Starting fish density in the raceway was 6.7 kg/m^3. Fish were initially fed No. 2 crumb starter feed. Feed size was increased to No. 2 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. Maximum density throughout rearing was approximately 9.0 kg/m^3 just prior to splitting, well below densities reported to adversely affect adult returns of Chinook salmon (see Martin and Wertheimer 1989; Banks 1994; Ewing and Ewing 1995). 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 48 h before tagging. Final rearing density in the raceways before tagging ranged from 5.0 to 6.0 kg/m^3. Temperatures in the raceways during tagging ranged from 7.0 to 8.0°C. Tagging began on 5/17 and was conducted daily during three periods; 05/17–05/21, 05/24–05/28, and 05/31–06/04. 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 (approximate range, 10.0–12.0°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 overall pre-release mortality rate was 0.01%. The tank was inspected for shed tags after fish were released. The overall shedding rate was 0.02%.

Clearwater River.—Acquisition of Lyons Ferry Hatchery subyearlings for 2010 releases of Clearwater River surrogate subyearlings was coordinated under *U.S. v. Oregon*. In December 2009 roughly 107,000 eyed eggs were transferred from Lyons Ferry Hatchery to Irrigon Hatchery where they were incubated in chilled well water. The incubation and feeding regimes were adjusted to produce about 354 fish per pound for transport to Dworshak National Fish Hatchery on 04/03/2010. In March 2010, we conducted disease sampling as described for Snake River surrogates. 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 04/03/2010 using a truck equipped with a 7,500-L tank and fry transport cylinders. Oxygen in the tank was kept near 100% saturation during the 4-h trip. Loading density in the cylinders was 0.004 kg/L. Upon arrival at Dworshak National Fish Hatchery, the subyearlings were piped from the tank into a 36-m^3 raceway supplied with 6.0°C water at approximately 1,136 L/min. The number of fish per pound was 354 (about 40-mm FL). The initial rearing density was 11.3 kg/m^3 and the fish were split into three raceways as they grew. Maximum density throughout rearing was approximately 12.8 kg/m^3. The subyearlings were fed, handled, tagged, and released as described for Snake River surrogates with the following five exceptions. Clearwater River surrogate subyearlings were:

1) tagged and released during 06/21–6/25, 06/28–07/2, and 07/06–07/09;
2) tagged at temperatures of 8.0–9.0°C;
3) transported for only 20-30 min to reach the release site at the mouth of Big Canyon Creek 57 km upstream from the Clearwater River mouth;
4) acclimated and released at temperatures of 12.0–13.0°C;
5) overall pre-release mortality and shedding rates were 0.0 and 0.001%, respectively.

Production Fall Chinook Salmon Subyearlings

Production subyearlings that were PIT-tagged and released in 2010 were incubated, reared, and tagged at Lyons Ferry, Oxbow, Umatilla, Irrigon, and Nez Perce Tribal hatcheries (Figure 1). In 2010, the production subyearlings were PIT tagged several weeks before release. See McCutcheon and Richmond (2010) 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 and Kellar (2010) for the upper Clearwater facilities.

Production subyearlings were PIT tagged with 12.5-mm tags by use of standard methods by both Biomark, Inc. and other agency/tribal staff. The number of production subyearlings that we PIT-tagged at a 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 2010, 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, Little Goose, Lower Monumental, 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 12/16/2010–03/23/2011;

2) Little Goose Dam 12/16/2010–03/22/2011;

3) Lower Monumental Dam 12/21/2010–03/14/2011;

4) Ice Harbor Dam never dewatered;

5) McNary Dam 11/22/2010–03/27/2011;

6) John Day Dam 11/29/2010–03/30/2011; and

7) Bonneville Dam 12/21/2010–02/17/2011.

We downloaded detection data collected at the dams from the PIT tag Information System (PTAGIS 2011).

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 2010. 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 and Kellar. 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 2010 and 2011. We analyzed data on fish from the Snake and Clearwater River rivers jointly. However, the natural subyearlings were not tagged in direct proportion to their abundance in each river. For example, in 2009 65% 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 35% 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, 73% were tagged in the Snake River and 27% were tagged in the Clearwater River. We calculated weights for the detection data as follows. For the Snake River, we divided 0.65 (i.e., the proportion of redds observed) by 0.73 (the proportion of tagging observed) to calculate a weight of 0.89. For the Clearwater River, we divided 0.35 by 0.27 to calculate a weight of 1.30. We then multiplied the daily number of detections made at Lower Granite Dam for Snake River and Clearwater River natural subyearlings by 0.89 and 1.30, respectively. The sum of the two products was taken as the daily number of detections for natural subyearlings. The same steps were not necessary for surrogate and production subyearlings because fish were tagged proportionately to redd counts and basinwide releases of production releases, respectively.

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:

$$B_t = \frac{e^{(-5.45 + 0.305 \times \text{outflow} + 4.3202 \times \text{turbine allocation})}}{1 + e^{(-5.45 + 0.305 \times \text{outflow} + 4.3202 \times \text{turbine allocation})}}$$

We input the observed outflows and turbine allocations for every day of the 2010–2011 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 2010 to calculate a migration year 2010 passage index, (3) the weekly passage indices in 2011 to calculate a migration year 2011 passage index and (3) the 2010 and 2011 passages indices to calculate the total passage index 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 2010 for each group of subyearlings. At each dam, we used detection data from 04/15/2010 through the last day in 2010 on which the PIT-tag detection system was operational at the dam (hereafter, "migration year 2010 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 2010 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; April–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 x 4 analysis, we used a chi-square analysis of 2 x 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 x 7 contingency table (natural versus one of the other two subyearling groups; April–June, July, August, September, October, November, and December..

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 2010 and 2011 combined) made in migration year 2011.

Detection Percentages during Spill Implementation

Summer spill was implemented at Lower Granite, Little Goose, and Lower Monumental Dams from 20 June to 31 August 2010. For each group of subyearlings, we calculated the percentage of the migration year 2010 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 2010 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 2010, 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. Releases from Cedar Flats and Luke's Gulch acclimation facilities were not included in travel time analyses because some fish escaped from the facilities prior to forced release and were subsequently detected downstream. In these instances, we did not know the true release date of the fish and some fish had negative travel times because they were detected before the forced release.

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.

Apparent 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 2010. 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 2011 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 2010.

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 2010) 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 2011) 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% × 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% × 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 (± SE; hereafter apparent survival) 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 apparent survival that exceeded 100% lacked accuracy, that had 95% C.I.s wider than ± 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 comparisons of apparent survival in 2010 from release to the tailrace of Lower Granite, and Little Goose dams for the Snake River and Lower Granite Dam for the Clearwater River. We subjectively compared the estimates of apparent survival of natural subyearlings and the two hatchery subyearling groups.

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 (2010 and 2011 combined) that occurred in 2010. We used the percentage of the migration year 2010 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 similarity indices for comparing apparent survival per survival period. For example, release to the tailrace of Lower Granite Dam was period 1. We then averaged the indices across periods to produce one index for final comparison. 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 2010 was lowest for natural fish and highest for surrogate subyearlings (Table 1). Natural subyearlings were released in the Snake River over a more protracted period than surrogate or production subyearlings. Fifty-nine percent of the Snake River natural subyearling group was tagged and released during the 05/17–06/04 period in which 100% of the Snake River surrogate subyearlings were released. Tagged Snake River natural subyearlings averaged 7 mm smaller in fork length at tagging than surrogate subyearlings and 28–38 mm smaller than production subyearlings.

The number of subyearlings PIT tagged and released into the Clearwater River in 2010 was lowest for natural fish and highest for surrogate subyearlings (Table 1). Natural subyearlings were released in the Clearwater River over a more protracted period than surrogate or production subyearlings. Seventy-four percent of the Clearwater River natural subyearling group was tagged and released during the 06/21–07/09 period in which 100% of the Clearwater River surrogate subyearlings were released. Tagged Clearwater River natural subyearlings averaged 5 mm smaller in fork length at tagging than surrogate subyearlings and 24–32 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 2010. Production subyearlings were measured at tagging but not at release. Fork length was estimated for production subyearlings assuming a growth rate of 0.5 mm/d between tagging and release.

Group	Subgroup	*N*	Release dates	Fork length
		Snake River		
Natural		8,169	03/30–07/22	61 ± 10
Surrogates		195,493	05/17–06/04	68 ± 5
Production	Hells Canyon Dam	64,767	05/06, 05/25	97 ± 7
	Pittsburg Landing	30,887	05/25	91 ± 5
	Captain John Rapids	38,550	05/24	94 ± 5
	Couse Creek	15,445	05/24	89 ± 4
	Cougar Creek	30,305	05/24	99 ± 5
		Clearwater River		
Natural		2,960	06/28–07/29	69 ± 8
Surrogates		107,497	06/21–07/09	74 ± 5
Production	Big Canyon Creek	38,422	05/25	93 ± 5
	Lukes Gulch	16,409	06/09	101 ± 7
	Cedar Flats	14,219	06/14	101 ± 7
		Totals		
Natural		11,129		
Surrogates		302,990		
Production		249,004		

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 2010, peaked in early summer 2010, continued throughout fall 2010, was still in progress when the PIT-tag detection system was dewatered in 2010, and resumed shortly after the system was watered back up in spring 2011 (Figure 2; top and middle panels). Passage of PIT-tagged production subyearlings peaked in late spring 2010 and was nearly complete by late July 2010 (Figure 2; bottom panel). Of the natural subyearlings that made up the passage index for 2010 (i.e., $\hat{i}_{2010}$); 64% passed by 07/31/2010, 15% passed during August, and the remaining 21% passed from September to 12/16/10 when the PIT-tag detection system was dewatered. The percentages for surrogate subyearlings were 55% by 07/31/2010, 18% during August, and 27% from September to 12/16/2010. The percentages for production subyearlings were 99.7% by 07/31/2010, 0.2% during August, and 0.1% from September to 12/16/2010.

