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

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ABSTRACT

In 2006, we continued a multi-year study to compare smolt-to-adult return rate (SAR) ratios between two groups of Snake River Basin 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 SAR ratios. To increase sample sizes, we also cultured Lyons Ferry Hatchery subyearlings under a surrogate rearing strategy, implanted them with PIT tags, and released them into the Snake and Clearwater rivers to migrate seaward. The surrogate rearing strategy involved slowing 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 2006 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 representative sample of hatchery subyearlings reared under a production rearing strategy and released them into the Snake and Clearwater rivers in 2006 as part of new research on dam passage experiences (i.e., transported from a dam, dam passage via bypass, dam passage via turbine intakes or spillways). The production rearing strategy involved accelerating growth at Lyons Ferry Hatchery, sometimes followed by a few weeks of acclimation at sites along the Snake and Clearwater rivers before release from May to June. Releasing production subyearlings has been suggested as a possible alternative for making inferences on the natural population if surrogate fish were not available. Smolt-to-adult return rates are not reported here, but will be presented in future reports written after workshops and input by federal, state, and tribal researchers. In this report, we compared the postrelease performance of natural subyearlings to the postrelease performance of surrogate and production subyearlings. We made this comparison to help the fisheries community determine which of the two hatchery rearing strategies produced fish that were more similar to natural subyearlings. We compared the following attributes of postrelease performance (1) detection dates at dams, (2) detections during the implementation of summer spill, (3) travel times, (4) migrant sizes, and (5) the joint probability of migration and survival. Overall, we found that postrelease performance was more similar between natural and surrogate subyearlings than between natural and production subyearlings. Further, the similarity between natural and surrogate subyearlings was greater in 2006 than in 2005, partly as the result of changes in incubation and early rearing practices we recommended based on 2005 results.

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 emerge and begin seaward movement earliest in the year followed by fish from the Snake River lower reach, Grande Ronde River, and 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 enter the ocean as yearlings (Arnsberg and Statler 1995; Connor et al. 2002). This "reservoir-type" juvenile life history is important to adult returns and is more prevalent in the Clearwater River than in the Snake River (Connor et al. 2002, 2005; Marsh et al. 2007a).

Understanding how the Snake River Basin fall Chinook salmon population responds to dam passage "strategies" is critical to recovery of this population. We developed a method to evaluate the response to dam passage strategies that accommodates the diverse juvenile life history of Snake River Basin fall Chinook salmon juveniles (Marsh et al. 2007b). This method involves comparing smolt-to-adult return rates (SAR) from release upstream of Lower Granite Reservoir to adult return at Lower Granite Dam between two groups of subyearlings implanted with passive integrated transponder (PIT) tags (Prentice et al. 1990a). Both groups are released upstream of Lower Granite Reservoir, but they are treated differently at Lower Granite, Little Goose, Lower Monumental, and McNary dams (i.e., the collector dams) to represent two different dam passage strategies: (1) transportation with summer spill and (2) bypass with summer spill. Because SARs of anadromous salmonids are usually low, large numbers of fish are required to calculate precise ratios of SARs between treatment groups. Natural fall Chinook salmon subyearlings (hereafter, natural subyearlings) are not currently available in these numbers. Therefore, to compare SARS of different treatment groups for this study, our only option was to tag large numbers of hatchery-reared fall Chinook salmon subyearlings to supplement tagged natural fish.

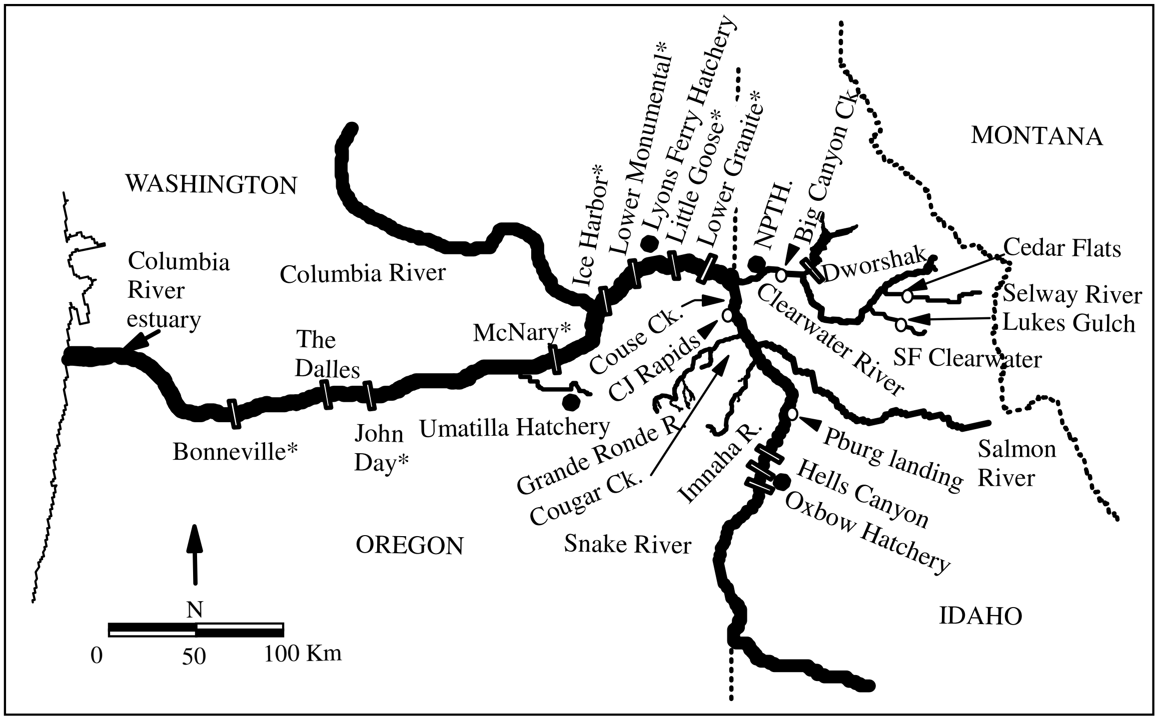


Figure 1.—The four major spawning areas of Snake River Basin fall Chinook salmon upstream of Lower Granite Reservoir include the Snake River upper reach (Hells Canyon Dam to Salmon River), Snake River lower reach (Salmon River to upper end of Lower Granite Reservoir), lower 83 km of the Grande Ronde River, and the lower 65 km of Clearwater River. Lyons Ferry Hatchery is the source 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 include the mouths of Couse and Big Canyon creeks. Release points of production subyearlings include: (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 an asterisk.

Surrogate and production rearing strategies are presently available for rearing large numbers of hatchery subyearlings. The surrogate rearing strategy involves slowing growth of Lyons Ferry Hatchery subyearlings to match the mean size of PIT-tagged natural subyearlings (70–75 mm; Connor et al. 2000) as closely as possible, while insuring that all of the surrogate subyearlings are large enough for tagging (i.e., 60-mm fork length). The surrogate rearing strategy also involves timing PIT tagging and release of the hatchery subyearlings to coincide with rearing and PIT tagging of natural subyearlings in the Snake and Clearwater rivers (e.g., Smith et al. 2003). The production rearing strategy is one of two strategies used to supplement production in the wild. It involves accelerating growth at Lyons Ferry Hatchery to achieve a target fork length of 90–95 mm fork length (Connor et al. 2004), sometimes followed by a few weeks of acclimation at sites along the Snake and Clearwater rivers (Figure 1). In contrast to surrogate subyearlings, the life history timing of natural fish is not considered when scheduling release dates of production subyearlings. Release dates of production subyearlings are based on factors such as in season flow levels, whether or not the fish have grown to the 90–95 mm target size, and the availability of acclimation facilities.

During 1995–2000, we PIT-tagged natural, surrogate, and production, subyearlings to study migrational behavior and survival and to monitor and evaluate supplementation (e.g., Connor et al. 2002, 2003b, 2003c, 2004; Smith et al. 2003). We learned through experience that the similarity in migrational behavior and passage timing at dams was greater between natural subyearlings and surrogate subyearlings than between natural subyearlings and production subyearlings. Thus, we selected the surrogate rearing strategy to provide the necessary numbers of fish for calculating precise SAR ratios when designing and implementing our passage strategy study. We made the first large-scale releases of surrogate subyearlings into the Snake and Clearwater rivers in 2005. Full-term adults began returning from our 2005 surrogate releases in 2007. As per the consensus proposal of Marsh et al. (2007b), we agreed not to report SARs observed for the surrogate releases until after a workshop is held to receive input from state, federal, and tribal researchers.

We made the second annual release of surrogate subyearlings in 2006. In 2006, we also PIT tagged a large number of production subyearlings and released them into the Snake and Clearwater rivers. The SARs from the 2006 production subyearling releases are not intended to represent SARs of natural subyearling, or to provide data for managing the river to increase the SARs of the natural population. As described in the consensus proposal (Marsh et al. 2007b), these releases were made to (1) calculate SARs for monitoring and evaluating supplementation and (2) understand the response of production subyearlings to dam passage "experiences" including transportation(T_0), bypass (C_1), and inriver migration without bypass (C_0). One important background issue requires clarification. The number of Lyons Ferry Hatchery fall Chinook salmon available for supplementation and research is finite. In 2006, culturing production subyearlings was a higher priority than culturing surrogate subyearlings. Surrogate subyearlings were only provided for 2006 research because egg take at Lyons Ferry Hatchery exceeded the level needed for the production subyearling program. Therefore, there is no guarantee that surrogate subyearlings will be available in future years for annual passage strategy research.

The objectives of this report are to: (1) depict passage timing of Snake River

Basin natural, surrogate, and production subyearlings through the lower Snake River in 2006; (2) compare the postrelease performance of 2006 releases of natural subyearlings to the postrelease performance of 2006 releases of surrogate and production subyearlings; and (3) determine if the level of similarity in post release performance between natural subyearlings and the two hatchery subyearling groups varied between the 2005 and 2006 releases. The attributes of postrelease performance we compare include: (1) detection timing; (2) detection during implementation of summer spill; (3) travel time; (4) migrant size; and (5) the joint probability of migration and survival. As in our 2005 analyses (Connor et al. 2007), we also use the results from these comparisons to discuss options for increasing the similarity in postrelease performance of natural and surrogate subyearlings in future years. The goal of this 2006 annual report of research is to provide the fisheries community with empirical information for evaluating our decision to use surrogate subyearlings to study the response of Snake River Basin fall Chinook salmon to passage strategies at dams.

METHODS

Fish Collection, Tagging, and Release

Natural Fall Chinook Salmon Subyearlings

Snake River.—We used a beach seine to capture subyearlings at sites in the free-flowing Snake River, as described by Connor et al. (1998, 2002). Sampling began at the onset of fry emergence in late March and was conducted 3 d/week. A total of 15 permanent stations from rkm 227 to 366 (rkm 0 = Snake River mouth) were sampled every week. During 15 May-6 June, supplemental stations were sampled to increase the number of natural subyearlings PIT tagged. Sampling ended after the first week in July, when catch was near zero.

Origin (hatchery or natural) of unmarked (i.e., adipose fin not clipped) and untagged fish (i.e., no coded wire or PIT tag) was determined based primarily on pupil diameter and body shape. Natural fish had smaller pupils and were more robust than their hatchery counterparts. 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 tissue sample was collected for future genetic analyses. Natural subyearlings 60-mm and longer were implanted with a PIT tag and released at the collection site after a 15-min recovery period.

Clearwater River.—We used beach seines, fyke nets, and rotary screw traps to capture subyearlings in the lower Clearwater River. Seining was conducted during 3 May–1 August along the lower Clearwater River from rkm 7 to 65 (rkm 0 = Clearwater River mouth). Permanent sites were seined 5 d/week 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. A total of four fyke nets were tested 23 June and 6 July. Two 2.4-m diameter rotary screw smolt traps arrived late in the season. The traps were suspended from a railroad bridge along both the north and south shorelines at rkm 20 from 30 June to 4 August. Catch neared zero the first week of August when beach seining and screw trapping were discontinued.

Origin (hatchery or natural) was determined as described for the Snake River. All subyearlings captured by all methods were placed in 18.9-L buckets and then in larger, aerated 114-L plastic holding bins. Subyearlings were anesthetized in a 3-mL MS-222 stock solution (100 g/L) per 19 L of water buffered with a sodium bicarbonate solution. All natural subyearlings were measured to the nearest 1.0 mm FL and weighed to the nearest 0.1 g. Tissue samples were collected (non-lethal upper caudal fin clip) from a random subsample of natural subyearlings for future genetic analyses. Natural subyearlings 60-mm FL and longer were implanted with PIT tags and released at the collection site after a 15-min recovery period.

Surrogate Fall Chinook Salmon Subyearlings

Snake River.**—**Acquisition of Lyons Ferry Hatchery fish for 2006 releases of Snake River surrogate subyearlings was coordinated under *U.S. v. Oregon*. In March, staff at Lyons Ferry Hatchery selected approximately 237,000 of the smaller more uniformly sized subyearlings for our study. We randomly selected 60 of these subyearlings and examined them for *Renibacterium salmoninarum* antigen by ELISA. In addition, gill/kidney/spleen tissue was examined for viruses associated with infectious pancreatic necrosis, infectious hematopoietic necrosis, and viral hemorrhagic septicemia. The ELISA results were low (optical density less than 0.09), and viral tests were negative.

After disease testing was completed, we transported the 237,000 subyearlings from Lyons Ferry Hatchery to Dworshak National Fish Hatchery using a truck equipped with a 7,500-L tank. Oxygen in the tank was kept near 100% saturation during each 3-h trip, with one trip each day on 11 and 12 April 2006. Average fish length was 66 mm FL, and loading density (kg of fish/[tank capacity in L – L water displaced by fish]) was 0.04 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 two separate 36-m^3 raceways supplied with 6.0°C water at approximately 1,136 L/min. Starting fish densities were 8.8 and 7.5 kg/m^3. Fish were split into a third raceway as they grew. Each raceway was treated with 45 kg of coarse water softening salt (NaCl) immediately after fish were transferred, after weekly cleaning, and after crowding during tagging. Surrogates were initially fed No. 2 crumb BioDiet starter. Feed size was increased to No. 1.5 BioDiet growth formula as surrogates grew. Feeding rates varied from 2 to 4% of total body weight to achieve a mean size at release of 70–75 mm FL. There were no bacterial or viral epizootics during rearing.

The subyearlings were taken off feed 24 to 48 h before tagging. Final rearing density in the raceways before tagging ranged from 3.0 to 10.4 kg/m^3, well below densities reported to adversely affect adult returns of Chinook salmon (see Martin and Wertheimer 1989; Banks 1994; Ewing and Ewing 1995). Temperatures in the raceways during tagging ranged from 8.7 to 9.9°C. Tagging began on 15 May and was conducted daily during three periods; 15–18 May, 22–26 May, and 30 May–3 June. These periods coincided 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 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 134.2-kHz ISO PIT tags (TX1400ST) using a modified syringe tipped with a 12-gauge hypodermic needle (Prentice et al. 1990a). Used needles were disinfected in a 70% alcohol solution for approximately 10 min before reuse. After tagging, each fish was measured (FL, mm) and each day a subsample of approximately 100 fish was wet weighed to the nearest 0.1 g. 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) or Asotin Washington (19 km downstream of Couse Creek). Releases were made at Asotin on 18, 22, 23, 24, 25 May when flooding prevented road access to Couse Creek. During each 1.5–2-h trip to the release points, oxygen in the tank was kept near 100% saturation. Loading density ranged from 0.01 to 0.02 kg/L. Snake River surrogates were acclimated to ambient river temperature (range, 13.3–14.4°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. Pre-release mortality ranged from 0.0 to 0.3%. The tank was inspected for shed tags after fish were released. Shedding ranged from 0.0 to 0.03%.

Clearwater River.—A critical component of the dam passage strategy study is to represent the population of fall Chinook salmon subyearlings by releasing surrogates into both the Snake and Clearwater Rivers in proportion to previous redd counts in each drainage. Based on these counts, we assumed the Snake River drainage accounted for 70% and the Clearwater River drainage 30% of all redds (hereafter, the "70:30 rule").

Acquisition of Lyons Ferry Hatchery subyearlings for 2006 releases of Clearwater River surrogate subyearlings was coordinated under *U.S. v. Oregon*. In December 2005, staff at Lyons Ferry Hatchery transferred approximately 110,000 eyed eggs to Umatilla Hatchery (Figure 1) where the eggs were incubated in 8–10°C water to delay hatching. In March, we randomly examined 60 of the button-up fry for the diseases described previously for the Snake River surrogate subyearlings. 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 7 April 2006 using a truck equipped with a 7,500-L tank. Oxygen in the tank was kept near 100% saturation during the 4-h trip. Average fish length was 36 mm FL, and loading density was 0.01 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 subyearlings were fed, handled, tagged, and released as described for Snake River surrogates with the following four exceptions. Clearwater River surrogate subyearlings were:

1) reared to final densities of 3.0–4.8 kg/m^3;
2) tagged and released during 19–23 June, 26–30 June, and 05–09 July;
3) transported for only 20-30 min to reach the release site at Big Canyon Creek 57 km upstream from the Clearwater River mouth; and
4) acclimated and released at temperatures ranging from 13.5 to 19.0°C.

