Snake River Fall Chinook Salmon Run Reconstruction

William Young, Debbie Milks, Stuart Rosenberger, Benjamin Sandford and Stuart Ellis

The fall Chinook salmon run reconstruction was completed through the collaborative efforts of individuals from multiple agencies with funding provided by Lower Snake River Compensation Program, Bonneville Power Administration and Idaho Power Company. The goal of this group was to develop consistent methods for estimating abundance and population composition of fall Chinook salmon returning to Lower Granite Dam (LGR). Methods should be applicable to multiple years regardless of sample collection and data handling method differences, thus providing the ability to estimate trends in abundance and an understanding of changes in population composition of Snake River fall Chinook salmon over time. After reviewing the data collection methods, trapping protocols and hatchery data from the mid 1990's to present, it was determined that the methods described in this report were applicable to at least the 2005 – 2012 return years. The run reconstruction group plans to evaluate the data collection methods from earlier years to determine if these methods could be applied, or modified in some way, to account for data collection/handling discrepancies in prior years. Since 2004 the trapping protocols were developed to systematically sample all fish that returned to LGR, providing a random sample of all fish that ascended the fish ladder. Previous sampling protocols were not random; fish were collected and retained based on the presence of coded wire tags (CWT) and/or exterior marks (visual injectable elastomer tags – VIE). Consequently, it will take additional investigation to determine if the methods developed here will accommodate variation in fish sampling regimes.

Previous run reconstructions began in the 1980's and have proceeded with various methods to account for the changes in fish abundance, sampling effort, collection location and changes in hatchery programs. Changes in fish abundance, hatchery production and broodstock collection were used to separate fall Chinook salmon returns to the Snake River into three distinct periods.

- Returns from 1980 – 1999 the returns were low, with fewer than 1000 adults counted at LGR. The hatchery program was still under development and the majority of juvenile releases occurred at Lyons Ferry Hatchery (LFH). Adult broodstock collections occurred at Ice Harbor, Little Goose and Lower Granite dams, along with LFH. The hatchery program relied on marked hatchery fish as broodstock, with selective trapping of CWT fish at very high rates (80% - 90%).
- Returns from 2000 – 2004 was characterized by rapid increases in abundance for both natural and hatchery fall Chinook salmon. In addition to continued hatchery releases at LFH, the hatchery program scope expanded to include releases above LGR with the initiation of the Fall Chinook Acclimation Project (FCAP). Broodstock collection mainly occurred at LFH, but was supplemented with fish trapped at LGR including, for the first time, unmarked, presumably natural-origin fish. This was possible because the LGR trap

was operated to systematically trap fish at a set rate, although the rate varied over the return period.

- Returns from 2005 – present were characterized by relatively high abundance of both hatchery and natural-origin fish. Full hatchery production was achieved in 2009 with releases above and below LGR. Broodstock were mainly trapped at LGR, with smaller proportions trapped at LFH and NPTH. The LGR trap systematically trapped fish at a set rate, generally 10% - 20%, depending on broodstock needs and predicted run size.

The run reconstruction group had two main goals related to understanding the abundance and population composition of the Snake River fall Chinook salmon population: 1) monitor the status and trends of the natural-origin component of Snake River fall Chinook salmon and; 2) assess the relative contribution of the various hatchery programs in the Snake Basin. Understanding the components described by the goals required a description of the abundance, age, sex composition hatchery fraction and stray rate of the population.

Methods

Daily raw count data were obtained from the U.S. Army Corps of Engineers. Counts of adult and jack Chinook salmon were generated visually through a viewing window in the LGR adult ladder during fall adult return period (08/18–12/15). A size scale mounted within the viewing area was used to distinguish between adults and jacks (less than 56 cm total length). The raw count of the total fish counted for 50 out of 60 minutes per hour was adjusted by dividing by 50/60 (0.833) to estimate the final hourly window count, which was summed over the hours counted to estimate the final daily window count (Figure 1).

Fish were only counted for 16 h/d during the early portion of the run, and the counting period was reduced to only 10 h/d during the latter portion of the run. Night passage was difined as the period when fish were not counted. The night passage rate was estimated using Passive Integrated Transponder (PIT) tag detection data (Prentice et al. 1990a, 1990b, PTAGIS 2012) collected 24 h/d on adults in the ladder and estimated as the percentage of the total detections made during the hours when fish were not counted. Overall, from 2009–2011 data revealed that 96.8% of the PIT-tagged fall Chinook salmon passed the ladder during the daytime counting period and daily window counts were adjusted by dividing by 0.968 (Figure 1). This provided a set of adjusted daily counts for a given year.

Daily counts are sometimes only partially completed or missed due to technical or logistical problems. Partial or missing daily counts were estimated as the average of adjusted daily counts made two days before and two days after the partial/missing counts. These estimated counts were then added to the annual set of adjusted daily counts, which was summed to estimate the total annual window count (Figure 1). Fallback and re-ascension also affected the total window count. These behaviors are addressed at the end of the section.