For natural juveniles, passage in 2011 after the PIT-tag detection system was watered back up made up 0.7% of the total passage index for 2010–2011 ($\hat{I}$) at Lower Granite Dam,. That is, an estimated 0.7% of natural juveniles were confirmed to have held in Lower Granite Reservoir in 2010 until after the PIT-tag detection systems at Lower Granite Dam was dewatered. This estimated percentage for surrogate and production juveniles was 0.5% and 0.02%, respectively.

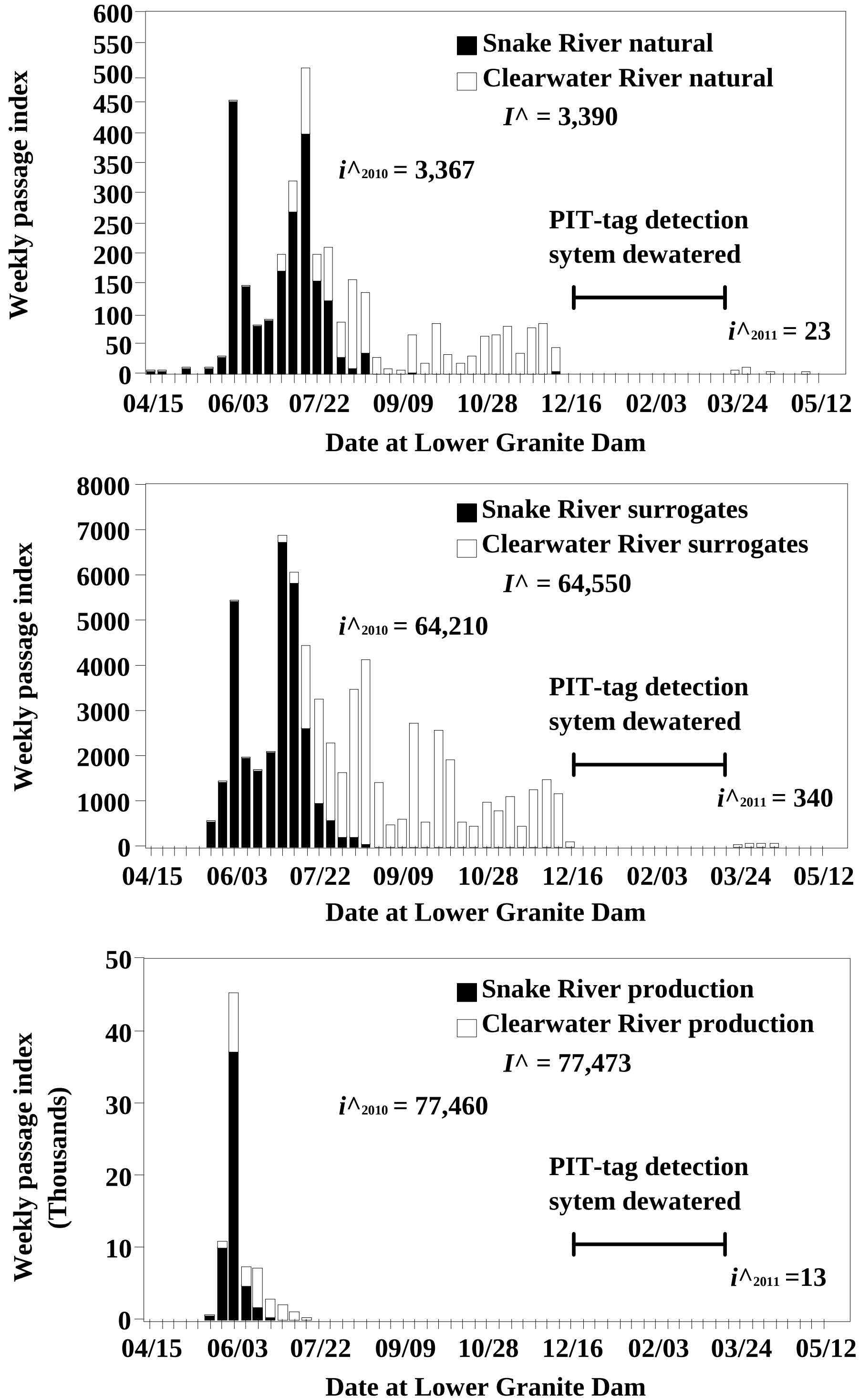

Figure 2.—Weekly passage indices at Lower Granite Dam during migration years 2010 and 2011 for Snake River and Clearwater River natural (top panel), surrogate (middle panel) and production (bottom panel) fall Chinook salmon juveniles based on fish that were PIT tagged and released in 2010. The weekly indices were summed across migration years 2010 and 2011 (*I*^) and within each migration year 2010 (*i*^2010) and 2011 (*i*^2011).

Objective 2: Snake River Comparisons

Detection Timing

On the date of maximum difference in the cumulative detection distributions (i.e., D_{max}) at Lower Granite Dam, the detection of Snake River natural subyearlings was further from completion than the detection of surrogate subyearlings; whereas 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 07/13, when D_{max} (16.7 percentage points) was observed at Lower Granite Dam, 71.8% of the eventual total detections of natural subyearlings had occurred, compared to 88.6% for surrogate subyearlings. On 06/20, when D_{max} (12.7 percentage points) was observed at Little Goose Dam, 41.3% of the eventual total detections of natural subyearlings had occurred, compared to 28.7% for surrogate subyearlings. On 06/23, when D_{max} (23.5 percentage points) was observed at Lower Monumental Dam, 49.0% of the eventual total detections of natural subyearlings had occurred, compared to 25.6% for surrogate subyearlings.

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

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 06/06, when D_{max} (60.5 percentage points) was observed at Lower Granite Dam, 12.4% of the eventual total detections of natural subyearlings had occurred, compared to 72.9% for production subyearlings. On 06/15, when D_{max} (60.4 percentage points) was observed at Little Goose Dam, 30.4% of the eventual total detections of natural subyearlings had occurred, compared to 90.8% for production subyearlings. On 06/14, when D_{max} (66.7 percentage points) was observed at Lower Monumental Dam, 21.0% of the eventual total detections of natural subyearlings had occurred, compared to 87.6% for production subyearlings.

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

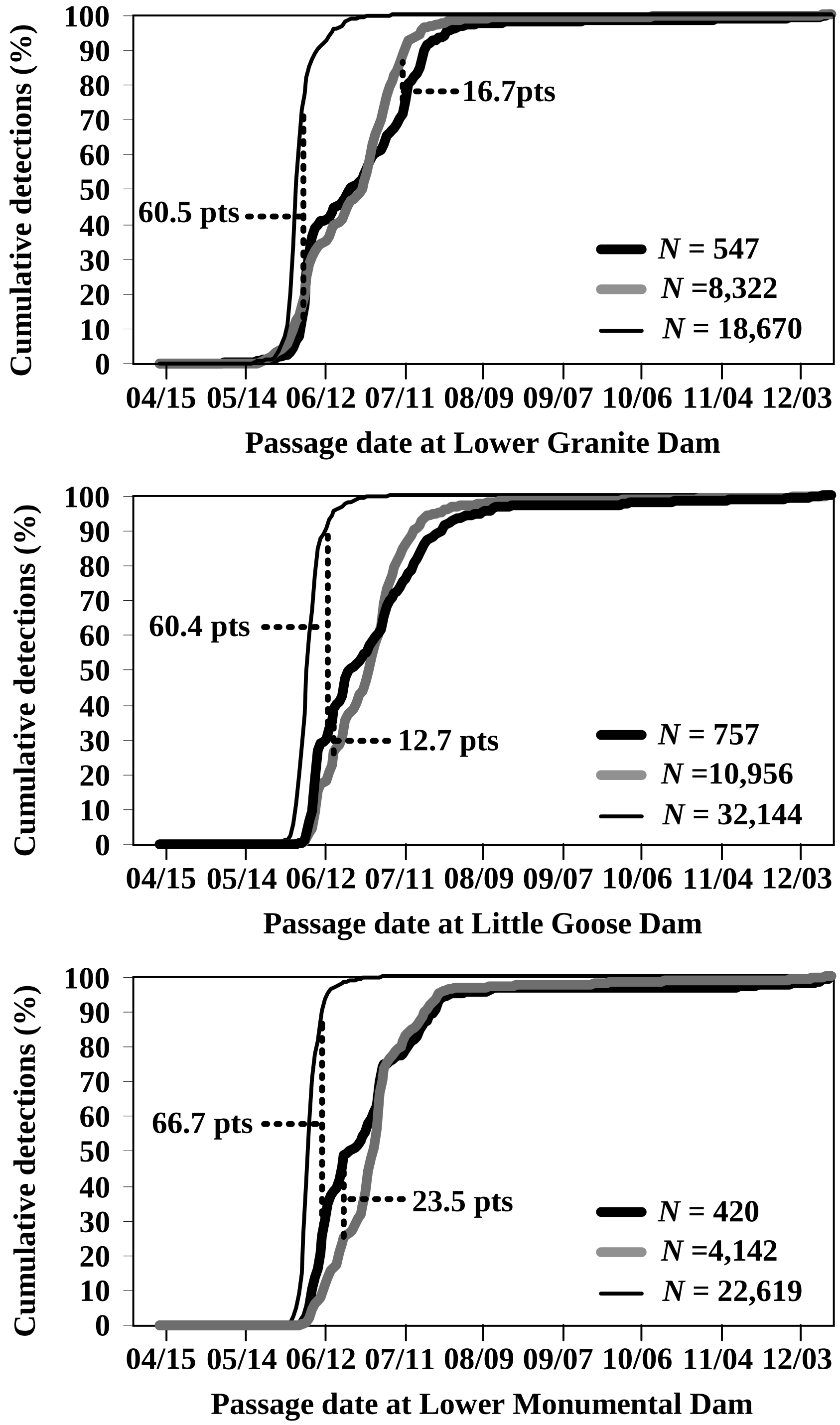

Figure 3.—Cumulative detection distributions at Lower Granite, Little Goose, and Lower Monumental dams for PIT-tagged Snake River natural (thick black line), surrogate (thick gray line), and production (thin black line) fall Chinook salmon subyearlings in migration year 2010. Percentage points (pts) 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.