Production Fall Chinook Salmon Subyearlings

Production subyearlings that were PIT-tagged and released in 2006 were all of Lyons Ferry Hatchery origin, but rearing and release locations varied as follows. Subyearlings reared at Lyons Ferry Hatchery were released at Captain John Rapids acclimation facility along the Snake River, the mouth of Couse Creek along the Snake River, the mouth of Cougar Creek along the Grande Ronde River, and Big Canyon Creek acclimation facility along the Clearwater River (Figure 1). Subyearlings reared at Oxbow Hatchery were directly released at Hells Canyon Dam (Figure 1). Subyearlings reared at Umatilla Hatchery were directly released at Hells Canyon Dam or were acclimated prior to release at Pittsburg Landing acclimation facility (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 acclimation facilities.

Production subyearlings were PIT tagged with standard methods by both Biomark, Inc. and other agency/tribal staff. Representative weights were not taken. Production subyearlings were not PIT-tagged in exact proportion in 2006 to represent their release distribution within the Snake River Basin upstream of Lower Granite Reservoir, but efforts were made to best represent the population of production subyearlings given existing constraints.

Detection of PIT-Tagged Fish

At Lower Granite Dam, PIT-tagged fish that were collected 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 a fish based on its PIT-tag code (Marsh et al. 1999; Downing et al. 2001). Study fish designated for transport (50% for natural and surrogate subyearlings; 65% 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 rearing capacity or being serviced. Under these situations, which did not occur in 2006, the fish would be routed back to the river. Those fish designated for inriver migration (50% for natural and surrogate subyearlings; 35% for production subyearlings) were routed back to the river.

The PIT-tagged subyearlings continued migration in the river if they were routed from the bypass system back to the river, if they passed Lower Granite Dam under submersible traveling screens and through turbines, or if they passed via the spillways. Those that survived downstream passage were potentially detected at Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dams. Fish were routed at Lower Granite, Little Goose, and McNary dams as described for Lower Granite Dam.

To be detected passing a dam, a PIT-tagged fish must enter the juvenile fish bypass system while flumes containing the PIT-tag detection systems are watered up (e.g., Prentice et al. 1990b). However, at dams along the Snake and Columbia rivers, these flumes were dewatered seasonally during our study. The PIT-tag detection systems were dewatered during the following periods:

(1) Lower Granite Dam 16 December 2006–25 March 2007;
(2) Little Goose Dam 31 October 2006–1 April 2007;
(3) Lower Monumental Dam 30 September 2006–19 March 2007;
(4) Ice Harbor Dam 20 December 2006–5 March 2007;
(5) McNary Dam 28 November 2006– 28 March 2007;
(6) John Day Dam 14 September 2006–2 April 2007; and
(7) Bonneville Dam 20 December 2006–16 February 2007.

Seasonal dewatering of the juvenile fish bypass and PIT-tag detection systems prohibited the detection of study fish that passed the dams during late fall and winter.

Detection data collected in 2006 and 2007 were downloaded from the PIT tag Information System (PTAGIS), a regional database operated and maintained by the Pacific States Marine Fisheries Commission (PSMFC 1996).

Downstream Recapture of Juveniles

We used the separation-by-code system at Lower Granite Dam (e.g., Downing et al. 2001) to recapture a randomly designated sample of PIT-tagged natural, surrogate, and production subyearlings in 2006 and 2007. We also compiled PIT-tag recapture records for fish that were sampled by hook and line by the Idaho Fishery Resource Office in Lower Granite Reservoir during fall 2006. Recaptured fish were measured (FL, mm) and weighed (wet weight, 0.1g) to evaluate size during seaward migration.

Data Analyses

Passage Timing for Combined PIT-tagged Groups

We referred to this particular analysis as a "population level" analysis in Connor et al. (2007). We conducted it to provide an index of passage timing at Lower Granite, Little Goose, and Lower Monumental dams for natural and hatchery fall Chinook salmon moving seaward from points upstream of Lower Granite Reservoir. The first step in this analysis was to pool the data on natural subyearlings from the Snake and Clearwater rivers. Fish were not tagged in proportion to their redd production in the Snake and Clearwater River basins (i.e., while 30% of redd production is in the Clearwater, more than 30% of the tagged fish were from there). Failure to weight the pooled data would put too much weight on the passage timing of Clearwater River fish. To adjust for this discrepancy, weights were calculated so that fish from the Snake River would carry 70% of the weight in the passage index. For example, if we denote the number tagged in the Snake and Clearwater as T_S and T_C, respectively, then the proportion of tagged fish from the Snake is $T_S/(T_S + T_C)$. Any set of weights, W_S and W_C, that satisfy $(W_S T_S)/(W_S T_S + W_C T_C) = 0.70$ will suffice for the index. Setting W_C to 1.0, the weighting factor for the Snake River is $W_S = 1.7$. We also pooled the Snake and Clearwater River surrogate data and the Snake and Clearwater River production data. We weighted the production data to since the fish were not tagged at each release location in proportion to the numbers released at each location.

The probability of a fish being detected at a dam is inversely proportional to the percentage of the outflow at a dam that is routed over the spillways (hereafter, percent spill). Percent spill at the Snake River dams was relatively high in 2006 as the result of the summer spill program. Therefore, it was necessary to expand the weighted daily counts to represent the true number of fish from each PIT-tagged group that passed a particular dam on a given day. We estimated the number of fish from a subyearling group that passed a dam on a particular day in 2006 as the number of detections from that group on that day divided by the estimated detection probability for the appropriate "season." Seasons were defined as follows: season 1 was 15 May–31 August and season 2 was 1 September until the PIT-tag detection system at a dam was dewatered. We used the methods described by Cormack (1964) and Skalski et al. (1998) to estimate the two seasonal detection probabilities separately for each dam and group of subyearlings. For fish that passed the dams after the PIT-tag detection systems were watered up in 2007, we estimated the number of fish from a PIT-tag group that passed a dam on a particular day as the number of detections from that group on that day divided by the daily detection probability estimate (Sandford and Smith 2002) from PIT-tagged yearling fall Chinook salmon released from the three acclimation facilities in 2007. We refer to daily indices as i^ and the sum of the daily indices for migration years 2006 and 2007 combined as I^. We refer to the sum of the daily indices for the separate migration years as $i\hat{}_{2006}$ and $i\hat{}_{2007}$.

Detection Date

All of the postrelease attributes described hereafter were calculated for each of the three subyearling groups and compared separately by river and dam. Unless stated otherwise later in this report, the dams for Snake River analyses included Lower Granite, Little Goose, and Lower Monumental. In the case of the Clearwater River, we focused on Lower Granite Dam because too few natural subyearlings were detected at Little Goose and Lower Monumental dams for statistical analyses. All statistical comparisons were made at alpha = 0.05. In contrast to our 2005 analyses (Connor et al. 2007), we did not expand daily detections by daily detection probability (Sandford and Smith 2002) and treat the expanded numbers as observed data because we encountered problems related to spill and sample sizes that introduced observable error in the expanded numbers. When analyzing the unexpanded detection data we assumed that daily changes in percent spill at the dams was not the sole factor for differences observed between natural subyearlings and the two hatchery subyearling groups.

We used the detection data collected from May 1 2006 to the last day in 2006 the juvenile PIT-tag detection system at a particular dam was watered up (hereafter, migration year 2006 detections) to calculate cumulative detection distributions. We used a two-sample Kolmogorov-Smirnov test to evaluate differences in cumulative detection distributions between natural subyearlings and surrogate subyearlings and between natural subyearlings and production subyearlings at each dam. We reported Kolmogorov-Smirnov D_{max} values in percentage points, which were calculated as the maximum daily difference in cumulative detection distributions between natural and surrogate subyearlings and between natural and production subyearlings.

We also used the migration year 2006 detection data to calculate the percentage of the detections made each month. For the Snake River analyses, we used chi-square analyses of 2 × 3 contingency tables (natural versus one of the other two subyearling groups; May, June, and July) 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 3 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 surrogate subyearlings; June, July, August, September, October, November, and December) for comparing natural and surrogate subyearlings and a 2 x 8 contingency table (natural versus production subyearlings; May, June, July, August, September, October, November, and December) for comparing natural and production subyearlings.

For each of the three groups of subyearlings, we also calculated the percentage of the total detections (i.e., migration years 2006 and 2007 combined) made in migration year 2006. This percentage provided an index of the relative prevalence of subyearling versus yearling migrants in each group, noting that PIT-tag detection systems were dewatered at the dams from late fall of 2006 through the winter of 2007. Therefore, some unknown number of PIT-tagged fish passed dams undetected.

Detection Percentages during Spill Implementation

Summer spill was implemented at Lower Granite, Little Goose, and Lower Monumental Dams from 20 June to 31 August 2006. We calculated the percentage of the migration year 2006 detections made 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. 2007) left some readers with the impression that many natural, surrogate, and production subyearlings were not being exposed to spill because it focused solely on summer spill. To provide the reader a more complete depiction of spill coverage, we calculated the percentage of the migration year 2006 detections made during implementation of spring and summer spill combined.

Travel Time

For each Snake River subyearling detected at one or more of the three Snake River dams during migration year 2006, we calculated travel time to a given dam as the number of days that elapsed between release and detection at the dam. In the case of Captain John Rapids production subyearlings that were released volitionally from 25 May to 28 May, we used a release date of 25 May for every detected fish to calculate travel times because we did not know the actual date a given fish departed from the acclimation site under the volitional release. In the case of the direct releases of production subyearlings into the Grande Ronde River that were released daily during 19 June–21 June, we used a release date of 19 June to calculate travel times. For the present analysis, we did not analyze travel time of production subyearlings reared at Umatilla Hatchery that were scheduled for release at Pittsburg Landing and Hells Canyon Dam. Some of the fish intended for release at these two sites were likely trucked and released at the opposite site indicated in the tagging file. Their release dates were consequently incorrect, which resulted in negative travel times. This error will be corrected after reviewing trucking records at Umatilla Hatchery.

We used a two-way analysis of variance (natural versus one of the other two subyearling groups; Lower Granite, Little Goose, and Lower Monumental dams) to test for differences in mean travel time between natural subyearlings and the two groups of hatchery subyearlings. We transformed (natural logarithm) the travel times to meet the normality assumption. We used Fisher's protected least significant difference method to evaluate pair-wise differences in mean travel time to a particular dam between natural subyearlings and surrogate subyearlings and between natural subyearlings and production subyearlings. In the case of the Clearwater River, plots of residuals were skewed and bimodal even after transforming the travel times. Since we could not meet the normality assumption, we used a median test (Daniel 1978) to compare median travel time to Lower Granite Dam between Clearwater River natural subyearlings and the two groups of hatchery subyearlings.

Migrant Size

We used data collected on fish recaptured at Lower Granite Dam and by hook and line sampling in Lower Granite Reservoir to characterize migrant size. The size characteristics analyzed included mean fork length (mm), mean weight (g) and mean condition factor K (weight divided by the cube of fork length multiplied by 10^5). Sample sizes were too small and unbalanced to conduct statistical analyses because spill decreased the number of subyearlings that were susceptible to diversion and recapture.

Joint Probability of Migration and Survival

Because of the reservoir-type juvenile life history, detection data did not always conform to the classic single-release recapture model described by Cormack (1964) and Skalski et al. (1998). Lowther and Skalski (1998) attempted to develop a model to deal with data of this nature. However, dewatering of PIT-tag detection systems at the dams during late fall and winter resulted in violation of a critical assumption of both the single release and Lowther and Skalski (1998) models.

One option for dealing with this situation was to use only detections of subyearlings that occurred during migration year 2006. This results in data more likely to fit assumptions of the single-release model, but requires a reinterpretation of model parameters. By ignoring information collected on reservoir-type juveniles in migration year 2007, there is no distinction between cessation of “directed” or “active” migration 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 2006.

Natural fall Chinook salmon from the Snake River upper reach rarely exhibit the reservoir-type juvenile life history (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 2006) 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 2007) after the PIT-tag detection systems are watered up, a typical 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 watered up (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 that of survival alone. Therefore, the joint probability estimate has relatively little bias as an estimate of actual survival probability alone.

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; B. Arnsberg, Nez Perce Tribe, unpublished data), 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 typical 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 watered up (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 alone.

We estimated the joint probability of migration and survival (± SE) from release to the tailrace of Lower Granite Dam, from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam, from the tailrace of Little Goose Dam to the tailrace of Lower Monumental Dam for the subgroups of subyearlings as described by Cormack (1964) and Skalski et al. (1998). We multiplied the SE for each estimate by 2 to calculate an approximate 95% confidence interval. The natural subyearling group was divided into subgroups by 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 = 7 in the Snake River; n = 3 release in the Clearwater River).

In contrast to our 2005 Snake River analyses (Connor et al. 2007), we did not: (1) report intra-annual means of the estimates for a subyearling group or (2) estimate the joint probability of migration and survival from release to Lower Monumental Dam. These two results were not reported herein because some of the intermediate estimates made between the tailraces of Lower Granite and Little Goose dams and the tailraces of Little Goose and Lower Monumental dams exceeded 100% (i.e., lacked accuracy), had 95%

C.I.s of ± 20% to ± 60% that contained zero or 100% (i.e. lacked precision) or exceeded 100% and had wide confidence intervals (i.e., lacked both accuracy and precision). In the instance of the Clearwater River analyses, we also noted imprecision in the estimates of natural cohort 2.

We limited our 2006 Snake River analyses to comparisons made between estimates of the joint probability of migration and survival to the tailrace of Lower Granite Dam because all of the estimates for this reach were accurate and the 95% C.I.s were narrower than ± 20%. We also limited our 2006 Clearwater River analysis to comparisons made between natural cohort 1 and the subgroups of hatchery subyearlings because of the estimate for natural cohort 2 was imprecise. We tested for significant differences between joint probability of migration and survival from release to the tailrace of Lower Granite Dam for the subgroups using likelihood ratio tests (alpha = 0.05).

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. We knew in advance that the outcome of these hypothesis tests would be of little use for determining if 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 regardless of the magnitude of the 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 most 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 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 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 the similarity in travel time was more similar between natural and surrogate subyearlings than between natural and production subyearlings.

Values used to calculate the indices varied by attribute. 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 unless no production subyearlings were detected during this month in which case we used the second highest monthly detection percentage for natural subyearlings. For age at migration, we divided the total number of fish detected in migration year 2006 by the total number detected in migration years 2006 to 2007 combined. We used the percentage of the migration year 2006 detections made during summer spill implementation to calculate the indices for this postrelease attribute. We explained similarity indices for travel time in the preceding paragraph. We calculated indices for comparing migrant size using fork length measurements taken at Lower Granite Dam for the Snake River comparisons (the only dam where adequate sample sizes could be collected). We calculated a total of six similarity indices for comparing the joint probability of migration and survival to the tailrace of Lower Granite Dam of the two Snake River natural subgroups and the three Snake River surrogate subgroups (i.e., cohort 1 versus weekly releases 1, 2, 3; cohort 2 versus weekly releases 1, 2, and 3). We then averaged the six indices to produce one index for final comparison (See Appendix Table A1). We followed the same procedure for comparisons made between Snake River natural and production subyearlings and for the Clearwater River subyearlings. We reported both the overall means and medians of the similarity indices for the comparisons made between natural and surrogate subyearlings and natural and production subyearlings. We reported the medians because some of the individual indices were very large. We focused the remainder of the analyses on the means, however, because the large differences in individual indices were biologically meaningful and needed to be given weight in our conclusions.

To determine if the level of similarity varied between migration years 2006 and 2005, we re-analyzed the migration year 2005 data reported in Connor et al. (2007) without adjusting for detection probability to standardize the calculation of similarity indices between migration years. The three most obvious factors for inter-annual variation in similarity levels were: (1) duration of hatchery subyearling releases; (2) inter-annual variation in detection timing and other related postrelease attributes of natural subyearlings; and (3) inter-annual variation in percent spill, and hence detection probability. We evaluated factors 1 and 2 above as described in the following example. Given observed overall mean similarity indices for the comparison between Snake River natural and surrogate subyearlings of 1.6 in 2005 and 1.1 in 2006, we would conclude that the concordance of postrelease attributes increased by 50% between years (1.6 minus 1.1 multiplied by 100). Adding a third weekly release of surrogates in 2006 would be supported as a factor affecting the 50% increase in concordance if the 2006 overall mean similarity index rose to 1.2 when the data collected on fish from the third weekly release were removed from the analysis. We would then conclude that the third surrogate release increased concordance by 10% (re-calculated 2006 overall mean of 1.2 minus the observed overall mean of 2006 overall mean of 1.1 multiplied by 100). Inter-annual variation in the postrelease attributes of natural subyearlings would also be supported as a factor affecting the 50% increase in concordance if the 2006 overall mean similarity index rose to 1.5 when the data collected on natural subyearlings in 2005 were substituted for the data collected on natural subyearlings in 2006. We would then conclude that the inter-annual variation in the postrelease attributes of natural subyearlings increased concordance by 40% (re-calculated 2006 overall mean of 1.5 minus observed overall mean of 1.1 multiplied by 100). Finally, we would conclude that the level of similarity between the postrelease attributes of Snake River natural and surrogate subyearlings increased by 50% from migration year 2005 to migration year 2006 because we added the third weekly release of surrogates and the postrelease attributes of natural subyearlings varied between 2005 and 2006. We used the same approach with data collected on natural and production subyearlings for evaluating factors 1 and 2 above.