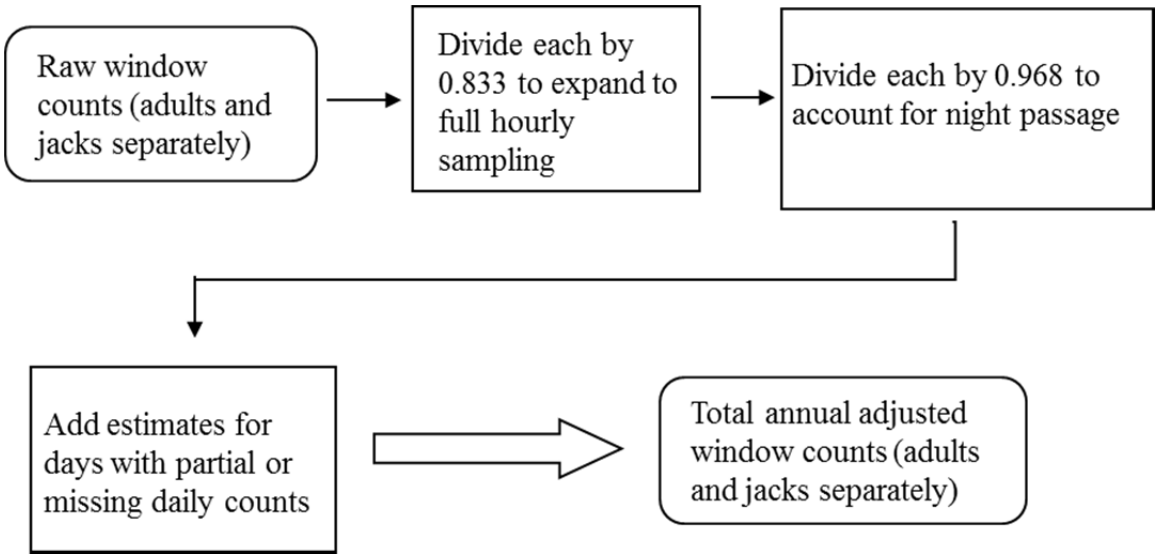


Figure 1. Process of estimating total abundance of adult and jack fall Chinook salmon at Lower Granite Dam by adjusting raw window counts for hourly sampling, night passage and partial and incomplete daily counts.

Population composition of fall Chinook salmon was determined using mark and tag recovery data collected on a sample of adults captured at the adult fish trap at Lower Granite Dam, and then proportionately assigned to the total annual adjusted window count (Figure 2). Tags that were available to identify groups of hatchery fall Chinook salmon distinguished by release location included CWT, PIT tags and visible implant elastomer (VIE) tags. Composition estimates mainly relied on CWT's to determine release year and location because nearly all hatchery releases in the Snake River basin have been represented by CWT's. There was one exception; PIT tags were used to identify hatchery surrogate subyearlings reared and released to mimic naturally-produced juveniles, with nearly 100% PIT tagged.