June was the peak month of detection at Lower Granite Dam during migration year 2010 for both Snake River natural (53.2%) and surrogate (49.4%) subyearlings (Figure 4). June was the peak month of detection at Little Goose Dam for natural subyearlings (55.2%). During June, 47.4% of the total detections of surrogate subyearlings at Little Goose Dam occurred but July was the peak month of detection for surrogate subyearlings at this dam (49.1%). June was also the peak month of detection at Lower Monumental Dam for natural subyearlings (55.1%), whereas 34.5% of the surrogate subyearling detections occurred in June and the peak month of detection at this dam for surrogate subyearlings was July (61.8%).

Monthly detections percentages in migration year 2010 between Snake River natural and surrogate subyearlings differed significantly (2 x 3 contingency table; $P < 0.0001$) at Lower Granite Dam because of significant differences in April–May ($P < 0.0001$) and August–December ($P < 0.0001$). Monthly detections percentages between natural and surrogate subyearlings differed significantly (2 x 3 contingency table; $P < 0.0001$) at Little Goose Dam because of significant differences in June, July, and August–December (all P-values < 0.0001). Monthly detections percentages between natural and surrogate subyearlings differed significantly (2 x 3 contingency table; $P < 0.0001$) at Lower Monumental Dam because of significant differences in June and July (both P-values < 0.0001). See Figure 4 to understand the actual extent of the monthly differences.

June was the peak month of detection for both Snake River natural and production subyearlings in migration year 2010, but the percentage of the total detections in June varied greatly between these two subyearling groups (Figure 4). The percentage of the two groups detected during June was 53.2% for natural subyearlings and 91.6% for production subyearlings at Lower Granite Dam, 55.2% and 98.3% at Little Goose Dam, and 55.1% and 99.3% at Lower Monumental Dam.

There were significant differences in monthly detections between Snake River natural and production subyearlings at all three dams in migration year 2010 (2 x 3 contingency tables; all P values < 0.0001). There were significant differences (all P values < 0.001) in detection for every month except April–May at Lower Monumental Dam ($P = 0.3$). See Figure 4 to understand the actual extent of the monthly differences.

Of the Snake River natural, surrogate and production juveniles detected during 2010–2011 at Lower Granite Dam; 0% of the natural, 0.05% of the surrogate, and 0.0% of the production juveniles were detected in 2011. These percentages at Little Goose Dam were 1.8% for natural juveniles, 0.8% for surrogate juveniles, and 0.0% for production juveniles. At Lower Monumental Dam, the percentages were 2.6% for natural juveniles, 3.3% for surrogate juveniles, and 0.01% for production juveniles. Of all fish that were detected during 2010–2011, the percentages that were last detected in 2011 were 1.6% (N = 1,962 detections) for natural subyearlings, 1.3% (N = 31,920 detections) for surrogate subyearlings, and 0.002% (N = 80,897 detections) for production subyearlings.

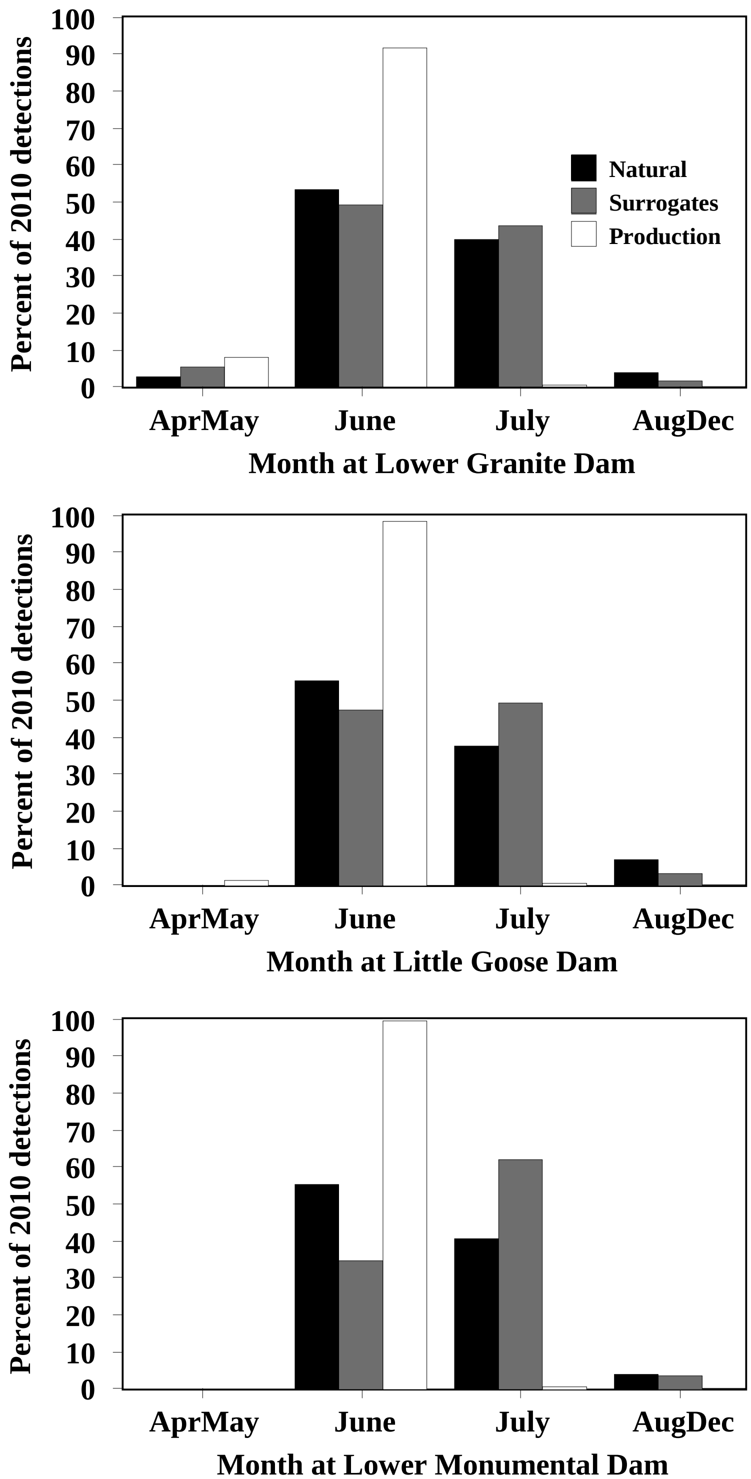

Figure 4.—Monthly percentages of the total detections made during migration year 2010 for PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings. The number of detections for each subyearling group at each dam is given in Figure 3.

Detection Percentages during Spill Implementation

The percentage of migration year 2010 detections made at Lower Granite Dam during summer spill implementation was 52.8% for Snake River natural subyearlings and 59.1% for Snake River surrogate subyearlings (Figure 5). The percentage of the migration year 2010 detections made at Little Goose Dam during summer spill implementation was 57.1% for natural subyearlings and 70.6% for surrogate subyearlings. The percentage of the migration year 2010 detections made at Lower Monumental Dam during summer spill implementation was 58.6% for natural subyearlings and 80.8% for surrogate subyearlings. Thus, there was a 6.3–22.2 percentage point difference between the migration year 2010 detection percentages made during summer spill implementation for natural and surrogate subyearlings.

The percentage of migration year 2010 detections made during summer spill implementation at Lower Granite ($P = 0.004$), Little Goose ($P < 0.0001$), and Lower Monumental ($P < 0.0001$) dams were significantly different between Snake River natural and surrogate subyearlings. See Figure 5 to understand the actual extent of these differences.

The percentages of migration year 2010 detections of Snake River production subyearlings made at Lower Granite, Little Goose, and Lower Monumental dams during summer spill implementation were 3.8, 4.0, and 3.3%, respectively (Figure 5). Thus, there was a 49.0–55.3 percentage point difference between the migration year 2010 detection percentages made during summer spill implementation for natural and production subyearlings.

The percentage of the migration year 2010 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 (97.5–100%) of the Snake River natural, surrogate, and production subyearlings that were detected at Lower Granite, Little Goose, and Lower Monumental dams in migration year 2010 were detected during the implementation of either spring or summer spill (Figure 5).