Inter-annual variation in percent spill at the dams could affect inter-annual variation in overall mean similarity indices by affecting detection percentages over time. To evaluate percent spill as a factor for inter-annual variation in the 2005 and 2006 overall mean similarity indices, we overlaid frequency histograms of detection date on line graphs of the daily percent spill values at Lower Granite, Little Goose, and Lower Monumental dams from May through August. Inter-annual variation in percent spill would be supported as a factor affecting inter-annual variation in the overall mean similarity indices if daily values of percent spill varied between years and periods of variation coincided with changes in detection percentages.

RESULTS

Fish Collection, Tagging, and Release

The number of subyearlings PIT tagged and released into the Snake River during 2006 was lowest for natural fish and highest for surrogates (Table 1). Natural subyearlings were released in the Snake River over a more protracted period than surrogate or production subyearlings. Seventy-five percent of the Snake River natural subyearling group was tagged and released during the 15 May–03 June release period of the Snake River surrogate subyearlings. Releases of production subyearlings were completed during 1–3 days, except at Captain John Rapids acclimation facility where the fish were volitionally released for 6 days and then crowded into the outlet flume and into the river. Tagged Snake River natural subyearlings averaged 5 mm smaller in fork length at tagging than surrogate subyearlings and 22–33 mm smaller than production subyearlings. Mean condition factor ($K \pm$ SD) at tagging was 1.12 ± 0.1 for natural subyearlings and 0.97 ± 0.1 for surrogate subyearlings.

The number of subyearlings PIT tagged and released into the Clearwater River in 2006 was lowest for natural fish and highest for surrogates (Table 1). Natural subyearlings were released in the Clearwater River over a more protracted period than surrogate or production subyearlings. Sixty-eight percent of the Clearwater River natural subyearling group was tagged and released during the 19 June–09 July release period of the Clearwater River surrogate subyearlings. Releases of production subyearlings were completed in one day at each release site. Natural Clearwater River subyearlings averaged 10 mm smaller in fork length than surrogate subyearlings and 24 mm smaller than production subyearlings. Mean condition factor ($K \pm$ SD) at tagging was 1.11 ± 0.1 for natural subyearlings and 1.0 ± 0.1 for surrogate 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 2006.

Group	Subgroup	*N*	Release dates	Fork length
		Snake River		
Natural		2,154	02 May–29 June	69 ± 8
Surrogates		229,063	15 May–03 June	74 ± 7
Production	Hells Canyon Dam	33,617	02 May, 09 May, 10 May	91 ± 7
	Pittsburg Landing[a]	26,896	22 May, 24 May	98 ± 6
	Couse Creek	15,479	30 May and 31 May	92 ± 6
		10,872	23 June	102 ± 6
	Captain John Rapids	3,487	25 May–30 May	97 ± 8
	Grande Ronde River	25,357	19 June–21 June	98 ± 4
		Clearwater River		
Natural		1,548	05 June–01 August	68 ± 7
Surrogates		97,715	19 June–09 July	78 ± 6
Production	Big Canyon Creek	58,340	26 May	92 ± 7
	Cedar Flats	4,900	13 June	109 ± 6
	Lukes Gulch	4,872	13 June	108 ± 5

[a]These fish may have been accidentally trucked from Umatilla Hatchery and released at Hells Canyon Dam or accidentally trucked from Umatilla Hatchery and released at Pittsburg Landing.

Passage Timing for the Combined PIT-tag Groups

Passage of the combined Snake River and Clearwater River natural subyearlings was protracted over time (Figures 2–4). Natural juveniles were present in Lower Granite, Little Goose, and Lower Monumental reservoirs every month from spring 2006 through spring 2007. Of the natural subyearlings destined to pass Lower Granite Dam in migration year 2006; 0.40% passed during the first week of May, 20.6% passed by the first week in June, 82.7% passed by the first week of July, and 90.3% passed by the first week of August. Of the natural subyearlings destined to pass Little Goose Dam in migration year 2006; 0.0% passed during the first week of May, 9.0% passed by the first week in June, 88.7% passed by the first week of July, and 95.3% passed by the first week of August. Of the natural subyearlings destined to pass Lower Monumental Dam in migration year 2006; 0.0% passed during the first week of May, 8.2% passed by the first week in June, 87.2% passed by the first week of July, and 96.5% passed by the first week of August. Passage was sporadic after the second week of August. Of particular import, 6.1% of the migration year 2006 passage at Lower Granite Dam was observed during the extended water up period 1 November to 16 December. Passage of natural yearlings was documented in early spring 2007 at all three dams, immediately or soon after the juvenile PIT-tag detection systems were watered up.

Passage of the combined Snake River and Clearwater River surrogate subyearlings was protracted over time (Figures 2–4). Surrogate juveniles were present in Lower Granite, Little Goose, and Lower Monumental reservoirs every month from spring 2006 through spring 2007. Of the surrogate subyearlings destined to pass Lower Granite Dam in migration year 2006; 0.0% passed during the first week of May, 27.4% passed by the first week in June, 89.9% passed by the first week of July, and 95.9% passed by the first week of August. Of the surrogate subyearlings destined to pass Little Goose Dam in migration year 2006; 0.0% passed during the first week of May, 4.9% passed by the first week in June, 91.4% passed by the first week of July, and 96.9% passed by the first week of August. Of the surrogate subyearlings destined to pass Lower Monumental Dam in migration year 2006; 0.0% passed during the first week of May, 4.8% passed by the first week in June, 88.3% passed by the first week of July, and 97.7% passed by the first week of August. Passage was sporadic after the second week of August. Consistent with natural subyearlings, a portion (2.3%) of the migration year 2006 passage at Lower Granite Dam was observed during the extended water up period 1 November to 16 December. Passage of surrogate yearlings was documented in early spring 2007 at all three dams, immediately or soon after the juvenile PIT-tag detection systems were watered up.

Passage of the combined Snake River and Clearwater River production subyearlings was compressed over time (Figures 2–4). Production subyearlings were present in Lower Granite, Little Goose, and Lower Monumental reservoirs primarily from spring 2006 to the second week of summer 2006. Of the production subyearlings destined to pass Lower Granite Dam in migration year 2006; 0.1% passed during the first week of May, 62.7% passed by the first week in June, 99.6% passed by the first week of July, and 99.98% passed by the first week of August. Of the production subyearlings destined to pass Little Goose Dam in migration year 2006; 0.0% passed during the first week of May, 42.6% passed by the first week in June, 99.6% passed by the first week of July, and 99.96% passed by the first week of August. Of the production subyearlings destined to pass Lower Monumental Dam in migration year 2006; 0.0% passed during the first week of May, 46.8% passed by the first week in June, 99.5% passed by the first week of July, and 99.97% passed by the first week of August. Few production subyearlings passed Lower Granite (*i*^ = 10), Little Goose (*i*^ = 38), and Lower Monumental (*i*^ = 28) after the second week of August. Very few production subyearlings passed in spring 2007 after the juvenile PIT-tag detection systems were watered up at Lower Granite (*i*^ = 0), Little Goose (*i*^ = 4), and Lower Monumental (*i*^ = 0) dams.

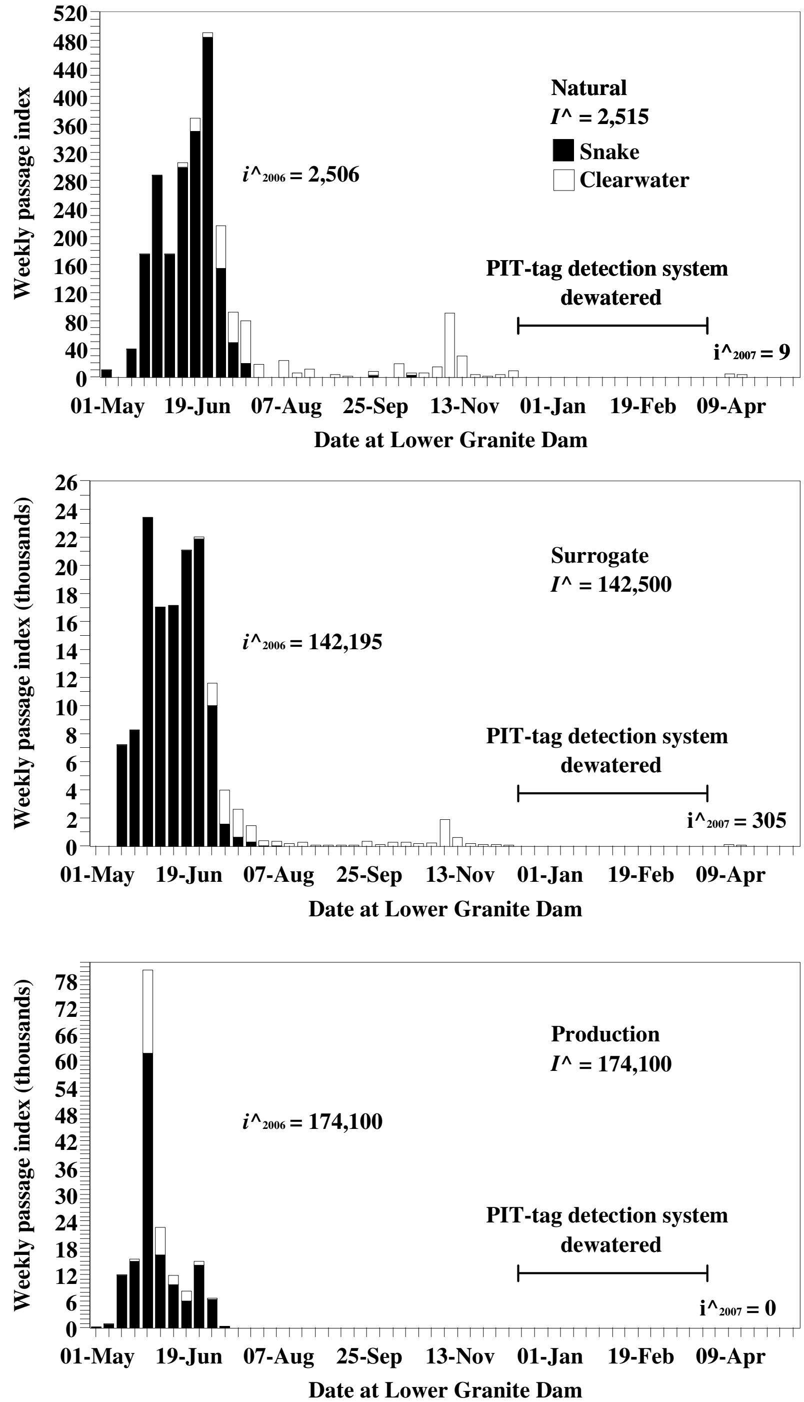


Figure 2.—Weekly passage indices at Lower Granite Dam during migration years 2006 and 2007 for the combined PIT-tagged groups of Snake River and Clearwater River natural (top panel), Snake River and Clearwater River surrogate (middle panel), and Snake and Clearwater River production fall Chinook salmon released in 2006. The weekly indices were summed across migration years 2006 and 2007 ($I^{\wedge}$) and within each migration year ($i^{\wedge}_{2006}$) and 2007 ($i^{\wedge}_{2007}$).

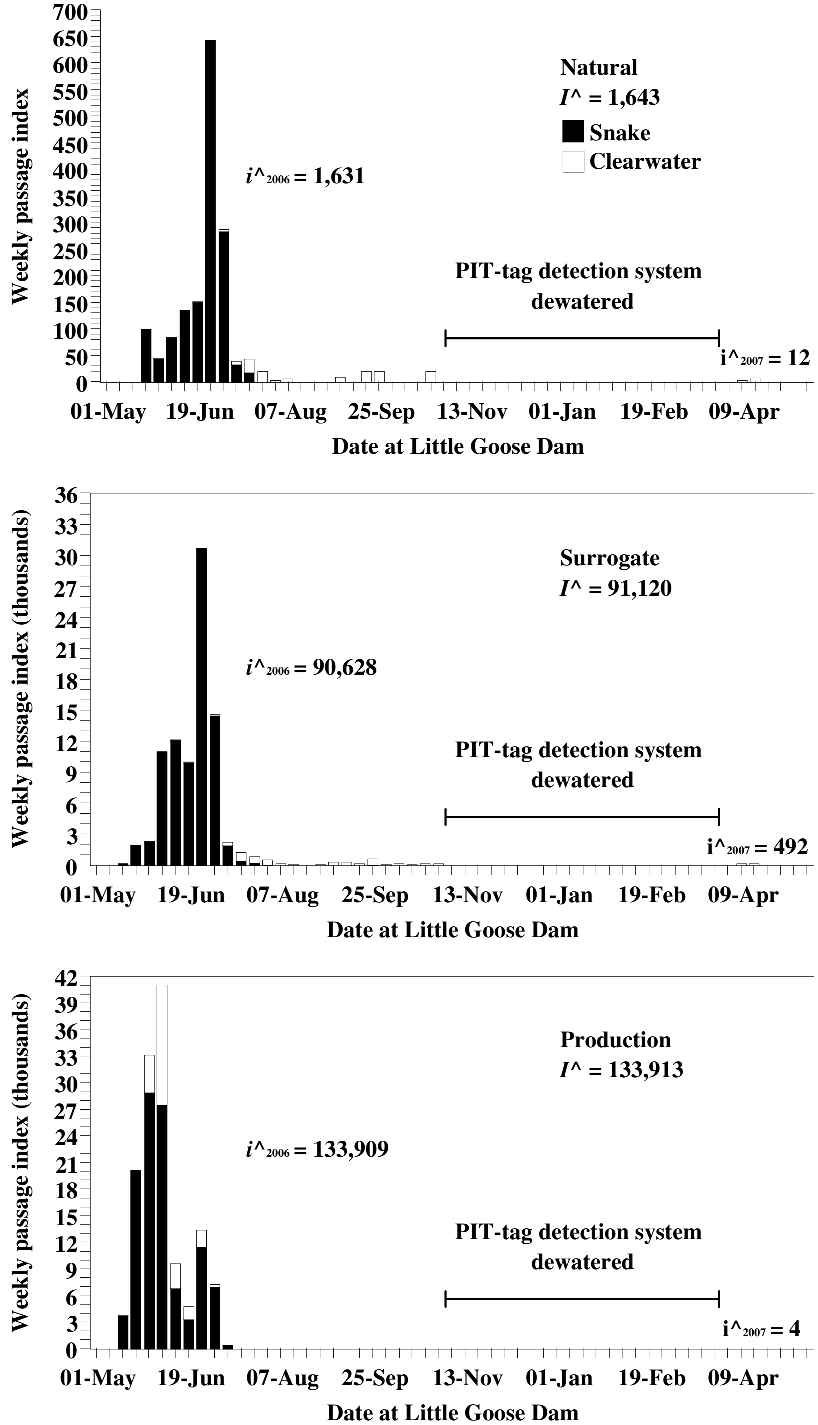


Figure 3.—Weekly passage indices at Little Goose Dam during migration years 2006 and 2007 for the combined PIT-tagged groups of Snake River and Clearwater River natural (top panel), Snake River and Clearwater River surrogate (middle panel), and Snake and Clearwater River production fall Chinook salmon released in 2006. The weekly indices were summed across migration years 2006 and 2007 (*I*^) and within each migration year ($i\hat{}_{2006}$) and 2007 ($i\hat{}_{2007}$).