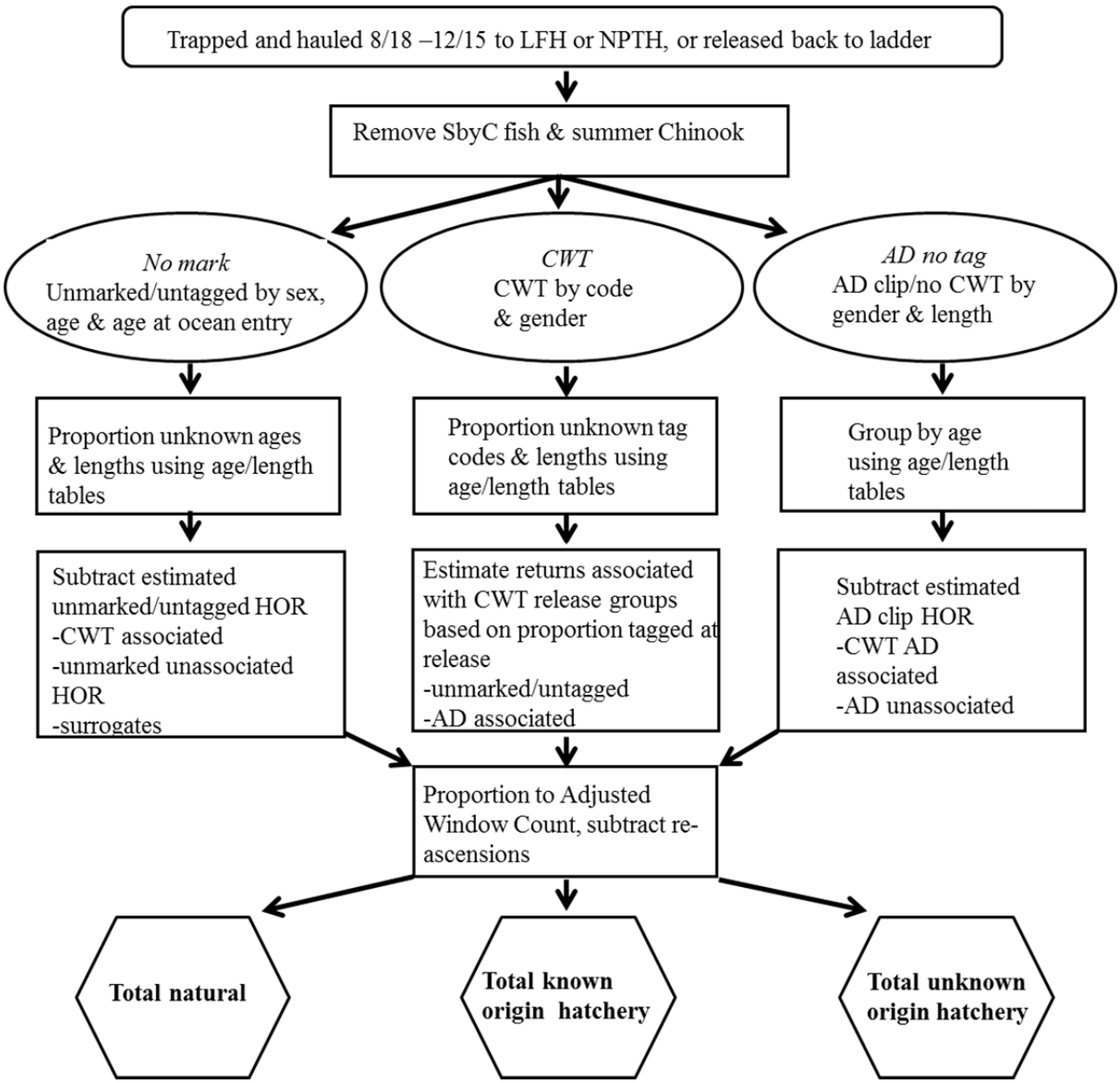


Figure 2. Steps for estimating the population composition of adult fall Chinook salmon returning to Lower Granite Dam.

The adult trap is located about midway in the adult fish ladder. Adults were trapped and diverted into holding tanks as they migrated up the ladder. The trap consisted of an automatic gate system programmed to systematically open at predetermined intervals, providing a systematic sample of all fish passing the ladder (Harmon 2003). The sampling rate was determined prior to 08/18 based on the predicted run size of both fall Chinook salmon and steelhead. The sampling rate needed to be high enough to collect adequate fall Chinook salmon hatchery broodstock to meet mitigation goals, sample fall Chinook for run reconstruction purposes and sample returning adult steelhead. Too high of a trap rate could result in overloading the trap and sampling crews. Trap operations were halted when water temperatures exceeded 20° C. From 2003 – 2012 the trap rates ranged from 9% to 20% and were frequently reduced part-way into sampling period when returns were higher than predicted.

Captured fish were anesthetized and visually examined for external fin clips/marks and tags, and scanned for CWT and PIT tags. Fork length and gender were recorded. Fish selected for broodstock were placed in a tank until transported to Lyons Ferry Hatchery (LFH) or Nez Perce Tribal Hatchery (NPTH) for spawning; fish not retained for broodstock were released into the ladder to continue their migration upstream of the LGR (Figure 6). Unique operculum punch marks were applied to fish from each of the three groups (i.e., released, LFH and NPTH).

The master data file used to estimate the composition of fall Chinook salmon returning to LGR included detailed data collected from three sources; broodstock trapped and transported to LFH and NPTH and fish trapped and released at LGR. The CWT tags were recovered from all wire-tagged fish that were transported to the hatcheries and killed during spawning, but not from live fish released at the trap. Scale samples were taken from all unmarked broodstock and a subset of unmarked released fish. Scale analysis estimated European age (freshwater and ocean residency) and age at ocean entry (i.e., subyearling or yearling). Scales were not used to determine origin (hatchery or natural) information because previous analyses revealed an unacceptably high misclassification rate.

Data collected from years when the sample rate changed part-way through the sampling period were adjusted by weighting the data from fish captured during the different sampling rate periods. This was achieved by dividing the higher sample rate by the lower sample rate. For example, if the trap sampling rate started at 12%, but was lowered to 10%, fish trapped during the 12% sampling period were counted 1 time in the data and fish in the 10% sampling period were counted 1.2 times (12/10 = 1.2). This allowed a single calculation for the run reconstruction as opposed to estimating population abundance and composition separately for fish sampled during each trapping period.

The sort-by-code (SbyC) feature at the trap enabled the capture of fish based on specific PIT-tag codes. Because these fish were not randomly sampled from the population, records of fish possessing SbyC PIT tag codes that entered the trap outside the systematic sampling periods were excluded from the sample. Records for adult fall Chinook salmon that ascended the

hatchery ladders (i.e., volunteered to the hatchery facilities) were also removed based on unique operculum punch patterns, and records for summer Chinook salmon were removed based on visual characteristics.