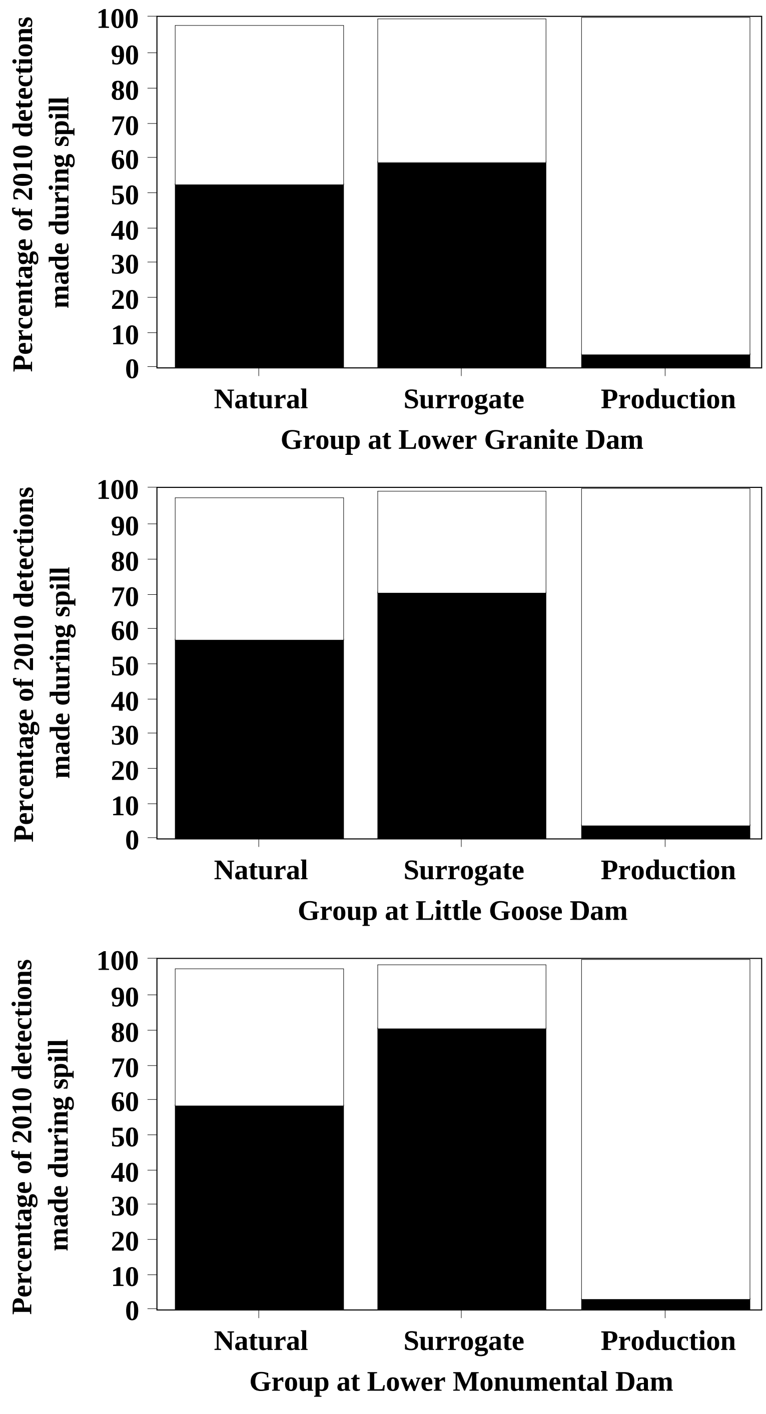

Figure 5.—The percentages of migration year 2010 detections of PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings made during summer (black portion of bar) or spring (white portion of bar) spill implementation at Lower Granite (top panel), Little Goose (middle 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 4-d difference in median travel time to Lower Granite Dam between Snake River natural and surrogate subyearlings in migration year 2010 (Table 2). The differences in median travel times between these two groups of subyearlings to Little Goose and Lower Monumental dams were 3 d and 4 d, respectively.

Median travel time of Snake River natural and surrogate subyearlings were significantly different at Lower Granite ($P = 0.004$), Little Goose ($P = 0.007$), and Lower Monumental ($P = 0.02$) dams.

There was a 20-d difference in median travel time to Lower Granite Dam between Snake River natural and production subyearlings in migration year 2010 (Table 2). There were 18-d and 20-d differences 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 2010.

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 2010.

Dam	Group	*N*	Travel time		
			Median	Minimum	Maximum
Lower Granite	Natural	547	28	1	195
	Surrogate	8,322	32	1	212
	Production	18,670	12	3	63
Little Goose	Natural	757	37	6	216
	Surrogate	10,956	34	2	211
	Production	32,144	16	6	76
Lower Monumental	Natural	420	41	6	205
	Surrogate	4,142	37	3	212
	Production	22,619	17	10	59

Migrant Size

For Snake River fish recaptured at Lower Granite Dam in migration year 2010, natural subyearlings averaged 2 mm smaller in fork length than surrogates and 19 mm smaller in fork length than production subyearlings (Table 3). Natural subyearlings averaged 0.3 g lighter than surrogates and 4.1 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 slightly higher for surrogate subyearlings than for natural subyearlings.

Mean fork length ($P < 0.6$), mean weight ($P = 0.7$), and mean condition factor ($P = 0.07$) did not differ significantly between Snake River natural and surrogate subyearlings. Mean fork length ($P < 0.0001$), mean weight ($P < 0.0001$), and mean condition factor ($P < 0.0001$) differed significantly between Snake River natural and production subyearlings.

Table 3.—Mean fork length (mm ± SD), weight (g ± SD), and condition factor (*K* ± SD) of PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings released in migration year 2010 and recaptured at Lower Granite Dam in migration year 2010.

		Recapture dates				
Group	*N*	Min	Max	Fork length	Weight	*K*
Natural	183	05/23	08/05	94 ± 18	8.7 ± 4.8	0.93 ± 0.07
Surrogates	48	06/02	07/30	96 ± 14	9.0 ± 4.0	0.96 ± 0.10
Production	54	05/30	07/02	113 ± 9	12.8 ± 3.6	0.87 ± 0.07

Apparent Survival

During migration year 2010, the estimate of apparent survival of Snake River Snake River natural subyearling cohort 2 from the tailrace of Little Goose to the tailrace of Lower Monumental Dam was imprecise (Table 4).

Apparent survival from release to the tailrace of Lower Granite Dam averaged 54.1% for Snake River natural subyearlings, 45.6% for Snake River surrogate subyearlings, and 70.1% for Snake River production subyearlings (Table 4). At the subgroup level, apparent survival from release to the tailrace of Lower Granite Dam was similar between both cohorts of natural subyearlings and the three releases of surrogate subyearlings (maximum difference, 13.6 percentage points), and between both cohorts of natural subyearlings and production subyearlings released at Hells Canyon Dam (maximum difference, 10.1 percentage points). Apparent survival from release to the tailrace of Lower Granite Dam was 20.7–35.5 percentage points lower for the two cohorts of natural subyearlings than production subyearlings released at Pittsburg Landing, Captain John Rapids, Couse Creek, and Cougar Creek.

Apparent survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam averaged 70.4% for Snake River natural subyearlings, 71.4% for Snake River surrogate subyearlings, and 93.2% for Snake River production subyearlings (Table 4). At the subgroup level, apparent survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam was similar between both cohorts of natural subyearlings and the three releases of surrogate subyearlings (maximum difference, 6.5 percentage points). Apparent survival of the two cohorts of natural subyearlings was from 19.1–25.8 percentage points lower than apparent survival of the production subyearling subgroups.

Table 4.—Estimated apparent 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 2010. Estimates that lack accuracy, precision, or both are indicated in bold (see page 16 for criteria). The means (% ± SE) of the individual estimates made for the period from release to the tailrace of Lower Granite Dam are also given.

		Apparent survival		
Group	Subgroup	Release to LGR	LGR to LGS	LGS to LMN
Natural	Cohort 1	55.5 ± 10.4	70.8 ± 15.6	80.6 ± 13.0
	Cohort 2	52.7 ± 10.9	70.1 ± 19.3	**90.3 ± 33.3**
	Mean	54.1 ± 1.4	70.1 ± 0.4	
Surrogate	Release 1	45.4 ± 3.4	68.2 ± 6.7	70.0 ± 7.7
	Release 2	41.9 ± 3.4	76.6 ± 8.3	68.9 ± 8.6
	Release 3	49.6 ± 3.7	69.5 ± 7.0	72.4 ± 8.7
	Mean	45.6 ± 2.3	71.4 ± 2.6	
Production	Hells Canyon Dam (Oxbow)	45.4 ± 1.9	94.6 ± 5.8	84.2 ± 7.4
	Hells Canyon Dam (Umatilla)	58.9 ± 1.8	95.9 ± 3.6	89.3 ± 3.1
	Pittsburg Landing	76.2 ± 2.1	89.9 ± 3.4	91.8 ± 3.7
	Captain John Rapids	88.2 ± 2.0	91.0 ± 2.8	92.0 ± 3.3
	Couse Creek	77.0 ± 3.8	93.1 ± 5.6	89.7 ± 4.8
	Cougar Creek	78.3 ± 2.9	94.8 ± 4.4	85.8 ± 3.7
	Mean	70.7 ± 6.4	93.2 ± 1.0	

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). Overall, there was a 20% difference in the postrelease attributes of natural and surrogate subyearlings compared to a 330% difference between natural and production subyearlings.

Table 5.—Similarity indices (higher value divided by lower value of the attribute) for each comparison between 2010 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 17 for attribute descriptions.