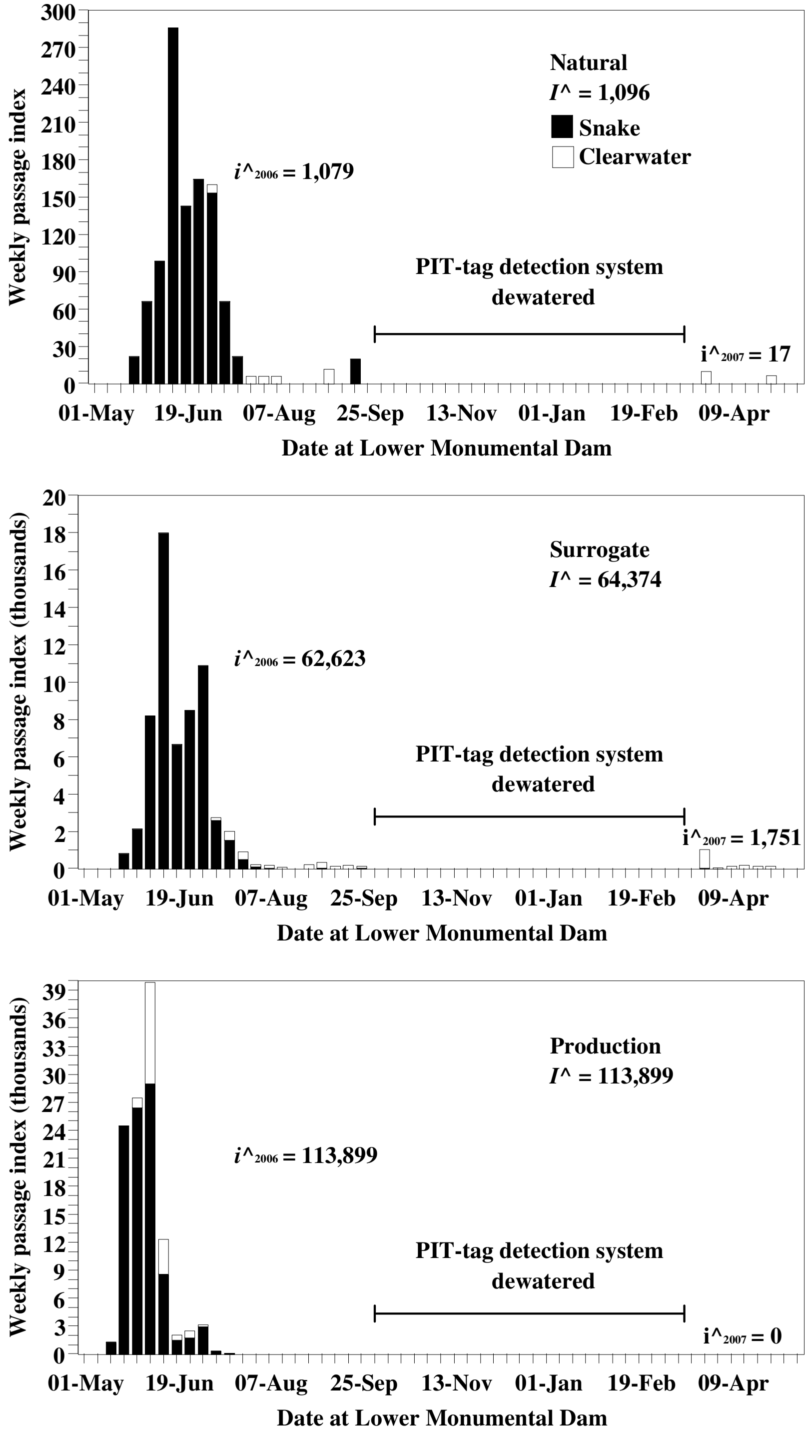


Figure 4.—Weekly passage indices at Lower Monumental Dam during migration years 2006 and 2007 for the combined PIT-tagged groups of Snake River and Clearwater River natural (top panel), Snake River and Clearwater River surrogate (middle panel), and Snake and Clearwater River production fall Chinook salmon released in 2006. The weekly indices were summed across migration years 2006 and 2007 (*I*^) and within each migration year ($i\hat{}_{2006}$) and 2007 ($i\hat{}_{2007}$).

Snake River Comparisons

Detection Date

Snake River natural subyearlings were detected on a later in the summer at Lower Granite and Little Goose dams than surrogate subyearlings (Figure 5). On 15 June when the maximum difference between the two cumulative detection distributions was observed (D_{max} = 11.4 percentage points), 48.3% of the surrogate subyearlings destined to be detected at Lower Granite Dam had already been detected compared to 36.9% for natural subyearlings. Only 3 days elapsed until the 48th percentile of cumulative detection was observed for natural subyearlings at Lower Granite Dam. The difference between the cumulative detection distributions of natural and surrogate subyearlings decreased as the fish passed downstream from Lower Granite Dam to Little Goose (D_{max} = 9.9 percentage points) and from Little Goose Dam (D_{max} = 11.4 percentage points) to Lower Monumental dams (D_{max} = 5.7 percentage points; Figure 5). Consequently, the cumulative detection distributions at Lower Monumental Dam were nearly identical between natural and surrogate subyearlings (Figure 5).

Migration year 2006 cumulative detection distributions varied significantly between Snake River natural and surrogate subyearlings at Lower Granite (P = 0.01) and Little Goose (P = 0.01) dams, but not at Lower Monumental Dam (P = 0.9).

Snake River natural subyearlings were detected at Lower Granite, Little Goose, and Lower Monumental dams on a later in the summer than the Snake River production subyearlings (Figure 5). On 3 June when maximum difference in between the two cumulative detection distributions was observed (D_{max} = 35.5 percentage points), 54% of the production subyearlings destined to be detected at Lower Granite Dam had already been detected compared to 18.5% for natural subyearlings. Another 18 days elapsed until the 54th percentile of detection was observed for natural subyearlings at Lower Granite Dam. In contrast to the observations on natural and surrogate subyearlings, the differences between the cumulative detection distributions of production and natural subyearlings increased as the fish passed downstream from Lower Granite Dam (D_{max} = 35.5 percentage points) to Little Goose Dam (D_{max} = 57 percentage points) and from Little Goose Dam to Lower Monumental dams (70.5 percentage points; Figure 5).

Migration year 2006 cumulative detection distributions varied significantly between Snake River natural and production fish at each dam (all P values < 0.0001).

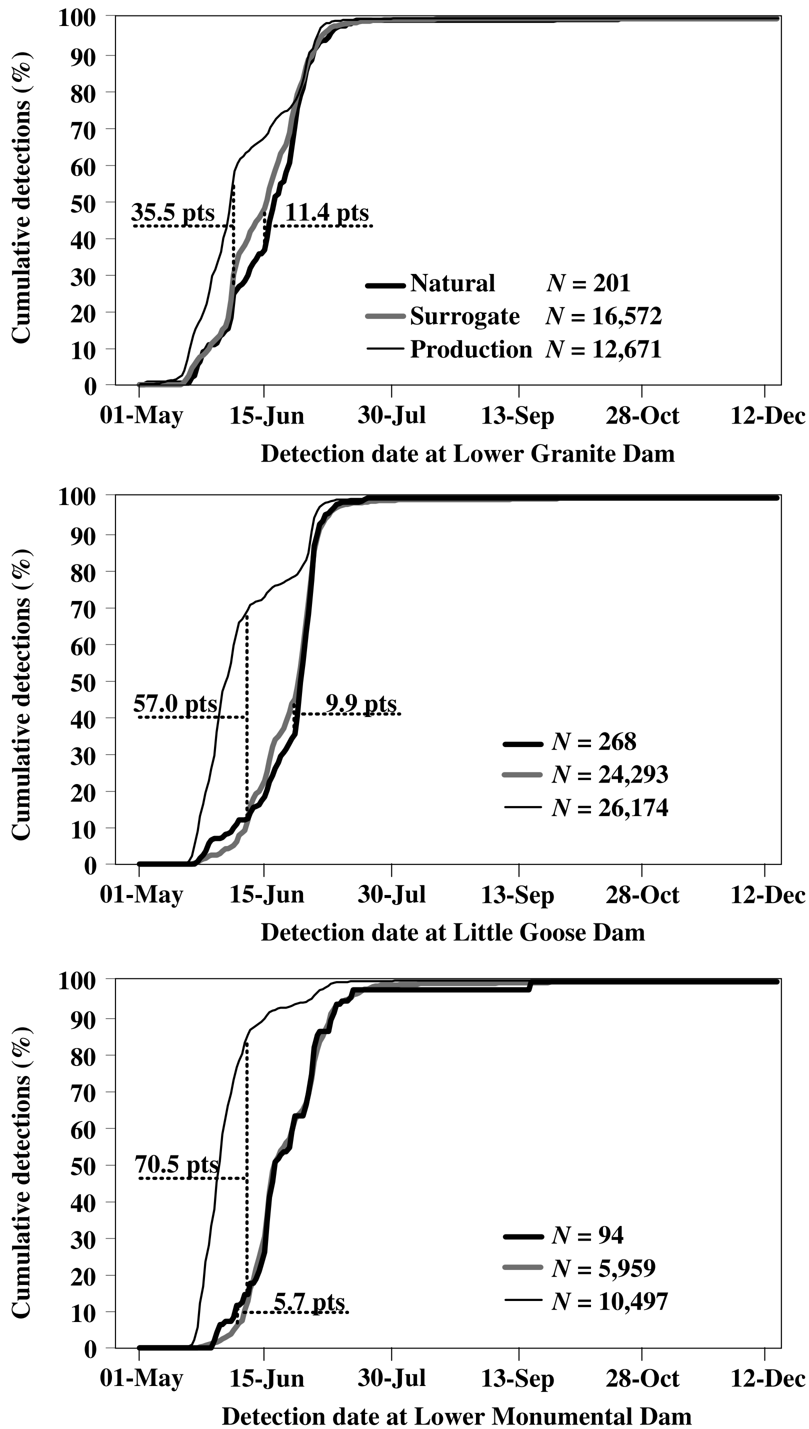


Figure 5.—Cumulative detection distributions at Lower Granite, Little Goose, and Lower Monumental dams for PIT-tagged Snake River natural, surrogate, and production subyearlings in migration year 2006. Percentage points (pts) and dotted arrows indicate D_{max} values calculated as the maximum daily difference between cumulative detection distributions of natural and surrogate subyearlings and between natural and production subyearlings.

The inter-monthly trend in detections at Lower Granite, Little Goose, and Lower Monumental dams in migration year 2006 was similar between Snake River natural and surrogate subyearlings, but there were differences in individual monthly detection percentages between these two groups of subyearlings (Figure 6). June was the peak month of detection in migration year 2006 for natural subyearlings at Lower Granite Dam (71.1% of 2006 detections), Little Goose Dam (56.3% of 2006 detections), and Lower Monumental Dam (60.6% of 2006 detections). June was also the peak month of detection in migration year 2006 for surrogate subyearlings at Lower Granite Dam (71.8% of 2006 detections), Little Goose Dam (63.0% of 2006 detections) and Lower Monumental Dam (64.5% of 2006 detections). Based on these results, there was a 0.0–6.6 percentage point difference in June detections between natural and surrogate subyearlings.

Monthly detections at Lower Granite and Lower Monumental dams in migration year 2006 did not vary significantly (2 x 3 contingency table; Lower Granite Dam, $P = 0.6$; Lower Monumental Dam, $P = 0.2$) between Snake River natural and surrogate subyearlings. Monthly detections did vary significantly between natural and surrogate subyearlings at Little Goose Dam (2 x 3 contingency table; both P values < 0.007) because of significant differences in May and June detections (2 x 2 contingency tables; May P value = 0.003; June P value = 0.03; July $P = 0.3$).

The inter-monthly trend in detections at Lower Granite Dam during migration year 2006 was similar between Snake River natural and production subyearlings, but the there were differences in monthly detection percentages between these two groups of subyearlings at the dam (Figure 6). The inter-monthly trends at Little Goose and Lower Monumental dams differed between natural and production subyearlings because detection of the production fish peaked in May and then declined in both June and July. The peak month of detection in migration year 2006 for natural subyearlings was in June at Lower Granite Dam (71.1% of 2006 detections), Little Goose Dam (56.3% of 2006 detections), and Lower Monumental Dam (60.6% of 2006 detections). The percentage of migration year 2006 detections made in June was 48.7% for production subyearlings at Lower Granite Dam, 35.9% at Little Goose Dam, and 36.3% at Lower Monumental Dam Based on these results, there was a 20.4–24.3 percentage point difference in June detections between production and natural subyearlings compared to the previously noted 0.0–6.6 percentage point difference in June detections between natural and surrogate subyearlings.

Monthly detection percentages varied significantly between Snake River natural and production subyearlings at all three dams (2 x 3 contingency tables; all P values < 0.007). Every monthly pair-wise comparison varied significantly (2 x 2 contingency tables; all P values < 0.0001) except at Lower Granite Dam in July ($P = 0.3$).

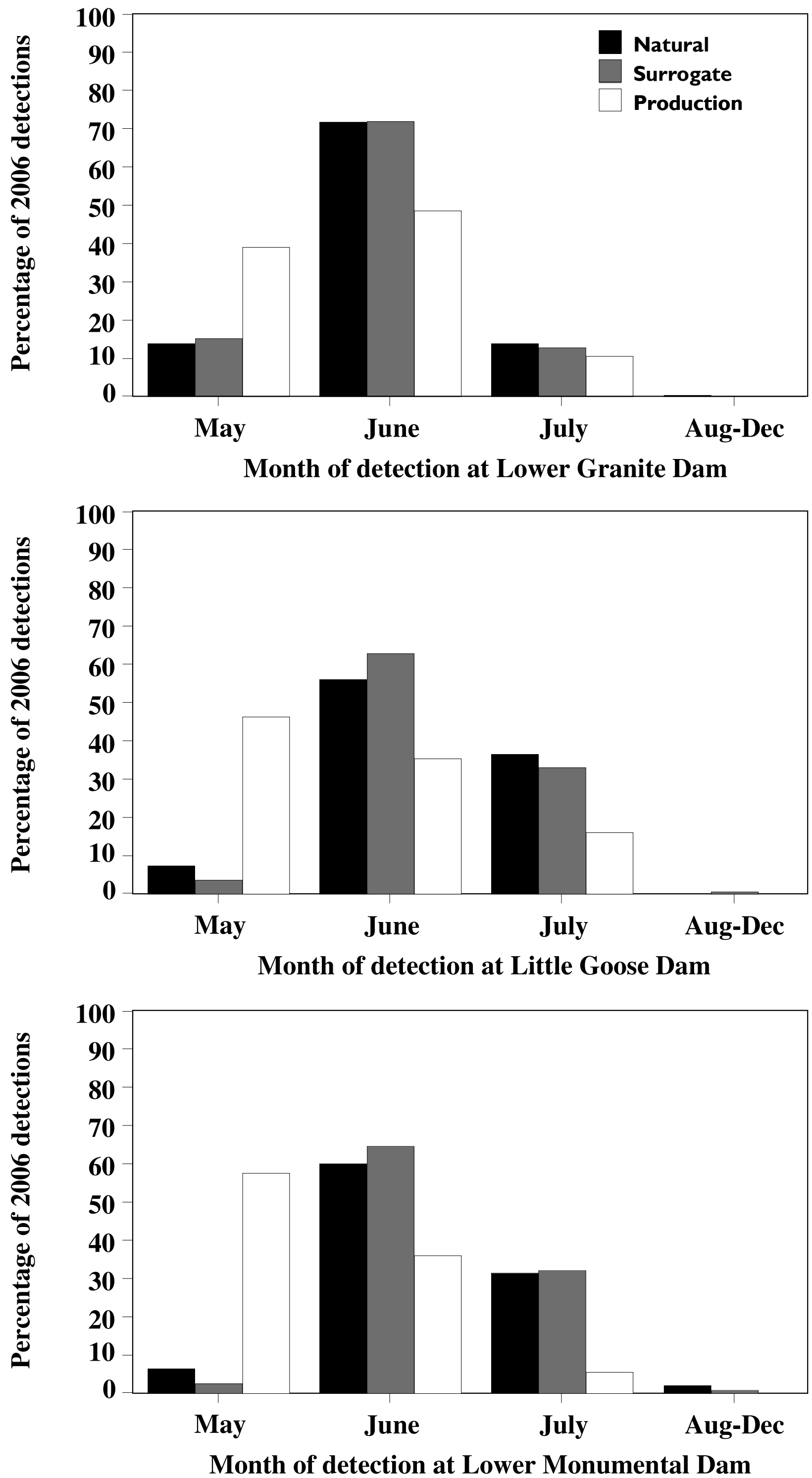


Figure 6.—Monthly percentages of the total detections made during migration year 2006 for PIT-tagged Snake River natural, surrogate, and production subyearlings. The number of detections for each subyearling group is given in Figure 4.

All of the Snake River natural juveniles that were detected at Lower Granite, Little Goose, and Lower Monumental dams were detected in migration year 2006. In the cases of the Snake River surrogate and production subyearlings, very small percentages of the combined detections for migration years 2006 and 2007 detections were made in migration year 2007. These percentages for surrogate subyearlings were 0.006% at Lower Granite Dam, 0.01% at Little Goose Dam, and 0.15% at Lower Monumental Dam. These percentages for production subyearlings were 0% at Lower Granite Dam, 0.004% at Little Goose Dam, and 0% for Lower Monumental Dam.