Individual fish records were categorized into three unique groups: 1) *No Mark* (unmarked and untagged); 2) *CWT* (possessed a CWT); and 3) *AD No Tag* (untagged but adipose fin-clipped). The No Mark group included natural and unmarked hatchery fish. The CWT group consisted of known hatchery fish that possessed a CWT. The AD No Tag group consisted of adipose fin-clipped (known hatchery) fish that did not possess a CWT. Two additional sub-groups were specified based on the data: a) *Surrogate* groups (nearly 100% PIT-tagged but otherwise unmarked) and b) *Unassociated* groups from releases of untagged hatchery fall Chinook salmon subyearlings above LGR. These may have been unmarked, partially AD clipped or 100% AD clipped but were not coded-wire tagged and were a subgroups of the *No Mark* and *AD No Tag* groups accounted for later in the process.

When estimating the composition of each of the above groups, a portion of the fish categorized into the groups lacked complete data records (missing age, length or tag code). Common data gaps included fish identified with a CWT that were released above LGR without recovering the CWT, unmarked fish not scale-sampled or records missing data (unreadable scales). Typically nearly all of the records had length data, so age/length or CWT code/length tables were used to proportion the fish missing data to a matrix of fish of known age or CWT code by length. The critical assumption was that the lengths of the known group were not different from that of the unknown group given a similar age or CWT code. Fish lengths were condensed into 5 cm pools and known fish were grouped by European age or CWT code, then fish lacking ages were proportionally assigned to ages based on pooled length.

The *No Mark* group consisted of natural and unmarked/untagged hatchery fish. Following proportional assignment of unknown age fish using an age/length table constructed from the known-age unmarked/untagged fish as described above, fish were grouped by sex and European ages (all males less than 53 cm FL were considered jacks to match the 56 cm total length window count length criteria). The sample estimate of natural fish was determined by subtracting the estimated sum of unmarked/untagged hatchery-origin fish by sex and European age. Unmarked/untagged hatchery fish were estimated as the sum of unmarked/untagged fish estimated from individual CWT release groups (CWT associated), an estimate of unmarked *unassociated* fish and known *surrogates* (see methods below). This assumed that all unmarked/untagged hatchery fish were identified and did not account for the return of unmarked hatchery strays. This process is referred to as the "subtraction method" for estimating natural-origin returns since it involved estimating all unmarked hatchery fish and subtracting them from the total unmarked group (Figure 6).

The *CWT* group consisted of known hatchery fish that possessed a CWT at capture. Following the proportional assignment of fish lacking CWT codes or lengths using a CWT

code/length table, CWT codes provided brood year, release location and smolt release stage (subyearling or yearling). The number of CWT fish captured was used to estimate the number of untagged CWT-associated fish that would be expected to return, assuming equal survival and no tag loss. This process involved taking the number of recovered CWT fish and dividing it by the known proportion of tagged fish at release for each CWT group (code). Total adipose fin clipped CWT-associated and unclipped CWT-associated fish were summarized by sex and European age and subtracted from the *AD No Tag* and *No Mark* groups, respectively.

The *AD No Tag* group consists of known hatchery fish from the AD clipped, untagged portion of the CWT release groups and unassociated releases, along with an unknown number of out of basin hatchery strays. Following the proportional assignment of fish lacking ages using an age/length table constructed from known age hatchery fish (largely CWT fish), the group was summarized by sex and European age.

The *Surrogate* groups were reared to have similar characteristics as natural juveniles and were assigned to the *No mark* group in the initial categorization. Once identified they were subtracted from the *No mark* fish based on PIT tag codes (they were nearly 100% PIT tagged at release), assuming no tag loss and 100% detection efficiency. For final run reconstruction accounting purposes the surrogate estimate was added to the known-origin (in-basin) hatchery group.

The *Unassociated* groups consisted of untagged (no CWT) releases of hatchery fall Chinook salmon subyearlings in the Snake River basin. Relatively few fish returned from these groups since most hatchery releases were proportionally tagged using CWT or PIT tags (surrogate releases only) and could be evaluated individually using tag recoveries. Unassociated groups may or may not have been marked with adipose-fin clips and would have been assigned to the *No mark* or *AD no tag* groups in the initial categorization. Estimating adult returns from these releases could not be done directly, but required estimating their survival from another release group. Initially the smolt to adult return (SAR) rates from CWT-tagged releases from the same year and site were used, but a closer examination of the SAR rates revealed that SAR rates were highly variable across the basin, with no clear pattern of higher SAR rates from specific release locations or release times (early or late). Therefore, a median SAR of all subyearling releases for a given brood year was used to estimate aggregate returns of all unassociated releases. The median SAR rate was multipled by the unassociated group release numbers to estimate return numbers separately by sex and brood year. Once identified, the unmarked, unassociated fish were subtracted from the *No mark* group and the AD clipped unassociated fish were subtracted from the *AD no tag* group by sex and European age. For final run reconstruction accounting purposes the *Unassociated* groups were added to the known-origin (in-basin) hatchery group.