Attribute	Attribute values		Similarity indices	Attribute values		Similarity indices
	Natural	Surrogates		Natural	Production	
Lower Granite Dam						
Cumulative detection	0.718	0.886	1.2	0.124	0.729	5.9
Peak monthly detection	0.532	0.494	1.1	0.532	0.900	1.7
2010 detection	1.000	1.000	1.0	1.000	1.000	1.0
Summer spill detection	0.528	0.591	1.1	0.528	0.038	13.9
Travel time	28	32	1.1	28	12	2.3
Migrant size	94	96	1.0	94	113	1.2
Apparent survival	See Table A2		1.2	See Table A2		1.3
Little Goose Dam						
Cumulative detection	0.413	0.287	1.4	0.304	0.908	3.0
Peak monthly detection	0.552	0.474	1.2	0.552	0.983	1.8
2010 detection	0.982	0.992	1.0	0.982	1.000	1.0
Summer spill detection	0.571	0.706	1.2	0.571	0.040	14.2
Travel time	37	34	1.1	37	16	2.3
Apparent survival	See Table A2		1.0	See Table A2		1.3
Lower Monumental Dam						
Cumulative detection	0.490	0.256	1.9	0.210	0.876	4.2
Peak monthly detection	0.551	0.345	1.6	0.551	0.993	1.8
2010 detection	0.974	0.967	1.0	0.974	1.000	1.0
Summer spill detection	0.586	0.808	1.4	0.586	0.033	17.8
Travel time	41	37	1.1	41	17	2.4
Overall mean			1.2			4.3
Overall median			1.1			2.1

Objective 2: Clearwater River Comparisons

Detection Timing

On the dates of maximum differences in the migration year 2010 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, Little Goose, and Lower Monumental dams (Figure 6). On 10/20, when D_{max} (17.7 percentage points) was observed at Lower Granite Dam, 44.6% of the eventual total detections of natural subyearlings had occurred, compared to 62.3% for surrogate subyearlings. On 11/13, when D_{max} (11.2 percentage points) was observed at Little Goose Dam, 29.0% of the eventual total detections of natural subyearlings had occurred, compared to 40.2% for surrogate subyearlings. On 11/30, when D_{max} (10.6 percentage points) was observed at Lower Monumental Dam, 14.5% of the eventual total detections of natural subyearlings had occurred, compared to 25.1% for surrogate subyearlings.

Cumulative detection distributions differed significantly between Clearwater River natural and surrogate subyearlings at Lower Granite ($P < 0.0001$) and Little Goose ($P = 0.006$) dams, but not at Lower Monumental Dam ($P = 0.2$).

On the dates that D_{max} was observed at Lower Granite, Little Goose, and Lower Monumental dams, the detection of Clearwater River natural subyearlings was just beginning or had yet to begin, whereas the detection of production subyearlings was nearly complete (Figure 6). On 07/11, when D_{max} (95.1 percentage points) was observed at Lower Granite Dam, 2.5% of the eventual total detections of natural subyearlings had occurred, compared to 97.6% for production subyearlings. On 07/14, when D_{max} (98.7 percentage points) was observed at Little Goose Dam, no natural subyearlings had yet been detected, compared to 98.7% of eventual total detections for production subyearlings. On 07/21, when D_{max} (99.5 percentage points) was observed at Lower Monumental Dam, no natural subyearlings had yet been detected, compared to 99.5% of eventual total detections for production subyearlings.

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

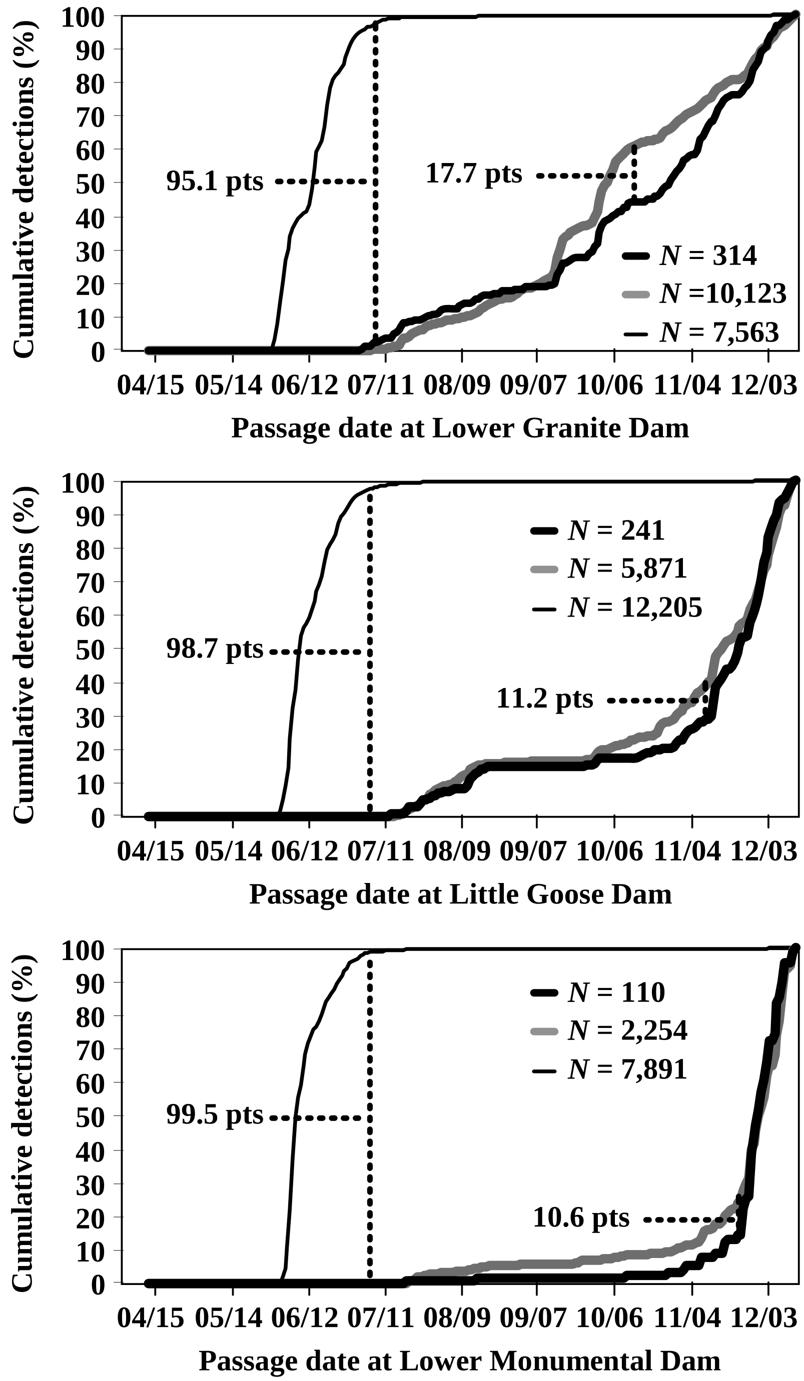

Figure 6.—Cumulative detection distributions at Lower Granite, Little Goose, and Lower Monumental dams for PIT-tagged Clearwater River natural (thick black line), surrogate (thick gray line), and production (thin black line) fall Chinook salmon subyearlings in migration year 2010. Percentage points (pts) 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.

October and November were the peak months of detection during migration year 2010 at Lower Granite Dam for Clearwater River natural (31.5%) and surrogate (28.9%) subyearlings, respectively (Figure 7). November was the peak month of detection at Little Goose Dam for both natural (39.4%) and surrogate (34.0%) subyearlings. December was the peak month of detection at Lower Monumental Dam for both natural (85.5%) and surrogate (74.9%) subyearlings.

Monthly detections percentages in migration year 2010 between Clearwater River natural and surrogate subyearlings differed significantly (2 x 3 contingency table; $P < 0.0001$) at Lower Granite Dam because of significant differences in September ($P < 0.0001$), October ($P = 0.01$), and November ($P < 0.0001$). Monthly detections percentages between natural and surrogate subyearlings differed significantly (2 x 3 contingency table; $P < 0.0001$) at Little Goose Dam because of significant differences in October ($P = 0.02$). Monthly detections percentages between natural and surrogate subyearlings did not differ significantly (2 x 3 contingency table; $P = 0.2$) at Lower Monumental Dam. See Figure 7 to understand the actual extent of the monthly differences and similarities.

November was the peak month of detection for Clearwater River natural subyearlings at Lower Granite (31.5%) and Little Goose (39.4%) dams and December (85.5%) was the peak month of detection for this subyearling group at Lower Monumental Dam (Figure 7). June was the peak month of detection for Clearwater River production subyearlings at Lower Granite (89.5%), Little Goose (92.5%), and Lower Monumental (93.0%) dams.

There were significant differences in monthly detections between Clearwater River natural and production subyearlings at all three dams in migration year 2010 (2 x 3 contingency tables; all P values < 0.0001). There were significant differences (all P values < 0.02) in detection for every month except July at Lower Granite and Little Goose dams (both P-values = 0.3) and September at Lower Monumental Dam (no fish were detected). See Figure 7 to understand the actual extent of the monthly differences and similarities.

Of the Clearwater River natural, surrogate and production juveniles detected during 2010–2011 at Lower Granite Dam; 2.2% of the natural, 1.2% of the surrogate, and 0.1% of the production juveniles were detected in 2011. These percentages at Little Goose Dam were 14.8% for natural juveniles, 15.7% for surrogate juveniles, and 0.1% for production juveniles. At Lower Monumental Dam, the percentages were 32.5% for natural juveniles, 38.8% for surrogate juveniles, and 0.02% for production juveniles. Of all fish that were detected during 2010–2011, the percentages that were last detected in 2011 were 18.9% ($N = 503$ detections) for natural subyearlings, 16.9% ($N = 15{,}975$ detections) for surrogate subyearlings, and 0.1% ($N = 32{,}293$ detections) for production subyearlings.