Detection Percentages during Spill Implementation

The percentage of the migration year 2006 detections made at Lower Granite Dam during summer spill implementation was 47.8% for Snake River natural subyearlings and 41.1% for Snake River surrogate subyearlings (Figure 7). The percentage of the migration year 2006 detections made at Little Goose Dam during summer spill implementation was 73.9% for natural subyearlings and 65.8% for surrogate subyearlings. The percentage of the migration year 2006 detections made at Lower Monumental Dam during summer spill implementation was 47.9% for natural subyearlings and 48.9% for surrogate subyearlings. Based on these results, there was a 1.0–8.1 percentage point difference between the migration year 2006 detection percentages of natural and surrogate subyearlings made during summer spill implementation.

The percentage of the migration year 2006 detections made during summer spill implementation did not vary significantly between Snake River natural and surrogate subyearlings at Lower Granite ($P = 0.06$) or Lower Monumental ($P = 0.8$), whereas the percentage of the migration year 2006 detections made during summer spill implementation at Little Goose Dam was significantly ($P = 0.006$) higher for natural subyearlings than for surrogate subyearlings.

The percentage of the migration year 2006 detections made at Lower Granite Dam during summer spill implementation was 47.8% for Snake River natural subyearlings and 27.4% for Snake River production subyearlings (Figure 7). The percentage of the migration year 2006 detections made at Little Goose Dam during summer spill implementation was 73.9% for natural subyearlings and 23.9% for production subyearlings. The percentage of migration year 2006 detections made at Lower Monumental Dam during summer spill implementation was 47.9% for natural subyearlings and 7.8% for production subyearlings. There was a 20.4–50.0 percentage point difference in percentages of the migration year 2006 detections made during summer spill implementation between natural and production subyearlings compared to the 1.0–8.1 percentage point difference observed between natural and surrogate subyearlings.

The percentage of the migration year 2006 detections made during implementation of summer spill was significantly higher for Snake River natural subyearlings than for Snake River production subyearlings at all three dams (all P values < 0.0001).

Nearly all (98.9–100%) of the Snake River natural, surrogate, and production subyearlings that were detected at Lower Granite, Little Goose, and Lower Monumental dams in migration year 2006 were detected during the implementation of spring and summer spill combined (Figures 7 and 8).

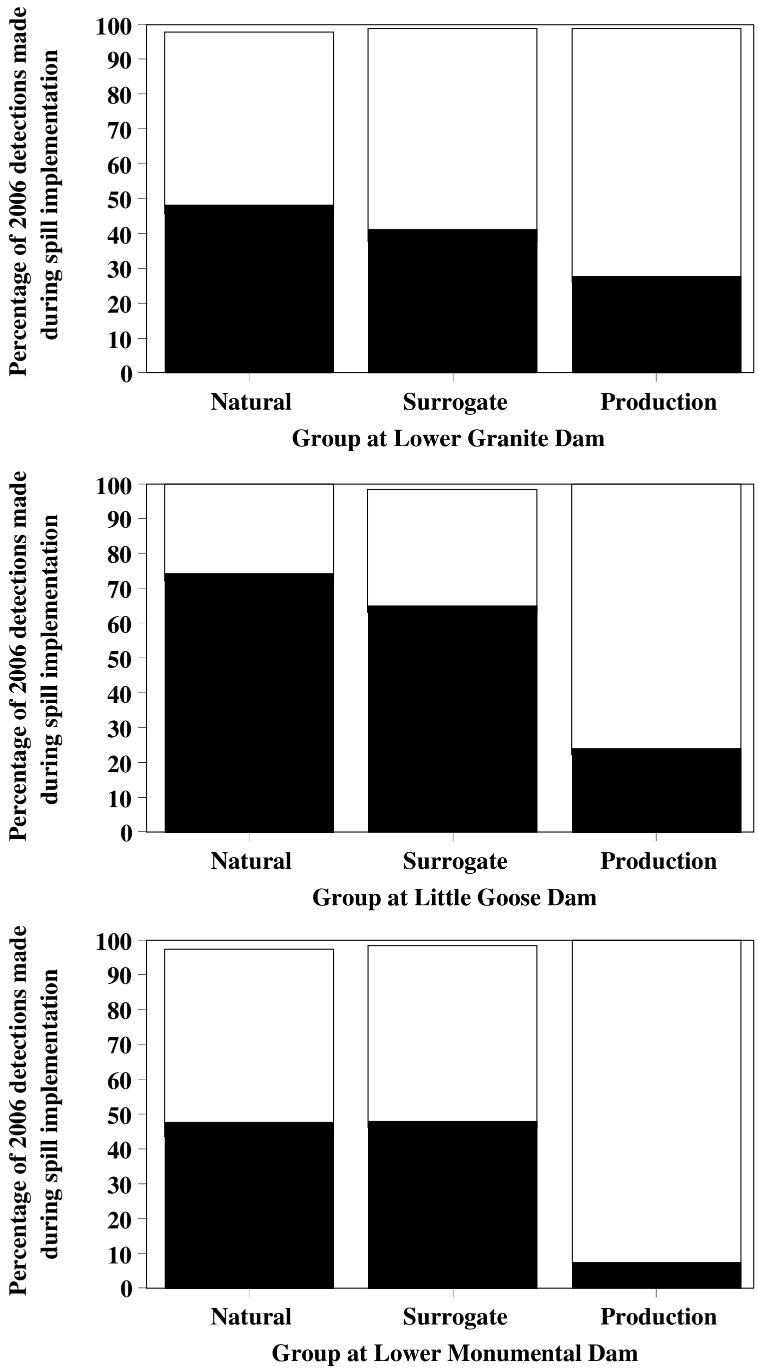


Figure 7.—The percentages of migration year 2006 detections for PIT-tagged Snake River natural, surrogate, and production fall Chinook salmon subyearlings made during summer (black portion of bar) or spring (white portion of bar) spill implementation at Lower Granite (top panel), Little Goose (middle panel), and Lower Monumental (bottom panel) dams in migration year 2006. The number of detections for each subyearling group is given in Figure 5.

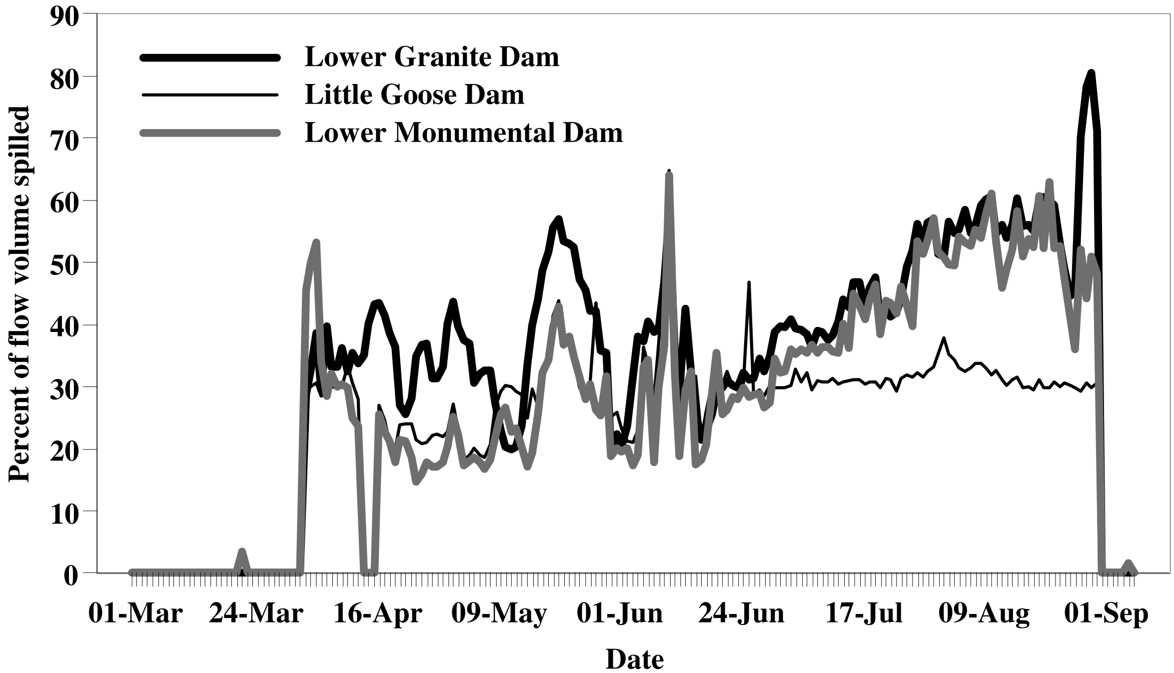


Figure 8.—The percentage of flow volume that was passed over the spillways at Lower Granite, Little Goose, and Lower Monumental dams during the 2006 spring-summer spill program.

Travel Time

Mean travel times to Lower Granite Dam, Little Goose, and Lower Monumental dams in migration year 2006 were longer for Snake River natural subyearlings than for Snake River surrogate subyearlings (Table 2). There was a 2-day difference in mean travel times of natural and surrogate subyearlings to Lower Granite and Little Goose dams. There was a 3-day difference in mean travel time of natural and surrogate subyearlings to Lower Monumental Dam.

Mean travel time to the three dams varied significantly between Snake River natural and surrogate subyearlings in migration year 2006 (two-way analysis of variance; $P < 0.0001$). Mean travel time to Lower Granite Dam was significantly ($P < 0.0001$) longer for natural subyearlings than for surrogate subyearlings, but there was not a significant difference in mean travel times to Little Goose ($P = 0.1$) or Lower Monumental ($P = 0.2$) dams between these two groups of subyearlings.

Mean travel times to Lower Granite Dam, Little Goose, and Lower Monumental dams in migration year 2006 were longer for Snake River natural subyearlings than for Snake River production subyearlings (Table 2). The difference between the mean travel times of natural and production subyearlings was 10 days to Lower Granite Dam, 15 days to Little Goose Dam, and 13 days to Lower Monumental Dam.

Mean travel time to the three dams varied significantly between Snake River natural and production subyearlings in migration year 2006 (two-way analysis of variance; $P < 0.0001$) and all pair-wise comparisons were significant (all P values < 0.0001).

Table 2.—Mean travel time (d ± SD) for PIT-tagged Snake River natural, surrogate, and production subyearlings from release to Lower Granite, Little Goose, and Lower Monumental dams in migration year 2006. The numbers of detected fish (*N*) in the production subyearling group do not match those reported in Figure 4 for reasons on described page 14.

Dam	Group	*N*	Travel time
Lower Granite	Natural	201	24 ± 15
	Surrogate	16,572	22 ± 14
	Production	6,982	14 ± 8
Little Goose	Natural	268	33 ± 12
	Surrogate	24,293	31 ± 11
	Production	11,777	18 ± 7
Lower Monumental	Natural	94	34 ± 13
	Surrogate	5,959	31 ± 12
	Production	4,021	21 ± 6

Migrant Size

For Snake River fish recaptured at Lower Granite Dam in migration year 2006, natural subyearlings averaged 3 mm larger in fork length than surrogates and 9 mm smaller in fork length than production subyearlings (Table 3). All subyearlings were robustly shaped (i.e., $K > 1.0$) when recaptured at Lower Granite Dam, but condition factor was higher for surrogate and production subyearlings than for natural 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 subyearlings released in migration year 2006 and recaptured at Lower Granite Dam in migration year 2006.

		Recapture dates				
Group	*N*	Min	Max	Fork length	Weight	*K*
Natural	15	23-May	06-Jul	94 ± 9	8.9 ± 2.5	1.03 ± 0.1
Surrogate	66	21-May	10-Jul	91 ± 13	8.8 ± 3.6	1.10 ± 0.1
Production	157	30-May	06-Jul	103 ± 21	11.6 ± 2.4	1.05 ± 0.1

Joint Probability of Migration and Survival.

The estimates of the joint probability of migration and survival made for Snake River natural subyearlings from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam, and from the tailrace of Little Goose Dam to the tailrace of Lower Monumental Dam, were inaccurate, imprecise, or both inaccurate and imprecise (Table 4). Inaccuracy and imprecision were also evident in the estimates from the tailrace of Little Goose Dam to the tailrace of Lower Monumental Dam made for production subyearlings released into the Grande Ronde River and the second release of production subyearlings at Couse Creek (Table 4).

The differences between the joint probability of migration and survival to the tailrace of Lower Granite Dam between Snake River natural cohort 1 and the subgroups of surrogate subyearlings ranged from 0.4 to 3.0 percentage points. This range increased to 3.0–4.1 percentage points in the comparison between Snake River natural cohort 2 and the subgroups of surrogate subyearlings.

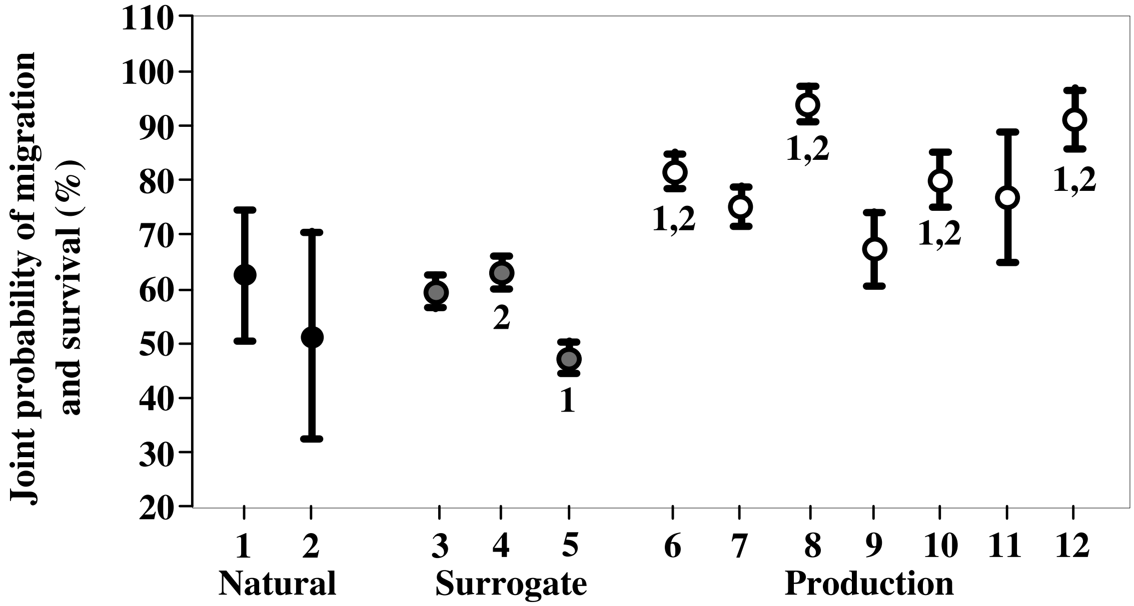
The following differences between joint probability of migration and survival to the tailrace of Lower Granite Dam were significant: Natural cohort 1 had significantly greater survival than Surrogate release 3; Natural cohort 2 had significantly lower survival than Surrogate release 2 (Figure 9). No other comparisons between natural cohorts and surrogate releases were significant.

The differences between the joint probability of migration and survival to the tailrace of Lower Granite Dam between Snake River natural cohort 1 and the subgroups of production subyearlings ranged from 4.7 to 31.5 percentage points. This range increased to 15.8–42.6 percentage points in the comparison between Snake River natural cohort 2 and the subgroups of production subyearlings.

The joint probability of migration and survival to the tailrace of Lower Granite Dam was significantly higher than either natural cohort for production releases from Hells Canyon (Oxbow), Pittsburg Landing, Couse Creek (Early), and Captain John Rapids (Figure 9). The estimated joint probably was also higher than both natural cohorts for production releases from Hells Canyon (Umatilla), Grande Ronde River, and Couse Creek (Late), but the differences were not significant.

Table 4.—The joint probability of migration and survival (% ± 95% C.I.) from release to the tailrace of Lower Granite Dam (LGR), from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam (LGS), from the tailrace of Little Goose Dam to the tailrace of Lower Monumental Dam (LMN), and from release to the tailrace of Lower Monumental Dam for PIT-tagged Snake River natural, surrogate, and production subyearlings in migration year 2006. Estimates that lack accuracy, precision, or both are indicated in bold (see page 18 for criteria).