Final passage abundance estimates for the three groups were determined by proportional allocation to the total annual adjusted window count after accounting for fall back and re-

ascension (Figure 6). A proportion of fish which successfully passed the ladder fell back through the dam and a portion of these re-ascended and were counted again at the window, inflating the window count. Fallback and re-ascension rates were determined by PIT tag detections and mark/recapture analysis and varied depending on age (i.e., jack fallback rate was greater than that of adults). Once the entire systematic sample compositions were applied to the adjusted window count, adults and jacks for each category were then adjusted by multiplying by the pertinent "1 minus the re-ascension rate" to account for re-ascension. Fallback without re-ascension does not affect the estimated return to LGR, but could have a significant impact to the estimates of the abundance and composition of spawner escapement above LGR.

Results

Abundance

Snake River fall Chinook salmon returns to LGR are presented in Figure 3. From 1975 through 1999 returns were generally below 1,000 individuals. Returns increased significantly starting in 2000 for both hatchery- and natural-origin fish with returns greater than 40,000 from 2009 – 2012. Increased abundance over the previous 10 years resulted in the 10-year geometric mean equaling 27,991 and 6,342 for total and natural-origin returns, respectively.

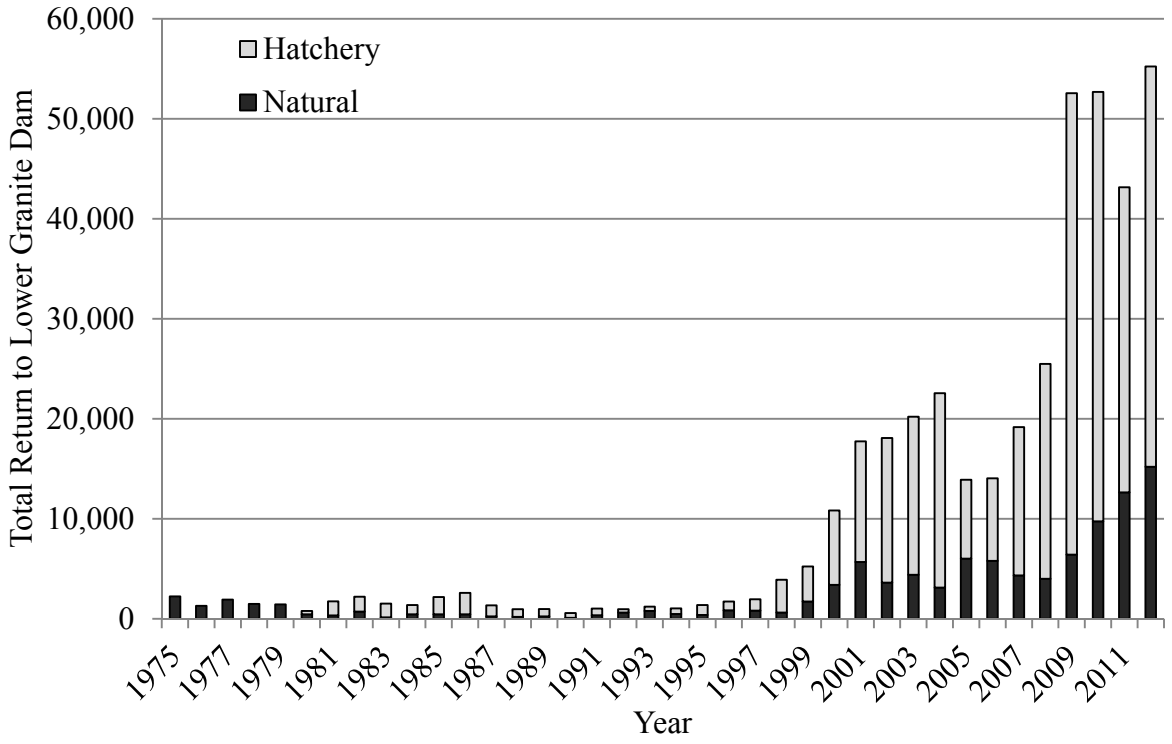


Figure 3. Abundance estimates of hatchery (gray) and natural (black) fall Chinook salmon returning to Lower Granite Dam from 1975 - 2012.

The run reconstruction methods described here were used to estimate abundance of natural-origin fall Chinook salmon to LGR for return years 2005 – 2012. Previous estimates were generated using different methods, and in general the new methods resulted in increased natural fall Chinook salmon abundance estimates (Figure 4). In 2010 an initial version of these methods was used that appeared to overestimate natural-origin returns. Subsequent modifications to the methods reduced the estimated natural-origin return for 2010.