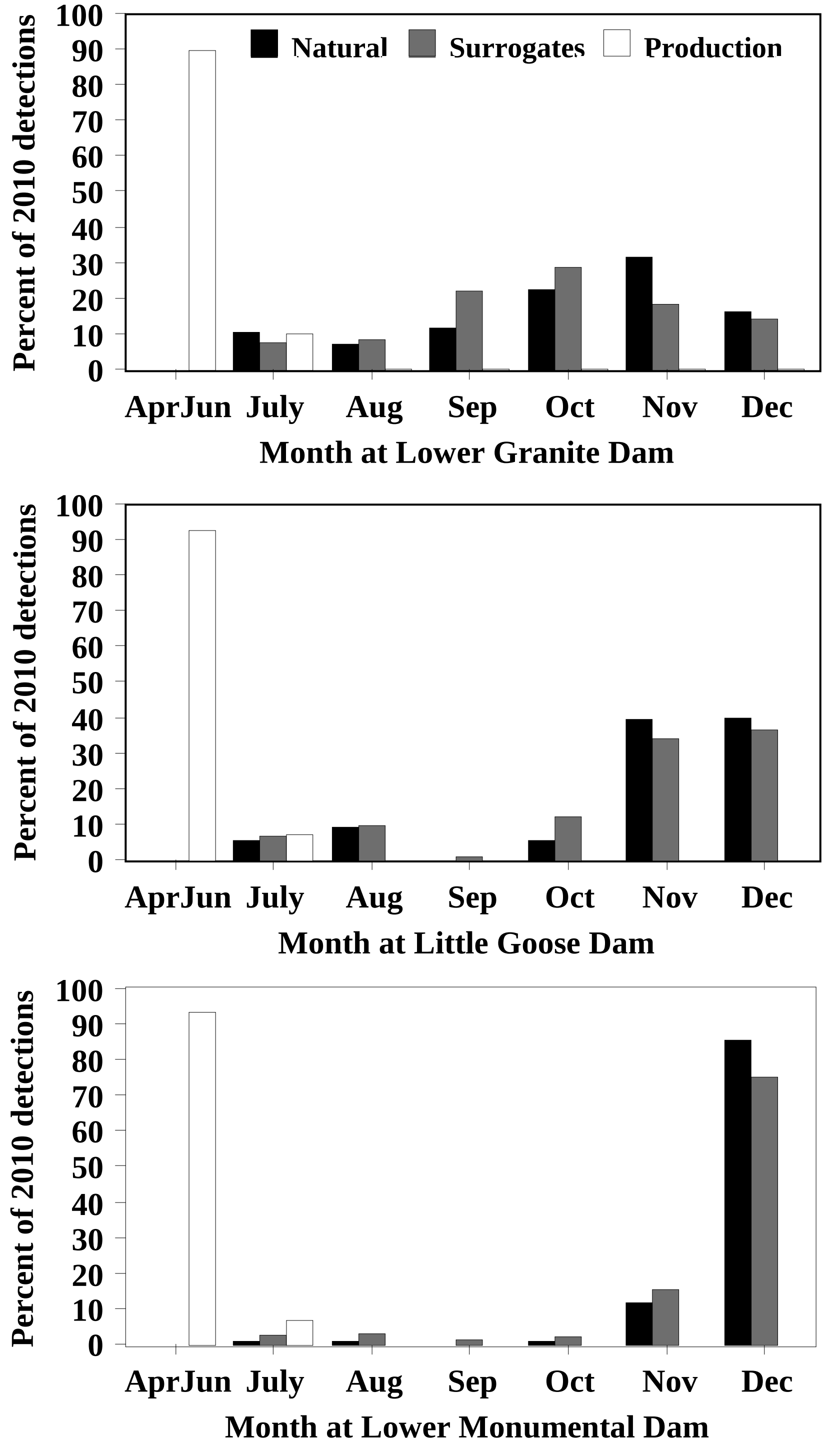

Figure 7.—Monthly percentages of the total detections made during migration year 2010 for PIT-tagged Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings at Lower Granite (top panel), Little Goose (middle panel), and Lower Monumental dams (bottom panel). The number of detections for each subyearling group at each dam is given in Figure 6.

Detection Percentages during Spill Implementation

The percentage of the migration year 2010 detections made at Lower Granite Dam during summer spill implementation was 17.8% for Clearwater River natural subyearlings and 16.3% for Clearwater River surrogate subyearlings (Figure 8). The percentage of the migration year 2010 detections made at Little Goose Dam during summer spill implementation was 14.9% for natural subyearlings and 16.3% for surrogate subyearlings. The percentage of the migration year 2010 detections made at Lower Monumental Dam during summer spill implementation was 1.8% for natural subyearlings and 5.5% for surrogate subyearlings. Thus, there was a 1.4–3.7 percentage point difference between the migration year 2010 detection percentages of natural and surrogate subyearlings made during summer spill implementation.

The percentage of the migration year 2010 detections made during summer spill implementation did not differ significantly between Clearwater River natural and surrogate subyearlings at Lower Granite Dam ($P = 0.5$), Little Goose Dam ($P = 0.6$), or Lower Monumental Dam ($P = 0.09$).

The percentages of the migration year 2010 detections of Clearwater River production subyearlings made at Lower Granite, Little Goose, and Lower Monumental dams during summer spill implementation were 38.5, 30.7, and 23.4%, respectively (Figure 8). Thus, there was a 15.7–21.6 percentage point difference between the migration year 2010 detection percentages made during summer spill implementation for natural and production subyearlings.

The percentage of the migration year 2010 detections made during implementation of summer spill was significantly lower for Clearwater River natural subyearlings than for Clearwater River production subyearlings at Lower Granite, Little Goose, and Lower Monumental dams (all 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 61.1% of detections at Lower Granite Dam, 69.2% at Little Goose Dam, and 76.5 at Lower Monumental Dam for Clearwater River production subyearlings (Figure 9).

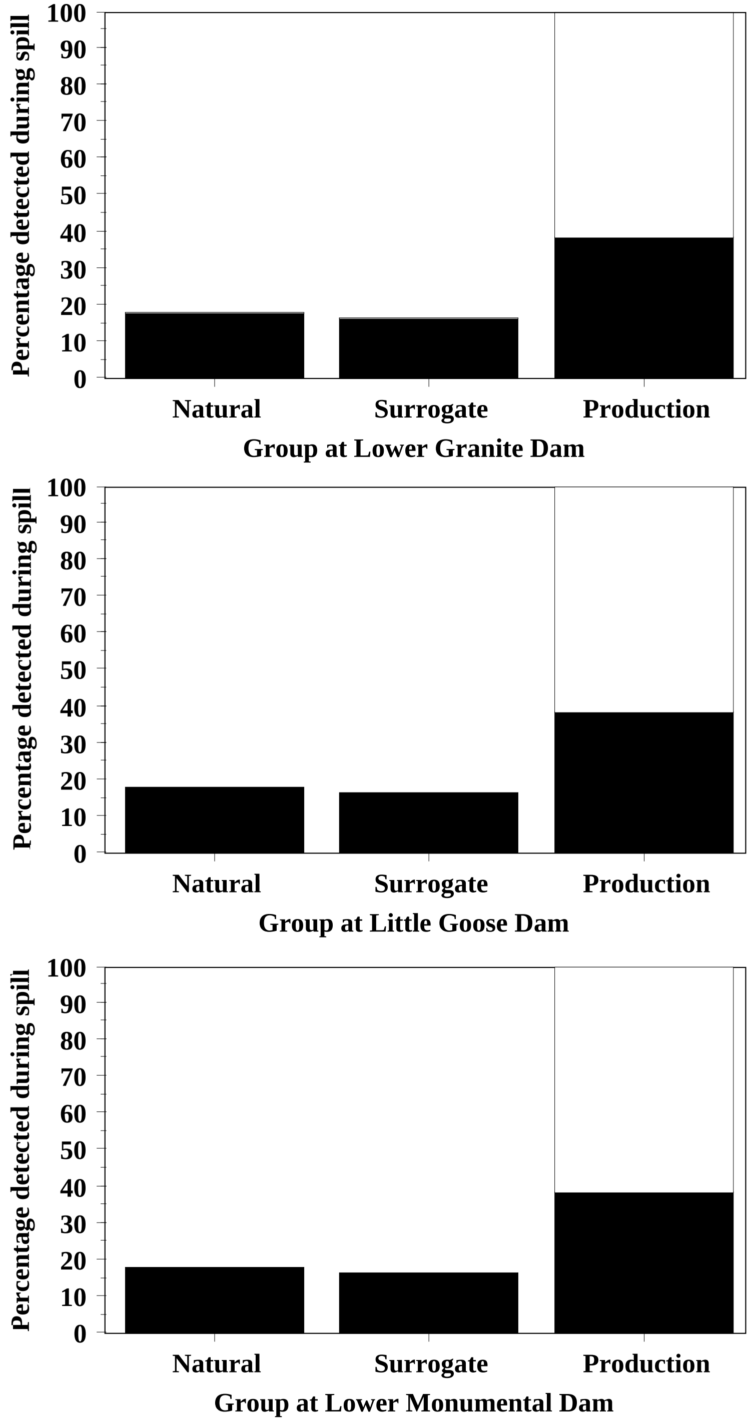

Figure 8.—The percentages of migration year 2010 detections of PIT-tagged Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings that occurred during implementation of summer spill (black portion of bar) or spring spill (white portion of bar) at Lower Granite (top panel), Little Goose (bottom panel), and Lower Monumental(bottom panel) dams. The number of detections for each subyearling group at each dam is given in Figure 7.