		Joint probability of migration and survival		
Group	Subgroup	Release to LGR	LGR to LGS	LGS to LMN
Natural	Cohort 1	62.7 ± 12.2	**93.4 ± 24.4**	**89.5 ± 30.2**
	Cohort 2	51.6 ± 18.8	**59.7 ± 28.0**	**151.5 ± 158.0**
Surrogate	Release 1	59.8 ± 2.8	74.6 ± 4.4	82.3 ± 6.0
	Release 2	63.1 ± 2.6	71.8 ± 3.8	85.0 ± 7.2
	Release 3	47.5 ± 2.2	67.8 ± 4.4	80.2 ± 8.4
Production	Hells Canyon (Oxbow)	81.8 ± 3.0	97.4 ± 4.4	85.8 ± 4.2
	Hells Canyon (Umatilla)	75.3 ± 3.8	97.4 ± 6.2	89.3 ± 6.6
	Pittsburg Landing	94.2 ± 3.2	92.5 ± 4.0	80.4 ± 3.8
	Grande Ronde River	67.4 ± 6.6	80.3 ± 10.6	**85.5 ± 26.6**
	Couse Creek Early	80.2 ± 5.0	85.7 ± 7.6	82.5 ± 11.2
	Couse Creek Late	77.1 ± 12.0	75.0 ± 15.8	**110.4 ± 60.6**
	Captain John Rapids	91.3 ± 5.2	88.9 ± 7.4	93.6 ± 12.4



Cohort 1 = 1, Cohort 2 = 2, first weekly release = 3, second weekly release = 4, third weekly release = 5, Hells Canyon Dam (Oxbow Hatchery) = 6, Hells Canyon Dam (Umatilla Hatchery) = 7, Pittsburg Landing acclimation facility = 8, Grande Ronde River = 9, Couse Creek early = 10, Couse Creek late = 11, Captain John Rapids acclimation facility = 12

Figure 9.—The joint probability of migration and survival from release to the tailrace of Lower Granite Dam for subgroups of PIT-tagged Snake River natural, surrogate, and production subyearlings in migration year 2006. An "1" below an estimate for a hatchery subgroup indicates a significant difference between the subgroup and the natural subyearling subgroup cohort 1; whereas, a "2" indicates a significant difference between the hatchery subgroup and the natural subyearling subgroup cohort 2.

Overall Comparison of Attributes

For Snake River fish, the migration year 2005 and 2006 indices showed greater similarity between natural and surrogate subyearlings than between natural and production subyearlings (Table 5 and 6). Overall, there was a 10% difference in the postrelease attributes of natural and surrogate subyearlings compared to a 140% difference for natural and production subyearlings. The level of similarity between the postrelease attributes of Snake River natural and surrogate subyearlings increased by 50% from migration year 2005 to migration year 2006 (Table 7). Adding the third weekly release of surrogates increased the concordance by 10% (Table 7). The detection timing and other related postrelease attributes of natural subyearlings differed between migration years 2005 and 2006, which increased the concordance by 40% (Table 7). Together, these two factors accounted for the 50% increase in similarity observed between natural and surrogate subyearlings from migration year 2005 to migration year 2006 leaving 0% to be explained by other factors.

The level of similarity between the postrelease attributes of Snake River natural and production subyearlings increased by 3,385% from migration year 2005 to migration year 2006 (Table 7). Removing the April releases of production subyearlings made at Hells Canyon Dam in 2005 increased the concordance by 1,830% (Table 7). Adding the June releases of production subyearlings into the Grande Ronde River and at Couse Creek increased the concordance by 130% (Table 7). The detection timing and other related postrelease attributes of natural subyearlings differed between migration years 2005 and 2006, which increased the concordance by 360% (Table 7). Together, these three factors accounted for 2,320% of the increase in similarity observed between natural and production subyearlings from migration year 2005 to migration year 2006 leaving 1,065% of the increase in similarity to be explained by other factors (Table 7).

The largest increases in similarity between the postrelease attributes of Snake River natural and production subyearlings were observed for detection percentages during the peak month of natural subyearling passage at Little Goose and Lower Monumental dams (Tables 5 and 6). Daily variation in percent spill at these two dams between migration years 2006 and 2005, combined with the sensitivity of the similarity indices to small detection percentages, probably explained much of the remaining 1,065% of the increase in similarity observed between these two years for natural and production subyearlings. For example, water was spilled at Little Goose Dam throughout the passage and detection of production subyearlings during migration year 2006 (Figure 10; top panel). This likely reduced the overall variability in detection probability during the migration year 2006 passage period compared to migration year 2005 (Figure 10; bottom panel). During migration year 2005, the majority of the detections were observed for production subyearlings when spill volume was 0% (Figure 10; top panel). Though a clear peak and a decline in detections were evident, and large numbers of production subyearlings would not have been detected in June and July because June releases were not made, the number of production subyearlings detected during these two months would have been higher than was observed if percent spill at Little Goose Dam had not increased so dramatically with the implementation of summer spill (Figure 10; top panel). A higher and relatively constant spill level in the spring of migration year 2005 would have resulted in an increase in the July detection percentage (i.e., the peak month of natural subyearling detection) for production subyearlings, which in turn would have decreased the similarity index calculated to compare detection percentages during the peak month of natural subyearling detections. For each 0.5% increase in the July detection percentage for production subyearlings, the similarity index for peak monthly passage of natural subyearlings would have been greatly reduced (Figure 11).

Table 5.—Similarity indices (higher value divided by lower value of the attribute) for each comparison between 2006 releases of PIT-tagged Snake River natural and the two groups of hatchery 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 percentages except for migrant size (mm) and travel time (days). See page 19 for attribute descriptions.

Attribute	Attribute values: Natural	Attribute values: Surrogates	Similarity indices	Attribute values: Natural	Attribute values: Production	Similarity indices
			Lower Granite Dam			
Cumulative detection	36.8	48.2	1.3	18.4	54.0	2.9
Peak monthly detection	71.1	71.8	1.0	71.1	48.7	1.5
Summer spill detection	47.8	41.1	1.2	47.8	27.4	1.7
Travel time	24	22	1.1	24	14	1.7
2006 detection	100.0	100.0	1.0	100.0	100.0	1.0
Migrant size	94	91	1.0	94	103	1.1
Migration/survival	See Table A1		1.1	See Table A1		1.4
			Little Goose Dam			
Cumulative detection	35.4	45.4	1.3	12.3	69.6	5.7
Peak monthly detection	56.3	63.0	1.1	56.3	35.9	1.6
Summer spill detection	73.9	65.8	1.1	73.9	23.9	3.1
Travel time	33	31	1.1	33	18	1.8
2006 detection	100.0	100.0	1.0	100.0	100.0	1.0
			Lower Monumental Dam			
Cumulative detection	11.7	6.0	1.9	14.9	85.2	5.7
Peak monthly detection	60.6	64.5	1.1	60.6	36.3	1.7
Summer spill detection	47.9	48.9	1.0	47.9	7.8	6.1
Travel time	34	31	1.1	34	21	1.6
2006 detection	100.0	100.0	1.0	100.0	100.0	1.0
Overall mean			1.1			2.4
Overall median			1.1			1.7

Table 6.—Similarity indices (higher value divided by lower value of the attribute) for each comparison between 2005 releases of PIT-tagged Snake River natural and the two groups of hatchery subyearlings. An index value of 1.0 indicates no difference, while a value of 2.0 indicates a two-fold difference and so on. The attribute values are percentages except for migrant size (mm) and travel time (days). See page 19 for attribute descriptions.

Attribute	Attribute values		Similarity indices	Attribute values		Similarity indices
	Natural	Surrogates		Natural	Production	
Lower Granite Dam						
Cumulative detection	55.3	74.5	1.3	18.3	75.9	4.1
Peak monthly detection	92.4	90.3	1.0	92.4	54.9	1.7
Summer spill detections	21.1	5.9	3.6	21.1	0.6	33.1
Travel time	27	20	1.4	27	18	1.5
2005 Detections	99.9	100.0	1.0	99.9	100.0	1.0
Migrant size	91	82	1.1	91	100	1.1
Migration/survival	See Table A2		1.2	See Table A2		1.7
Little Goose Dam						
Cumulative detection	32.6	71.8	2.2	10.7	87.5	8.2
Peak monthly detection	59.4	22.1	2.7	59.4	0.2	239.9
Summer spill detections	73.6	38.6	1.9	73.6	1.8	40.9
Travel time	39	30	1.3	39	29	1.4
2005 Passage	98.8	98.5	1.0	98.8	100.0	1.0
Lower Monumental Dam						
Cumulative detection	22.8	59.2	2.6	11.0	87.5	7.9
Peak monthly detection	70.6	35.7	2.0	70.6	0.3	250.5
Summer spill detections	89.0	59.9	1.5	89.0	4.5	19.9
Travel time	39	37	1.1	39	29	1.4
2005 Passage	92.6	99.3	1.1	92.6	100.0	1.1
Overall mean			1.6			36.3
Overall median			1.3			1.7

Table 7.—The difference between the migration year 2006 and 2005 overall mean similarity indices calculated for comparing the postrelease attributes of Snake River natural subyearlings to the postrelease attributes of the two groups of hatchery subyearlings. All values except the overall mean indices are percentages

Natural versus	Overall mean 2006	Overall mean 2005	Overall mean Difference	Amount of difference explained: Early releases	Amount of difference explained: Late releases	Amount of difference explained: Natural timing	Amount of difference explained: Total	Total unexplained
Surrogates	1.1	1.6	50		10	40	50	0
Production	2.4	36.3	3,385	1,830	130	360	2,320	1,065

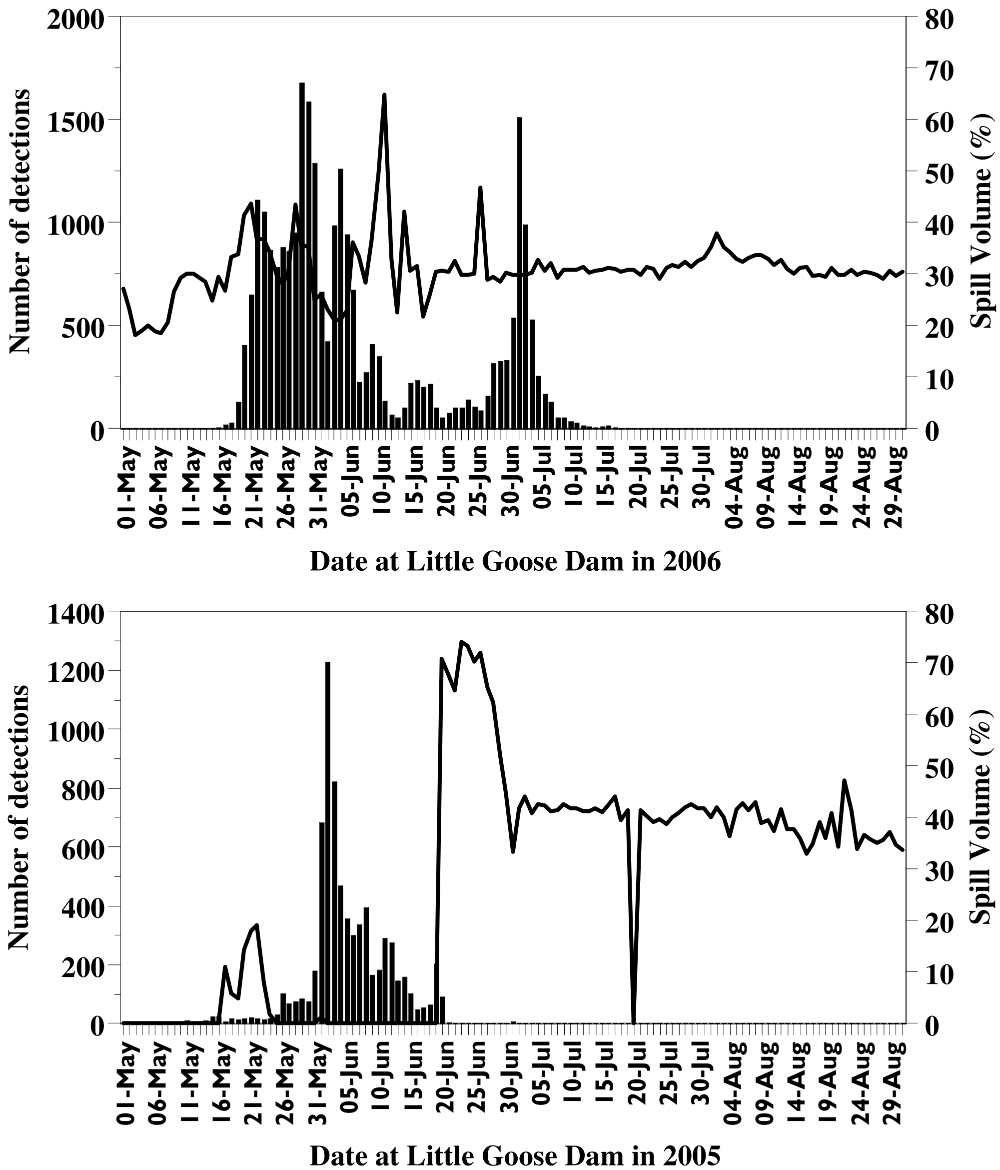


Figure 10.—Detection timing of PIT-tagged Snake River production subyearlings and the percentage of outflow volume spilled at Little Goose Dam in migration years 2006 (top panel) and 2005 (bottom panel).

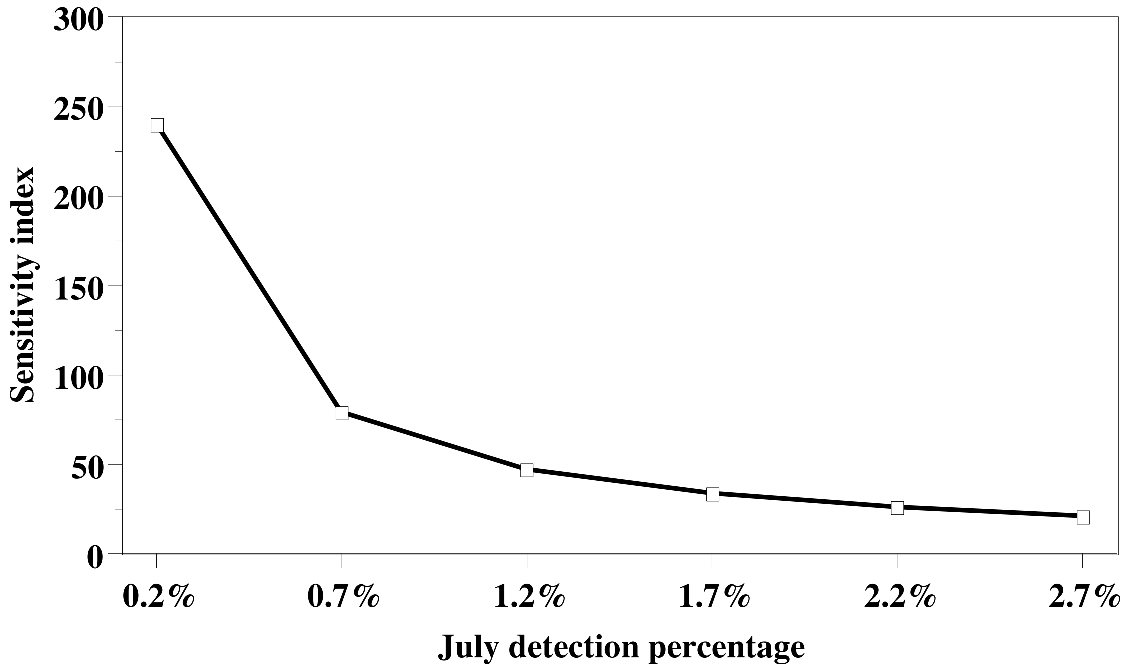


Figure 11.—An example of the sensitivity of the similarity indices sensitivity to small detection percentages. In this example, the percentage of the migration year 2005 detections made in July for natural subyearlings at Little Goose Dam (59.4%; the peak value of monthly detection percentages) was held constant and the detection percentage for July was varied by 0.5% starting with the observed value of 0.2%.

Clearwater River Comparisons

Detection Date

Clearwater River natural subyearlings were detected on an earlier time schedule at Lower Granite Dam than Clearwater River surrogate subyearlings (Figure 12). On 15 August when the maximum difference between the two cumulative detection distributions was observed (D_{max} = 13.2 percentage points), 19.6% of the surrogate subyearlings destined to be detected at Lower Granite Dam had already been detected compared to 32.8% for natural subyearlings. Over the next 62 days the cumulative detection distributions gradually converged until they began to overlap on 23 October.

The migration year 2006 cumulative detection distribution varied significantly between Clearwater River natural and surrogate subyearlings at Lower Granite Dam (P = 0.03).

Clearwater River natural subyearlings were detected at Lower Granite Dam on a later time schedule than Clearwater River production subyearlings (Figure 12). On 3 July when maximum difference in between the two cumulative detection distributions was observed (D_{max} = 95.7 percentage points), 99.6% of the production subyearlings destined to be detected at Lower Granite Dam had already been detected compared to 3.9% for natural subyearlings. A total of 164 days would elapse before the 99th percentile of passage would be observed for natural subyearlings. In contrast to the eventual overlap between the cumulative detection distributions of natural and surrogate subyearlings, the cumulative detection distributions of natural and production subyearlings never overlapped.

The migration year 2006 cumulative detection distributions varied significantly between Clearwater River natural and production subyearlings at Lower Granite Dam (P < 0.0001).