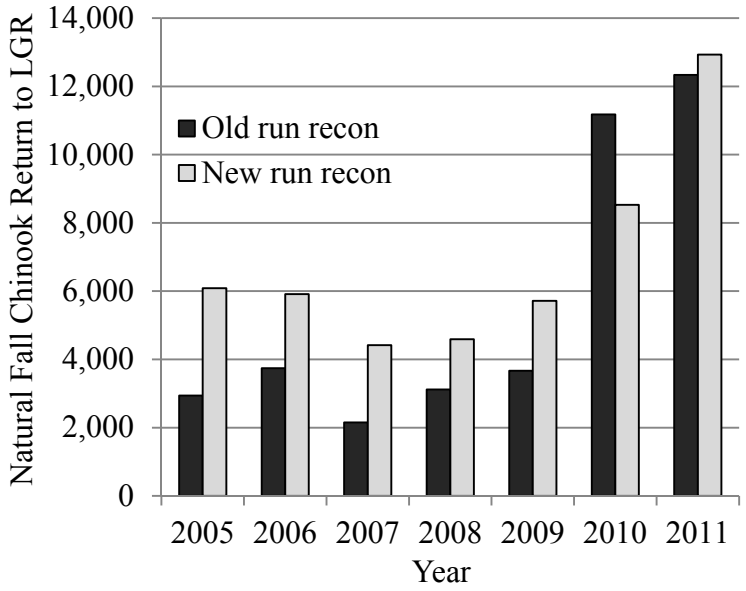


Figure 4. Comparison of natural-origin fall Chinook salmon abundance estimates at Lower Granite Dam (LGR) generated by old and new run reconstruction methods from 2005 – 2011.

The significant increase observed in the estimated abundance of natural fall Chinook salmon obtained using the new "subtraction" methods compared to that obtained using the previous methods raised questions as to the accuracy or validity of these methods. Although it was not possible to definitively identify natural-origin fish, an analysis of the results from the subtraction method using adipose clipped and unclipped CWT groups provided some level of validation regarding the accuracy of these methods. Generally CWT tagging rates varied from 20% - 99% for individual hatchery release groups. Assuming equal survival of tagged and untagged fish, the number of returning adults and jacks with CWTs and the tag rate at release can be used to estimate the number of untagged fish expected to return (untagged associated) from each release group. Results could be validated by subtracting the estimated untagged associated returns from the total return of unmarked/untagged and adipose clipped/untagged groups and evaluating the number of leftover fish of each type (unclipped and adipose clipped). Using these methods we expected there to be a large surplus of unmarked/untagged fish representing returning natural-

origin fall Chinook salmon. We expected all of the adipose clipped/untagged fish to be accounted for resulting in zero, or even negative, (± random variation) left over adipose clipped/untagged fish.

Results revealed that nearly all of the untagged, adipose-clipped fish could be accounted for, but a large surplus of unmarked/untagged fish could not be accounted for (Table 1). This difference suggested that the large surplus of unmarked/untagged fish were natural-origin, and not unknown hatchery fish. This analysis also revealed that for all years the number of leftover adipose clipped fish was small, but positive, suggesting that the methods were negatively biased, resulting in an underestimate of CWTs in the population and an overestimate of number of natural fish. This bias likely resulted from lost or missed CWTs or reduced survival of tagged and untagged fish (Crozier and Kennedy. 2002), which has not been consistently demonstrated (Vander Haegen, et. al., 2005). We plan to explore these factors and incorporate an adjustment into our methods.

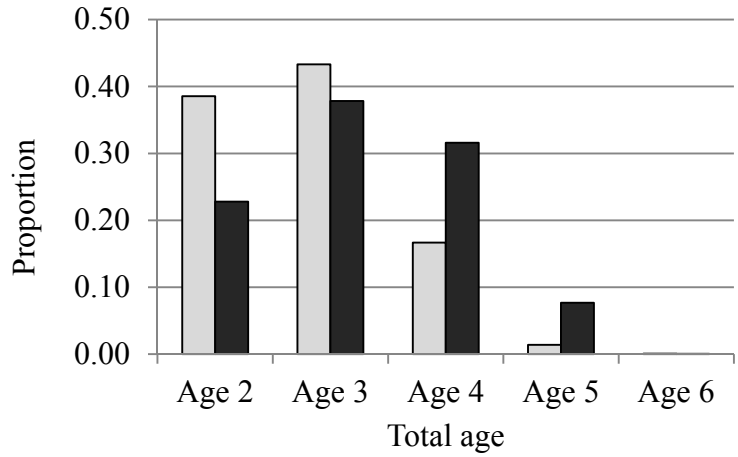
Table 1. Validation of methods used to estimate returns of natural-origin fall Chinook salmon.

Total unmarked/untagged	Estimated CWT associated unmarked/untagged	Leftover – Natural-origin
2,373	1,085	1,288
Total adipose clipped/untagged	Estimated CWT associated adipose clipped /untagged	Leftover – adipose clipped hatchery-origin
694	677	17

Age Composition

An analysis of age composition from 2005 – 2012 revealed significantly younger total and ocean age at return for hatchery compared to natural fall Chinook salmon returning to LGR (Chi-square, 4 D.F., $P < 0.001$; Figure 5). Three-year old fish predominated for both hatchery and natural fall Chinook salmon. The differences resulted from a higher proportion of age 2 and lower proportion of age 4 and age 5 hatchery compared to natural fish. Few age 6 fish returned from either group. Ocean ages showed a similar pattern, with a higher proportion of zero ocean (minijacks) hatchery compared to natural fish, with an estimated 5% of the natural fish returning as minijacks (Figure 5).

a.