Travel Time

There was a difference in median travel times between Clearwater River natural and surrogate subyearlings in migration year 2010 of 15 d to Lower Granite Dam, 3 d to Little Goose Dam, and 8 d to Lower Monumental Dam (Table 6).

Median travel time of Clearwater River natural and surrogate subyearlings to Lower Granite ($P = 0.0005$), Little Goose ($P = 0.008$), and Lower Monumental ($P < 0.0001$) differed significantly in migration year 2010.

There was a difference in median travel times between Clearwater River natural and production subyearlings in migration year 2010 of 99 d to Lower Granite Dam, 121 d to Little Goose Dam, and 133 d to Lower Monumental Dam (Table 6).

Median travel time of Clearwater River natural and production subyearlings to Lower Granite, Little Goose, and Lower Monumental dams differed significantly (al *P* values < 0.0001) in migration year 2010.

Table 6.— Number detected (*N*) and median, minimum, and maximum travel time (days) from release to Lower Granite, Little Goose, and Lower Monumental Dams for PIT-tagged Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2010.

Dam	Group	*N*	Travel time		
			Median	Minimum	Maximum
Lower Granite	Natural	314	111	3	169
	Surrogate	10,123	96	3	177
	Production	4,010	12	4	134
Little Goose	Natural	241	137	16	168
	Surrogate	5,871	140	15	177
	Production	8,543	16	8	80
Lower Monumental	Natural	110	150	24	174
	Surrogate	2,254	158	25	183
	Production	6,356	17	10	61

Apparent Survival

During migration year 2010, the estimates of apparent survival for Clearwater 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 inaccurate and imprecise (Table 7).

Apparent survival from release to the tailrace of Lower Granite Dam averaged 20.7% for natural Clearwater River subyearlings, 20.4% for Clearwater River surrogate subyearlings, and 69.4% for Clearwater River production subyearlings (Table 7). At the subgroup level, apparent survival from release to the tailrace of Lower Granite Dam was similar between both cohorts of natural subyearlings and the three releases of surrogate subyearlings (maximum difference, 5.6 percentage points). Apparent survival from release to the tailrace of Lower Granite Dam of the two cohorts of natural subyearlings was 32.8–61.7 percentage points lower than for the production subyearling subgroups.

Table 7.—Estimated apparent 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 Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2010. Estimates that lack accuracy, precision, or both are indicated in bold (see page 16 for criteria). The means (% ± SE) of the individual estimates made for the period from release to the tailrace of Lower Granite Dam are also given.

		Apparent survival		
Group	Subgroup	Release to LGR	LGR to LGS	LGS to LMN
Natural	Cohort 1	22.7 ± 3.1	**111.3 ± 46.0**	**40.0 ± 29.4**
	Cohort 2	18.7 ± 2.4	**119.8 ± 64.2**	**33.7 ± 30.7**
	Mean	20.7 ± 2.0		
Surrogate	Release 1	24.3 ± 1.4	61.6 ± 8.3	50.8 ± 13.4
	Release 2	18.4 ± 0.7	63.4 ± 8.1	37.5 ± 10.8
	Release 3	18.5 ± 0.5	86.5 ± 10.5	49.3 ± 12.9
	Mean	20.4 ± 2.0		
Production	Big Canyon Creek	80.4 ± 2.4	93.7 ± 3.5	87.6 ± 3.1
	Lukes Gulch	72.3 ± 3.5	91.6 ± 6.7	91.3 ± 9.9
	Cedar Flats	55.5 ± 4.3	84.0 ± 9.9	87.8 ± 14.2
	Mean	69.4 ± 7.3		

Overall Comparison of Attributes

The indices for Clearwater River fish showed greater similarity between natural and surrogate subyearlings than between natural and production subyearlings (Table 8). Overall, there was a 30% difference in the postrelease attributes of natural and surrogate subyearlings compared to a 16,484% difference between natural and production subyearlings.

Table 8.—Similarity indices (higher value divided by lower value of the attribute) for each comparison between 2010 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 17 for attribute descriptions.

Attribute	Attribute values		Similarity indices	Attribute values		Similarity indices
	Natural	Surrogates		Natural	Production	
Lower Granite Dam						
Cumulative detection	0.446	0.623	1.4	0.025	0.976	38.3
Peak monthly detection	0.315	0.184	1.7	0.315	0.001	397.4
2010 detection	0.978	0.988	1.0	0.978	0.999	1.0
Summer spill detection	0.178	0.163	1.1	0.178	0.385	2.2
Travel time	111	96	1.2	111	11	10.1
Apparent survival	See Table A3		1.0	See Table A3		3.4
Little Goose Dam						
Cumulative detection	0.290	0.402	1.4	0.004[a]	0.988	238.2
Peak monthly detection	0.398	0.367	1.1	0.398	0.001	694.5
2010 detection	0.852	0.843	1.0	0.852	0.999	1.2
Summer spill detection	0.149	0.163	1.1	0.149	0.307	2.1
Travel time	137	140	1.0	137	16	8.6
Lower Monumental Dam						
Cumulative detection	0.145	0.251	1.7	0.009[b]	0.996	109.5
Peak monthly detection	0.855	0.749	1.1	0.855	0.001	1123.9
2010 detection	0.675	0.612	1.1	0.675	0.998	1.5
Summer spill detection	0.018	0.055	3.0	0.018	0.234	12.9
Travel time	150	158	1.1	150	17	8.8
Overall mean			1.3			165.8
Overall median			1.1			9.5

[a]The day after Dmax was observed provided the data for this calculation because no natural fish were detected the day Dmax was observed.
[b]Three days 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 precedes or follows 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. For the first time during this study, we analyzed data collected on 50–59 mm fish tagged with 8.5-mm tags. This increased our ability to represent the population of natural fish, but we were still unable to represent fish that disperse into the lower Snake River reservoirs at fork lengths less than 50 mm. 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 will not be completed until 2011.

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., 33% of the 4,500,000 released in 2010 [including fish released from the Nez Perce Tribal Hatchery and into Lapwai Creek that were not part of our study]), 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 9). 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 2011). 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 9 separate occasions (i.e., once a week for the first 9 weeks of sampling) 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 ± 13%). After the hatchery releases begin, we seined and tagged natural subyearlings at each supplemental station once and the permanent stations 10 times (once per week for the last 10 weeks of sampling). In contrast to the Snake River, we began to seine and tag natural subyearlings in the Clearwater River after the time the first releases of Clearwater River production subyearlings were made. This brings us to the third reason we do not believe our results are largely affected by incidental tagging of unmarked production subyearlings in the Snake or Clearwater rivers. 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 2011) and these fish are likely stragglers based on observed travel times to Lower Granite Dam (e.g., 11 d in 2010). 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 some natural fry are still emerging from the gravel.

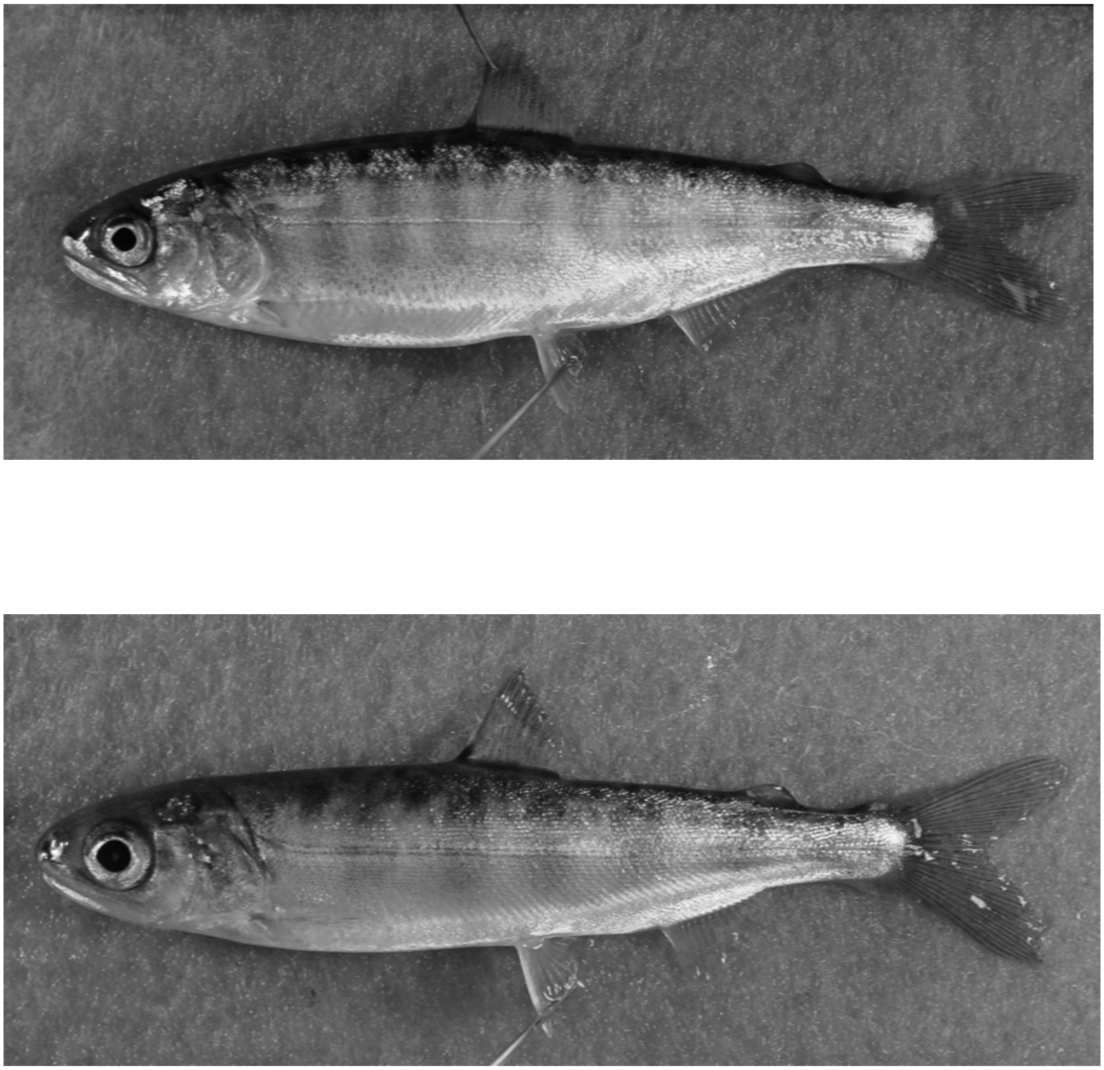

Figure 9.—An example of some of the morphological differences between rearing subyearling fall Chinook salmon of natural origin (top panel) and hatchery origin (bottom panel). Both fish were 70 mm fork length. From Tiffan and Connor (2011).