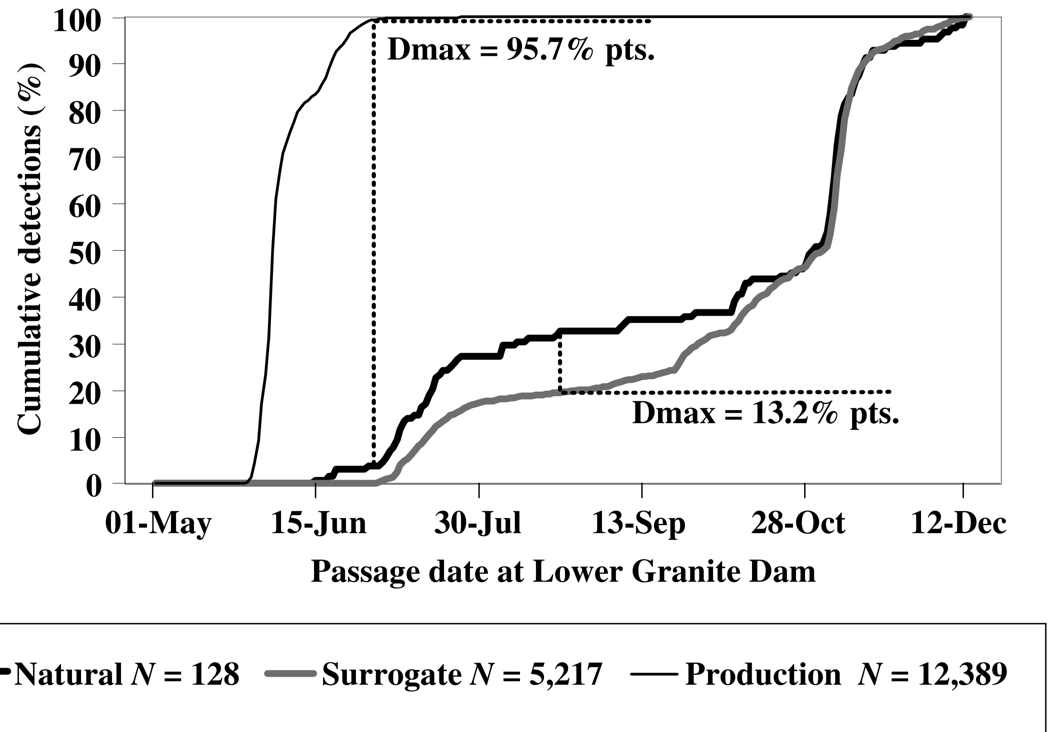


Figure 12.—Cumulative detection distributions at Lower Granite Dam for PIT-tagged Clearwater River natural, surrogate, and production subyearlings in migration year 2006. Percentage points (pts) and dotted arrows indicate D_{max} values calculated as the maximum daily difference between cumulative detection distributions of natural and surrogate subyearlings and between natural and production subyearlings.

The inter-monthly trend in detections at Lower Granite Dam in migration year 2006 was similar between Clearwater River natural and surrogate subyearlings except from August to September when monthly detections decreased for natural subyearlings and increased for surrogate subyearlings (Figure 13). November was the peak month of detection in migration year 2006 at Lower Granite Dam for both natural subyearlings (47.7% of 2006 detections) and surrogate subyearlings (49.6% of 2006 detections). For May through December, the intra-monthly differences in detection percentages between natural and surrogate subyearlings ranged from 0.0 to 6.8 percentage points.

Monthly detection percentages at Lower Granite in migration year 2006 varied significantly (2 x 7 contingency table; $P < 0.0001$) between Clearwater River natural and surrogate subyearlings in migration year 2006. Monthly detections varied significantly between natural and surrogate subyearlings at the dam (2 x 2 contingency tables) in June ($P < 0.0001$), September ($P = 0.03$), and October ($P = 0.04$). Monthly detection percentages did not vary significantly between natural and surrogate subyearlings at the dam (2 x 2 contingency tables) in July ($P = 0.07$), August ($P = 0.08$), November (the peak month of detection; $P = 0.7$), and December ($P = 0.4$).

Neither the inter-monthly trend or individual monthly detection percentages were similar between Clearwater River natural and production subyearlings at Lower Granite Dam in migration year 2006 (Figure 13). June and July were the only two months in migration year 2006 when both of these subyearling groups were detected together in sizeable numbers (i.e., more than one or two detections). Detection of natural subyearlings increased from June to July; whereas, detection of production subyearlings decreased (Figure 13). During the November when detection of natural subyearlings peaked (47.7% of 2006 detections), detection of production subyearlings was low (0.008% of 2006 detections). For May through December, the intra-monthly differences in detection percentages between natural and production subyearlings ranged from 5.5 to 78.2 percentage point compared to 0.0 to 6.8 percentage points for natural versus surrogate subyearlings.

Monthly detections varied significantly between Clearwater River natural and production subyearlings at Lower Granite Dam (2 x 8 contingency table; $P < 0.0001$) from May to December (2 x 2 contingency tables; all P values < 0.0001).

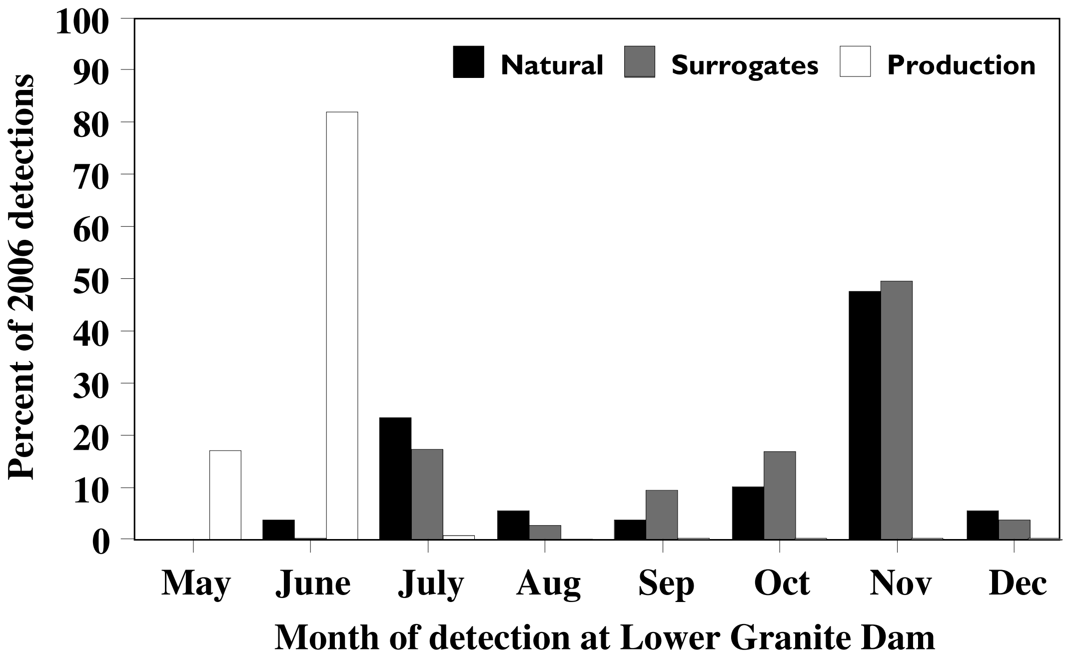


Figure 13.—Monthly percentages of the total detections in migration year 2006 for PIT-tagged Clearwater River natural, surrogate, and production subyearlings. No natural or surrogate subyearlings were detected in May. A small number of surrogate subyearlings were detected in June and small numbers of production subyearlings were detected every month after June except for August. The number of detections for each subyearling group is given in Figure 9.

Detection Percentages during Spill Implementation

The percentage of the migration year 2006 detections made at Lower Granite Dam during summer spill implementation was 31.3% for Clearwater River natural subyearlings and 20.2% for Clearwater River surrogate subyearlings (Figure 14). There was an 11.0 percentage point difference between these two detection percentages. The percentage of migration year 2006 detections made at Lower Granite Dam during summer spill implementation varied significantly ($P = 0.002$) between these two subyearling groups.

The percentage of migration year 2006 detections made at Lower Granite Dam during summer spill implementation was 31.3% for Clearwater River natural subyearlings and 8.9% for Clearwater River production subyearlings (Figure 14). There was a 22.4 percentage point difference between these two detection percentages compared to the 11.0 percentage point difference between natural and surrogate subyearlings. The percentage of the migration year 2006 detections made at Lower Granite Dam during summer spill implementation varied significantly ($P < 0.0001$) between natural and production subyearlings.

Only 1.5% of the migration year 2006 detections for Clearwater River natural subyearlings were made at Lower Granite Dam during spring spill implementation (Figure 14). None of the Clearwater River surrogate subyearlings was detected at Lower Granite Dam during spring spill implementation (Figure 14). Nearly all (99.96%) of the migration year 2006 detections for Clearwater River production subyearlings at Lower Granite Dam were made during the implementation of spring-summer spill combined (Figure 14).

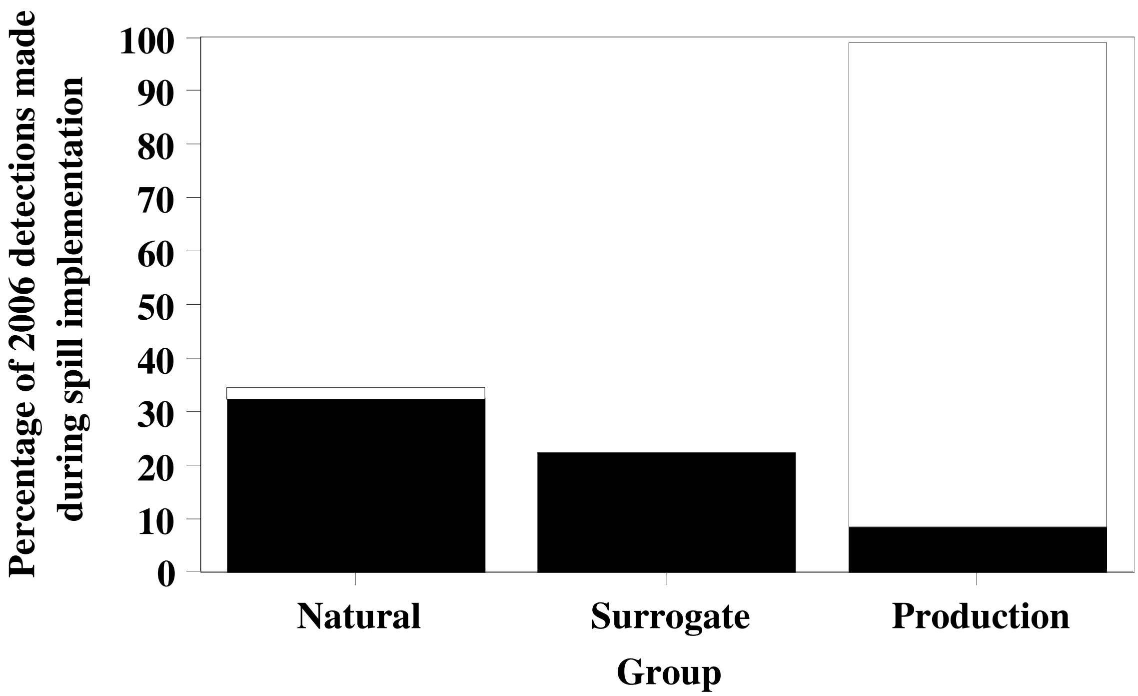


Figure 14.—The percentages of the migration year 2006 detections for PIT-tagged Clearwater River natural, surrogate, and production subyearlings made at Lower Granite Dam during summer (solid portion of bar) or spring (open portion of bar) spill implementation. The number of detections for each subyearling group is given in Figure 12.

Travel Time

The median travel time to Lower Granite Dam in migration year 2006 was 113 days (range, 2–179; mean ± SD, 89 ± 51 days) for Clearwater River natural subyearlings and 123 days (range, 6–177; mean ± SD, 102 ± 43 days) for Clearwater River surrogate subyearlings. The difference in median travel times was 10 days between natural and surrogate subyearlings. Median travel time to Lower Granite Dam varied significantly ($P < 0.0001$) between these two subyearling groups.

The median travel time to Lower Granite Dam in migration year 2006 was 113 days (range, 2–179; mean ± SD, 89 ± 51 days) for Clearwater River natural subyearlings and 8 days (range, 1–203; mean ± SD, 10 ± 6 days) for Clearwater River production subyearlings. The difference in median travel times between natural and production subyearlings was 105 days compared to 10 days between natural and surrogate subyearlings. Median travel time to Lower Granite Dam varied significantly ($P < 0.0001$) between the natural and production subyearlings.

Migrant Size

We did not recapture any Clearwater River natural subyearlings in migration year 2006 because relatively small numbers of fish were tagged and recapture efficiency was reduced by spill during July when passage peaked. Clearwater surrogate subyearlings were smaller and more robust at recapture at Lower Granite Dam than Clearwater production subyearlings (Table 8). We recaptured more surrogate subyearlings residing in Lower Granite Reservoir than at the dam in migration year 2006 (Table 8). These fish, which were likely to become reservoir-type juveniles, were large in fork length and robust (Table 8).

Table 8.—Mean fork length (mm ± SD), weight (g ± SD), and condition factor (*K* ± SD) of PIT-tagged Clearwater River surrogate and production subyearlings recaptured at Lower Granite Dam in migration year 2006 and Clearwater River surrogate subyearlings recaptured by hook and line sampling in Lower Granite Reservoir in migration year 2006.

		Recapture dates				
Group	*N*	Min	Max	Fork length	Weight	K
Recaptured at Lower Granite Dam						
Surrogate	9	06-Jul	25-Jul	96 ± 5	10.0 ± 1.5	1.13 ± 0.06
Production	112	30-May	22-Jun	103 ± 6	11.4 ± 2.3	1.04 ± 0.08
Recaptured in Lower Granite Reservoir						
Surrogate	46	01-Nov	08-Nov	184 ± 14	72.6 ± 20.0	1.15 ± 0.09

Joint Probability of Migration and Survival

The estimates of the joint probability of migration and survival made for Clearwater River natural subyearling cohort 2 from release to the tailrace of Lower Granite Dam was imprecise (Table 9).

The differences between the joint probability of migration and survival to the tailrace of Lower Granite Dam between Clearwater River natural cohort 1 and the subgroups of surrogate subyearlings ranged from 13.2 to 19.6 percentage points. This range increased to 48.1–56.8 percentage points in the comparison between Snake River natural cohort 1 and the subgroups of production subyearlings.

The joint probability of migration and survival to the tailrace of Lower Granite Dam was significantly higher for Clearwater River natural cohort 1 than for the three subgroups of Clearwater River surrogate subyearlings (Figure 15). The joint probability of migration and survival to the tailrace of Lower Granite Dam was significantly lower for Clearwater River cohort 1 than for the three subgroups of Clearwater River production subyearlings (Figure 15).

Table 9.—The joint probability of migration and survival (% ± 95% C.I.) from release to the tailrace of Lower Granite Dam for PIT-tagged Clearwater River natural, surrogate, and production subyearlings in migration year 2006. Estimates that lack precision are indicated in bold (see page 18 for criteria).