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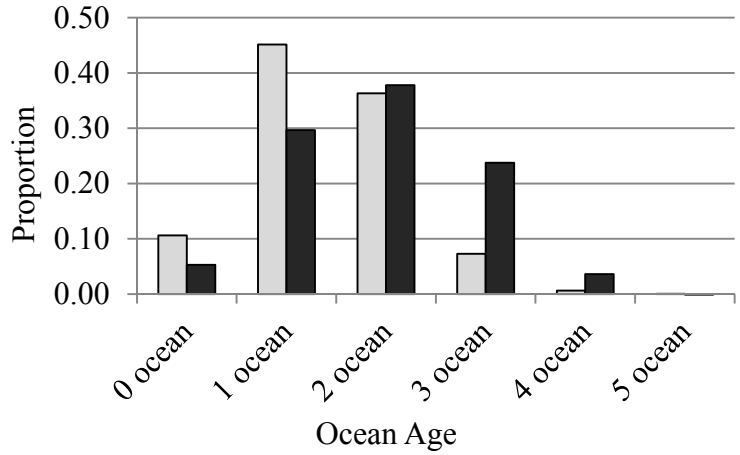


Figure 5. Proportion of hatchery (gray) and natural (black) origin Snake River fall Chinook salmon returning to Lower Granite Dam by total (a) and ocean (b) age from 2005 – 2012.

Jack proportion

Similar to age at return results, hatchery fish demonstrated a significantly higher proportion of jacks as defined by length (≤53 cm fork length) and ocean age (≤ 1 year of ocean residency; Figure 6). Both were presented because dam counts separate adults from jacks based on length, and these counts have important implications to harvest and recovery management. Understanding returns by ocean age is particularly important to the Snake River population because of the large reliance on juvenile yearling releases and the development of a reservoir-

rearing life history in the natural population (Conner et. al., 2005). The increased proportion of jacks by ocean age compared to length reflects the magnitude of the return of yearling and/or reservoir-rearing adults (>53 cm fork length) that only spent a single year in the ocean (jack by age).

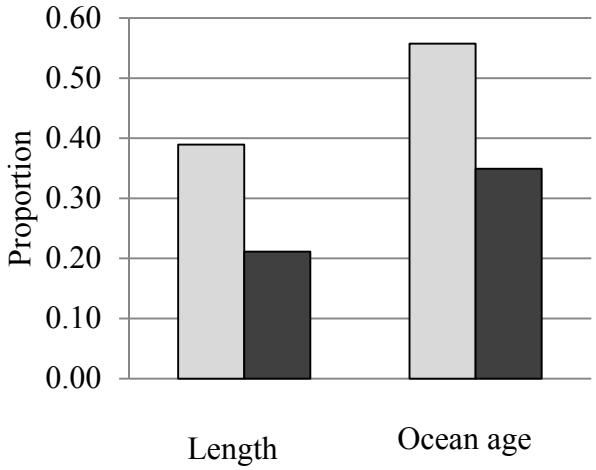
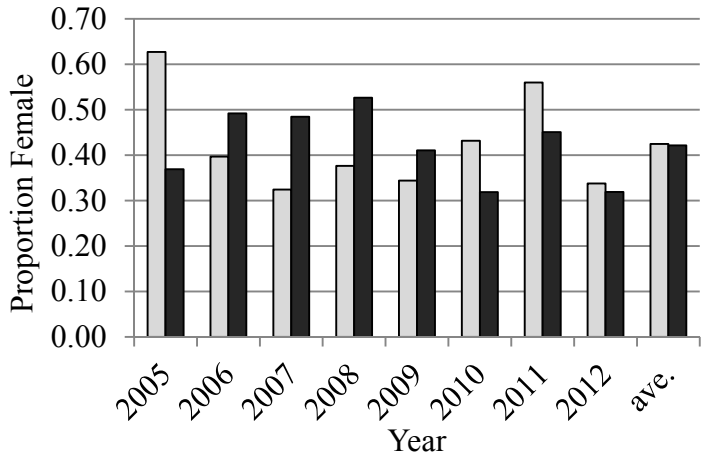


Figure 6. Proportion of hatchery (gray) and natural (black) Snake River fall Chinook salmon returning to Lower Granite Dam as jacks by length (≤53 cm fork length) and ocean age (≤1 ocean) from 2005 – 2012.

Sex Composition

Sex composition was estimated as the proportion of females in the hatchery and natural populations. Female proportion of total returns was highly variable for both groups, averaging 0.27 (SD = 0.13) and 0.34 (SD = 0.07) for hatchery and natural fall Chinook salmon, respectively (Figure 7a). Adult (fish ≥ 53 cm) female proportions averaged 0.42 (SD = 0.11) for hatchery and 0.43 (SD = 0.08) for natural fish (Figure 7b). Neither difference was significant (T-test, $P < 0.05$).

a.