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 and Little Goose dams through 12/16/2010, Lower Monumental Dam through 12/21/2010, the winter at Ice Harbor Dam, 11/22/2010 at McNary Dam, 11/29/2010 at John Day Dam, and 12/21/2010 at Bonneville Dam. Evaluating the efficacy of extended water up of the PIT-tag detection systems is beyond the scope of this report. However, the 2010 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 strategies and 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 08/31/2010 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 in the Clearwater River are still in the fry and parr stages.

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 2010 to spring 2011, while passage of production subyearlings was essentially complete by the end of July 2010. 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 2010 releases of natural subyearlings to the postrelease performance of 2010 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 330% difference between Snake River natural and production subyearlings. We also found that there was an overall difference of 30% in the postrelease attributes of Clearwater River natural and surrogate subyearlings compared to a 16,484% difference between Clearwater River natural and production subyearlings.

Consistent with our 2005, 2006, 2008, and 2009 findings (Connor et al. 2008a,b, 2009, 2010; the study was not conducted in 2007), we conclude the postrelease attributes measured on 2010 releases were more similar between Snake River and Clearwater River natural and surrogate subyearlings than between natural and production subyearlings from these two rivers. As of the writing of this report in 2011, we have made one pilot release of surrogate subyearlings in 2005, five full-scale releases of surrogate subyearlings (2006, 2008, 2009, 2010, and 2011), one pilot release of production subyearlings in 2006, and four full-scale releases of production subyearlings (2008, 2009, 2010, and 2011). There was confusion with respect to the end date of the study specified in the consensus study design (Marsh et al 2007b). As such, the planning team for the study sought and obtained agreement within U.S. v OR to maintain the culturing of surrogate subyearlings as a priority in 2012. This will allow the full study (i.e., releases of natural, surrogate, and production subyearlings) to repeated for the last time in 2012.

ACKNOWLEDGEMENTS

We thank the field crews of the Nez Perce Tribe and U. S. Fish and Wildlife Service for their many hours in the field. Extra recognition goes to staff of the Washington Department of Fish Wildlife staff at the Dayton Lab and Lyons Ferry Hatchery as well as the staff of Irrigon Hatchery, who spent many hours planning and coordinating to make the surrogate releases possible in 2010. We appreciate the efforts of BioMark, inter-agency, and tribal staff for PIT tagging the fish. The 2010 summary report written by S. McCutcheon and R. Richmond provided was invaluable when writing this report. R. Bohn reared the surrogates at Dworshak National Fish Hatchery with valuable assistance from hatchery staff. This study (and many other studies we have conducted) would not have been possible without personnel of the Pacific States Marine Fisheries Commission, including D. Marvin (2010) and N. Tancreto (2011), who operated and maintained the Columbia Basin PIT-tag Information System. Funding was provided by the U.S. Army Corps of Engineers Walla Walla District and Bonneville Power Administration projects 1983350003, 199102900, and 199801004. We greatly appreciate the contracting efforts of S. Dunmire, D. Holecek, D. Docherty, and J. George. Use of trade names does not imply endorsement by the U.S. National Marine Fisheries Service, U.S. Fish and Wildlife Service, or Nez Perce Tribe.

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 2010.

		Total release		PIT-tagged release	
River	Site	*N*	%	*n*	%
Snake	Hells Canyon Dam	878,429	27	64,767	26
	Pittsburg Landing	405,041	12	30,887	12
	Captain John Rapids	528,777	16	38,550	15
	Couse Creek boat launch	203,162	6	15,445	6
	Cougar Creek	386,840	12	30,305	12
Clearwater					
	Big Canyon Creek	511,236	15	38,422	15
	Lukes Gulch	198,969	6	16,409	7
	Cedar Flats	188,411	6	14,219	6
Totals		3,300,865		249,004	

Table A2.—Calculating similarity indices for comparing the apparent survival (%) between PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2010. The mean index was used in Table 5.

Group	Subgroup	Apparent survival	Similarity indices		Mean index
			vs. cohort 1	vs. cohort 2	
Release to Lower Granite Dam					
Natural	Cohort 1	55.5			
	Cohort 2	52.7			
Surrogate	Release 1	45.4	1.2	1.2	1.2
	Release 2	41.9	1.3	1.3	
	Release 3	49.6	1.1	1.1	
Production	Hells Canyon (Oxbow)	45.4	0.8	0.9	1.3
	Hells Canyon (Umatilla)	58.9	1.1	1.1	
	Pittsburg Landing	76.2	1.4	1.4	
	Captain John Rapids	88.2	1.6	1.7	
	Couse Creek	77.0	1.4	1.5	
	Cougar Creek	78.3	1.4	1.5	
Lower Granite to Little Goose Dam					
Natural	Cohort 1	70.8			
	Cohort 2	70.1			
Surrogate	Release 1	68.2	1.0	1.0	1.0
	Release 2	76.6	0.9	0.9	
	Release 3	69.5	1.0	1.0	
Production	Hells Canyon (Oxbow)	94.6	1.3	1.3	1.3
	Hells Canyon (Umatilla)	95.9	1.4	1.4	
	Pittsburg Landing	89.9	1.3	1.3	
	Captain John Rapids	91.0	1.3	1.3	
	Couse Creek	93.1	1.3	1.3	
	Cougar Creek	94.8	1.3	1.4	

Table A3.—Calculating similarity indices for comparing the apparent survival (%) between PIT-tagged Clearwater River natural, surrogate, and production fall Chinook salmon subyearlings in migration year 2010. The mean index was used in Table 8.

Group	Subgroup	Apparent survival	Similarity indices vs. cohort 1	Similarity indices vs. cohort 2	Mean index
Release to Lower Granite Dam					
Natural	Cohort 1	55.5			
	Cohort 2	52.7			
Surrogate	Release 1	45.4	1.2	1.2	1.2
	Release 2	41.9	1.3	1.3	
	Release 3	49.6	1.1	1.1	
Production	Hells Canyon (Oxbow)	45.4	0.8	0.9	1.3
	Hells Canyon (Umatilla)	58.9	1.1	1.1	
	Pittsburg Landing	76.2	1.4	1.4	
	Captain John Rapids	88.2	1.6	1.7	
	Couse Creek	77.0	1.4	1.5	
	Cougar Creek	78.3	1.4	1.5	
Lower Granite to Little Goose Dam					
Natural	Cohort 1	70.8			
	Cohort 2	70.1			
Surrogate	Release 1	68.2	1.0	1.0	1.0
	Release 2	76.6	0.9	0.9	
	Release 3	69.5	1.0	1.0	
Production	Hells Canyon (Oxbow)	94.6	1.3	1.3	1.3
	Hells Canyon (Umatilla)	95.9	1.4	1.4	
	Pittsburg Landing	89.9	1.3	1.3	
	Captain John Rapids	91.0	1.3	1.3	
	Couse Creek	93.1	1.3	1.3	
	Cougar Creek	94.8	1.3	1.4	

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. and D.S. Kellar. 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. Waitt, 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.

Connor, W. P. B. D. Arnsberg, S. G. Smith, D. M. Marsh, and W. D. Muir. 2010. 2009 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. 2010. 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., and W. P. Connor. 2004. A study to compare SARs of Snake River fall Chinook salmon under alternative transportation and dam operational strategies. A proposal to the U. S. Army Corps of Engineers, Wall Walla District, Walla Walla, Washington.

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. Moffitt, 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). 2011. Pacific States Marine Fisheries Commission, Portland, Oregon. Available: www.ptagis.org. (July 2011).

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.

Schaller H., P. Wilson, S. Haeseker, C. Petrosky, E. Tinus, T. Dalton, R. Woodin, E. Weber, N. Bouwes, T. Berggren, J. McCann, S. Rassk, H. Franzoni, and P. McHugh. 2007. Comparative Survival Study (CSS) of PIT-tagged Spring/Summer Chinook and Summer Steelhead. Ten-year Retrospective Summary Report. BPA Contract # 19960200.

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. 2011. Distinguishing between natural and hatchery Snake River fall Chinook salmon subyearlings in the field using body morphology. Transactions of the American Fisheries Society 140:21–30.

Tiffan, K.F., W. P. Connor, G. A. McMichael, M. C. Richmond, B.J. Bellgraph, W. A. Perkins, P. S. Titzler, I. D. Welch, J. A. Vucelick, K. A. Deters, and R. A. Buchanan. 2008. Migration delay and survival of juvenile fall Chinook salmon in the vicinity of the confluence of the Snake and Clearwater rivers. 2007 annual report. BPA project 200203200.

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