Group	Subgroup	Joint probability of migration and survival from release to Lower Granite Dam
Natural	Cohort 1	27.9 ± 18.7
	Cohort 2	**26.6 ± 36.3**
Surrogates	Release 1	14.7 ± 1.5
	Release 2	8.3 ± 1.0
	Release 3	10.4 ± 0.8
Production	Big Canyon Creek	84.7 ± 1.9
	Lukes Gulch	79.6 ± 6.8
	Cedar Flats	76.0 ± 7.2

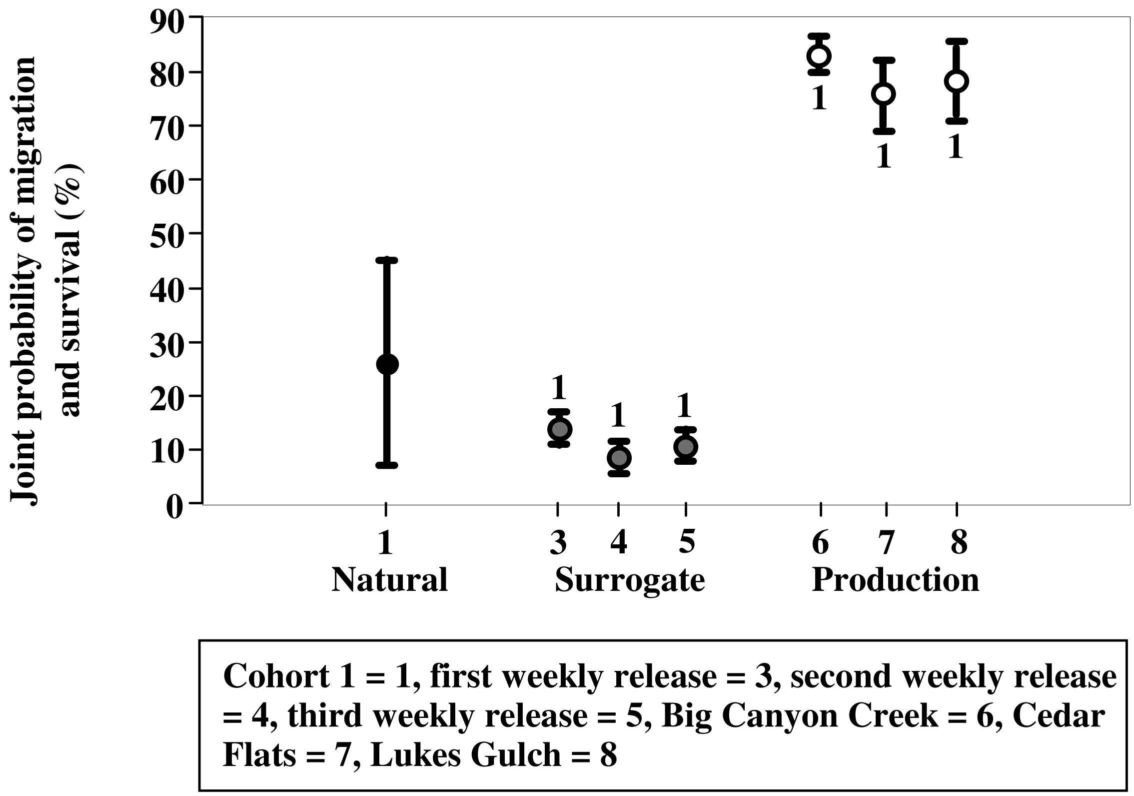


Figure 15.—The joint probability of migration and survival from release to the tailrace of Lower Granite Dam for subgroups of PIT-tagged Clearwater River natural, surrogate, and production subyearlings in migration year 2006. An "1" above or below an estimate for a hatchery subgroup indicates a significant difference between the subgroup and the natural subyearling subgroup cohort 1.

Overall Comparison of Attributes

For Clearwater River fish, the migration year 2005 and 2006 indices showed greater similarity between natural and surrogate subyearlings than between natural and production subyearlings (Table 10). Overall, there was a 60% difference in the postrelease attributes of natural and surrogate subyearlings compared to 1,200% differences for natural and production subyearlings. The level of similarity between the postrelease attributes of Clearwater River natural and surrogate subyearlings increased by 40% from migration year 2005 to migration year 2006 (Table 10). The detection timing and other related postrelease attributes of natural subyearlings differed between migration years 2005 and 2006. This difference accounted for the increase in the similarity of natural and surrogate subyearlings between migration years.

The level of similarity between the postrelease attributes of Clearwater River natural and production subyearlings decreased by 360% from migration year 2005 to migration year 2006 (Table 10). The detection timing and other related postrelease attributes of natural subyearlings differed between migration years 2005 and 2006. This difference accounted for the decrease in the similarity of natural and production subyearlings between migration years.

Table 10.—Similarity indices (higher value divided by lower value of the attribute) for each comparison between 2006 releases of PIT-tagged Clearwater River natural and the two groups of hatchery subyearlings. The indices for 2005 are given for comparison to 2006 results. 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 percentages except for travel time (days). See page 19 for attribute descriptions.

Attribute	Attribute values		Similarity indices	Attribute values		Similarity indices
	Natural	Surrogates		Natural	Production	
Migration year 2006						
Cumulative detection	32.8	19.6	1.7	3.9	99.6	25.5
Peak monthly detection	23.4	17.3	1.4	23.4	0.8	30.9
Summer spill detections	31.3	20.2	1.5	31.3	8.9	3.5
Travel time	113	123	1.1	113	8	14.1
2006 detections	98.5	98.8	1.0	98.5	100.0	1.0
Migration/survival	See Table A2		2.6	See Table A2		2.9
Overall mean			1.6			13.0
Overall median			1.5			8.8
Migration year 2005						
Cumulative detection	27.5	5.7	4.8	15.7	98.9	6.3
Peak monthly detection	11.8	8.3	1.4	11.8	0.8	14.7
Summer spill detections	19.6	19.3	1.0	19.6	3.2	6.1
Travel time	77	116	1.5	77	11	7.3
2006 detections	83.6	88.0	1.1	83.6	99.9	1.2
Migration/survival	See Table A2		1.9	See Table A2		4.5
Overall mean			2.0			6.7
Overall median			1.5			6.2

DISCUSSION

Assumptions and Limitations

Our analysis on the combined PIT-tag groups of subyearlings provides an index of passage timing at Lower Granite, Little Goose, and Lower Monumental dams for natural and hatchery fall Chinook salmon moving seaward from points upstream of Lower Granite Reservoir. Differences in sampling efficiency across the season, an inability to sample every rearing area in the roughly 133 km of riverine habitat upstream of Lower Granite Reservoir, and our present inability to tag fish less than 60-mm fork length made PIT tagging a 100% representative sample of natural fish infeasible. The natural portion of study fish; however, was a generally representative index of the overall natural population of fall Chinook salmon produced upstream of Lower Granite Reservoir.

In contrast to our 2005 analyses on the combined PIT-tag groups of subyearlings (Connor et al. 2007) that were based on daily detection probabilities (Sandford and Smith 2002); we estimated the number of fish from a subyearling group that passed a dam on a particular day in 2006 as the number of detections from that group on that day divided by a seasonal detection probability. We used seasonal detection probability instead of daily detection probability because some anomalies were observed when we applied daily detection probabilities to the 2006 data. For example, more fish were estimated to have passed Little Goose Dam than Lower Granite Dam. Furthermore, the daily detection probabilities for September–November were the lowest we had ever observed for fall migrants. Consequently, adjusting daily detection numbers by daily detection probabilities might have exaggerated November passage. Seasonal detection probabilities addressed these anomalies, but gave rise to another problem. The seasonal detection probabilities did not accurately define daily trends between the onset (e.g., 0–5th percentile) and end (e.g., 95–100th percentile) of passage. Thus, large daily changes in passage could be more of an effect of variation in daily detection probability than daily passage.

In the case of our comparisons of postrelease attributes, we opted against the use of seasonal detection probabilities because statistical analyses of cumulative distributions and monthly percentages are very sensitive to daily trends in passage. We used the unexpanded detection data as an alternative for comparing the postrelease attributes of natural subyearlings to those of the two hatchery subyearling groups. 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 the following: (1) during time t group A passed the dams via the juvenile bypass and PIT-tag detection systems and group B passed under the submersible traveling screens or over the spillways and (2) during time $t + 1$ B passed the dams via the juvenile bypass and PIT-tag detection systems and group A passed under the submersible traveling screens or over the spillways. The large difference in percent spill observed between spring/summer and fall 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, coincident to the emergence of 36-mm natural fry.

Passage Index for the Overall Snake River Basin Population

The passage index for the overall population clearly illustrated the diverse juvenile life history of natural Snake River Basin fall Chinook salmon. Consistent with observations during several non-spill years (e.g., Connor et al. 2002; Marsh et al. 2007a), natural juveniles from the population were present in the Lower Snake River hydropower system year round. Some natural subyearlings migrated downstream actively during spring and early summer, whereas others migrated less actively in late summer and fall. A substantial number of natural subyearlings from the Clearwater River was detected when the PIT-tag detection system at Lower Granite Dam remained watered up for the extended period 1 November–16 December 2006. Some natural subyearlings exhibited a reservoir-type juvenile life history by wintering in reservoirs and resuming seaward movement in spring 2007. An unknown portion of reservoir-type juveniles ceased active migration upstream from Lower Granite Dam and then dispersed downstream during winter, when the PIT-tag detection system was dewatered on 16 December.

Evidence supporting the importance of juvenile life history diversity to production of Snake River Basin fall Chinook salmon is growing beyond the original findings of Arnsberg and Statler (1995), Connor et al. (2002, 2005), and Marsh et al. (2007a). To complete a rigorous and unbiased comparison of transportation and bypass with spill (or transport and bypass without spill), a strategy designed to foster juvenile life history diversity will have to be used to rear large numbers of hatchery fall Chinook salmon subyearlings for tagging and release.

Snake River Natural and Surrogate Subyearlings

Consistent with our 2005 findings (Connor et al. 2007), we conclude the postrelease attributes measured on 2006 releases were more similar between Snake River natural and surrogate subyearlings than between Snake River natural and production subyearlings. Snake River surrogates were also more similar to natural subyearlings in migration year 2006 than they were in 2005. Part of this improvement in surrogate performance resulted from the provision of surrogate subyearlings from Lyons Ferry Hatchery that did not have a bimodal size distribution. This made it easier to control growth and insure that the large majority of the fish designated for release into the Snake River were large enough to tag in late May and early June. In turn, we were able to make all three weekly releases of Snake River surrogate subyearlings in migration year 2006 instead of two as was the case in 2005.

An increase in the similarity in the joint probability of active migration and survival of Snake River natural and surrogate subyearlings would increase the overall similarity in the post-release attributes of these two subyearling groups. However, increasing the joint probability of active migration and survival of the Snake River surrogates will be difficult. We could release surrogates earlier and at larger fork lengths to increase migrational disposition and survival, but increasing the tendency to migrate would decrease the similarity in other post-release attributes of the two Snake River subyearling groups (e.g., Connor et al. 2004). We suggested in Connor et al. (2007) that providing Snake River surrogates of uniform size was a feasible alternative for increasing survival because it had been necessary in 2005 to reduce feed rations for Snake River surrogates to slow growth enough to keep half the fish provided in the 70-75 mm target size range. This resulted in a condition factor of 0.95 that might have reduced survival. Though we were provided with surrogate subyearlings of uniform size in migration year 2006 and condition factor increased modestly to 0.97, we were still unable to match the condition factor of 1.12 observed for natural subyearlings. Whereas condition factor of the surrogate subyearlings was slightly higher in migration year 2006 than in 2005, we did not observe an increase in similarity between the joint probability of active migration and survival of the Snake River natural and surrogate subyearlings. Acclimation for extended periods increases the survival of production subyearlings (S. Rosenberger, Idaho Fishery Resource Office, 2005 and 2006 unpublished data), but acclimation facilities are presently operating at capacity under the production subyearling program. Acclimation also increases rate of seaward movement of production subyearlings. If surrogates were acclimated, they might also have an increased rate of movement, which would decrease the similarity between natural and surrogate subyearlings.

Clearwater River Natural and Surrogate Subyearlings

Consistent with our 2005 findings (Connor et al. 2007), we conclude the postrelease attributes measured on 2006 releases were more similar between Clearwater River natural and surrogate subyearlings than between Clearwater River natural and production subyearlings. Clearwater River surrogates were also more similar to natural subyearlings in migration year 2006 than they were in 2005. We credit this increase to inter-annual variation in the postrelease attributes of natural subyearlings. For Clearwater River fish, the primary differences between natural and surrogate subyearlings were that (1) passage timing and related post-release attributes was earlier for natural subyearlings than for surrogate subyearlings and (2) the joint probability of active migration and survival was higher for natural subyearlings than for surrogate subyearlings. In 2005, we recommended trying a variety of sampling methods in migration year 2006 and the future to capture subyearlings at the confluence of the Snake and Clearwater River. Increasing PIT tagging efforts during the later rearing period of the natural population would increase the sample size of natural subyearlings and probably increase the similarity in passage timing at the dams between natural and surrogate subyearlings as well as the similarity in joint probability of active migration and survival.

Production Subyearlings

The similarity in post-release performance of Snake River natural and production subyearlings increased from 2005 to migration year 2006. This was the result of: (1) moving the release date of production subyearlings cultured at Oxbow Hatchery from April to May; (2) adding a June releases of production subyearlings into the Grande Ronde River and at Couse Creek; (3) inter-annual variation in the postrelease attributes of natural subyearlings; and (4) daily variation in percent spill between migration years 2006 and 2005 combined with the sensitivity of the similarity indices to small detection percentages. Though the similarity increased between natural and production subyearlings from migration year 2005 to 2006, the similarity was still much less than between natural and surrogate subyearlings. For Snake River releases made in 2006, there was a 10% difference in the postrelease attributes of natural and surrogate subyearlings compared to a 140% difference for natural and production subyearlings. For Clearwater River releases made in 2006, there was a 60% difference in the postrelease attributes of natural and surrogate subyearlings compared to 1,200% differences for natural and production subyearlings.

If fish are not provided for surrogate releases in future years, analyses on large tag groups of production subyearlings might be used to shape the summer transportation and spill programs in the Snake and Columbia River basins. If so, the downstream passage environment experienced by natural subyearlings will be determined based on data collected on hatchery fish that are deliberately cultured to migrate seaward at larger sizes, migrate seaward faster, pass downstream in the hydroelectric power system earlier, enter the estuary earlier, and exhibit higher survival than natural subyearlings (e.g., Connor et al. 2002, 2004). Consistent with the consensus proposal of Marsh et al. (2007b), we recommend providing (1) surrogate subyearlings for five release years to evaluate the response of natural subyearlings to dam passage strategies and (2) production subyearlings for five release years to evaluate the response of production subyearlings to dam passage experiences and to evaluate supplementation.

Future Comparisons

A comparison of SARs, as well as other demographics such as age at return, will be an appealing future option for evaluating the similarity between natural fall Chinook salmon and the surrogate and production fall Chinook salmon. Comparisons made on adults will also be subject to limitations and assumptions. Complete demographic data on adults will not be available for several years. As stated previously, we will follow the guidelines proposed for coordinating the analysis of adult return data with the research community (Marsh et al. 2007b). Any analyses made before adult returns are complete, and without coordination, will be premature and possibly misleading. For the present, researchers should be aware that the final number of returning natural adults that had been PIT tagged as subyearlings will be small. Therefore, the SARs will lack precision and using them in comparisons will produce results fraught with uncertainty. In 2008, we plan to increase the sample size of tagged natural subyearlings by tagging natural subyearlings smaller than 60 mm fork length with the new 8.5 mm PIT tag. To reduce the potential for sample size limitations on future comparisons of demographic traits, we also recommend maximizing efforts at the Lower Granite Dam trap to recapture both natural and hatchery adults tagged during our study (Marsh et al. 2007a). This will provide scale data for updating criteria for distinguishing natural from hatchery fish, as well as information on age at return, size at return, and gender composition.

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Table A1.—Calculating similarity indices for comparing the joint probability of migration and survival (%) from release to the tailrace of Lower Granite Dam between PIT-tagged Snake River natural subyearlings and the two groups of PIT-tagged hatchery subyearlings in migration years 2006 and 2005. The mean index was used in Tables 5 and 6.

Group	Subgroup	Joint probability of migration and survival	Similarity indices vs. cohort 1	Similarity indices vs. cohort 2	Mean index
		Migration year 2006			
Natural	Cohort 1	0.627			
	Cohort 2	0.516			
Surrogates	Release 1	0.598	1.0	1.2	1.1
	Release 2	0.631	1.0	1.2	
	Release 3	0.475	1.3	1.1	
Production	Hells Canyon	0.818	1.3	1.6	1.4
	Hells Canyon	0.753	1.2	1.5	
	Pittsburg	0.942	1.5	1.8	
	Grande Ronde	0.674	1.1	1.3	
	Couse Creek	0.802	1.3	1.6	
	Couse Creek	0.771	1.2	1.5	
	CJ Rapids	0.913	1.5	1.8	
		Migration year 2005			
Natural	Cohort 1	0.475			
	Cohort 2	0.448			
Surrogates	Release 1	0.399	1.2	1.1	1.2
	Release 2	0.344	1.4	1.3	
Production	Hells Canyon	0.664	1.4	1.5	1.7
	Pittsburg	0.811	1.7	1.8	
	Couse Creek	0.731	1.5	1.6	
	CJ Rapids	0.846	1.8	1.9	

Table A2.—Calculating similarity indices for comparing the joint probability of migration and survival (%) from release to the tailrace of Lower Granite Dam between PIT-tagged natural subyearlings and the two groups of Clearwater River PIT-tagged hatchery subyearlings in migration years 2006 and 2005. The mean index was used in Table 10.

Group	Subgroup	Joint probability of migration and survival	Similarity indices vs. cohort 1	Similarity indices vs. cohort 2	Mean index
		Migration year 2006			
Natural	Cohort 1	0.279			
Surrogates	Release 1	0.147	1.9		2.6
	Release 2	0.083	3.3		
	Release 3	0.104	2.7		
Production	Big Canyon	0.847	3.0		2.9
	Lukes Gulch	0.796	2.9		
	Cedar Flats	0.760	2.7		
		Migration year 2005			
Natural	Cohort 1	0.147			
Surrogates	Release 1	0.108	1.4		1.9
	Release 2	0.084	1.8		
	Release 3	0.056	2.6		
Production	Big Canyon	0.664	4.5		4.5

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