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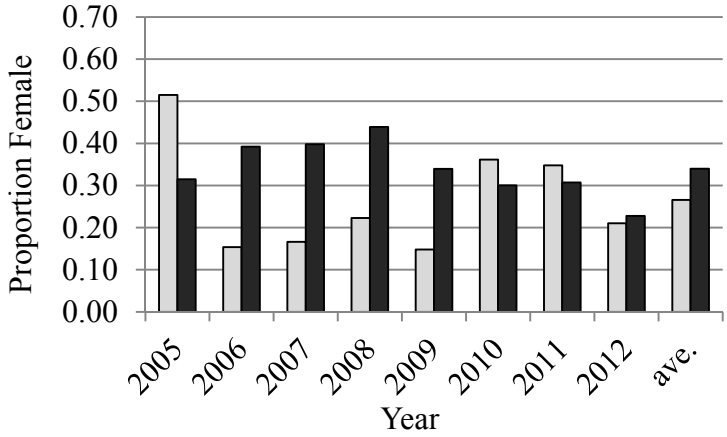

Figure 7. Annual proportion of female hatchery (gray) and natural (black) Snake River fall Chinook salmon returning to Lower Granite Dam for all fish (a) and adults only (b) from 2005 – 2012.

Hatchery fraction and stray rate

Hatchery fraction of fall Chinook salmon returning to LGR averaged 74% from 2000 – 2012, with a higher percentage of hatchery jacks (83%, SD = 12%) compared to adults (68%, SD = 15%). Hatchery fraction was variable, ranging from a low of 56% in 2005 to a high of 89% in 2009 (Figure 8).

Stray rates were generally low, ranging from a low of 0.3% in 2012 to a high of 7% in 2003. From 2000 – 2012 the stray rate averaged 2% of the total population (Figure 8).

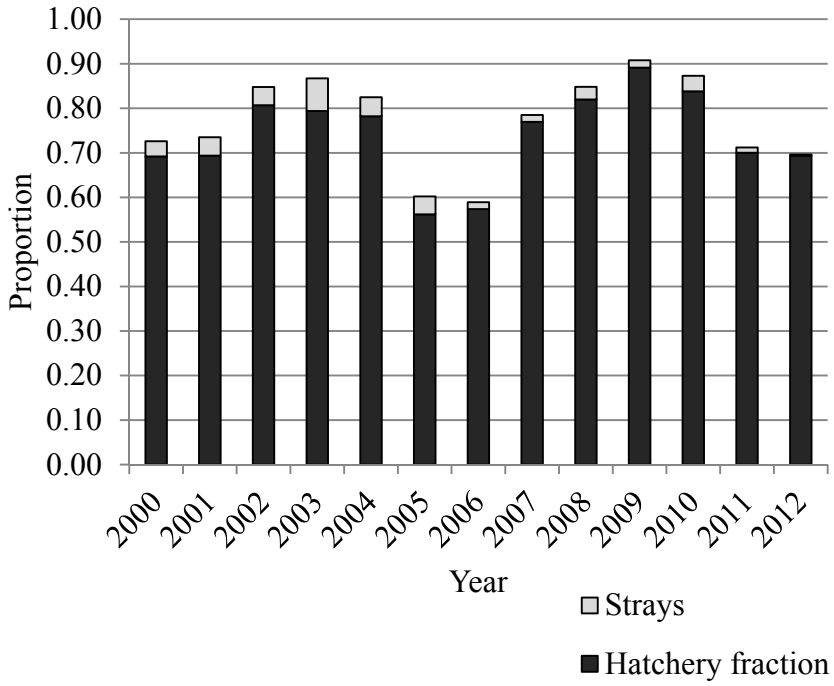

Figure 8. Annual proportion of hatchery-origin fall Chinook salmon (black) and stray (gray) fall Chinook salmon returning to Lower Granite Dam from 2000 – 2012.

Stray origin

The origin of stray fall Chinook salmon returning to LGR were identified by CWT recoveries (Figure 9). Two locations accounted for the majority of strays to the Snake River, with multiple CWT's recovered from Umatilla and Klickitat Rivers every year from 2005 – 2012. Tags recovered from other locations within the Columbia River basin included fish from Wells, Ringold Springs and Bonneville Hatcheries on the Columbia River. Tags were also recovered from locations outside of the Columbia River basin including fish from hatcheries at Youngs Bay, and the Elhwa, Trinity, Feather and Rogue Rivers. Only one tag was recovered from each of these locations over this time period. A single tag was also recovered from a Hanford Reach natural-origin fish which was not expanded to account for untagged associated strays from this population. Umatilla River strays represented an average of 1.53% of the total return to LGR, with Klickitat fish accounting for 0.11% over this time period.

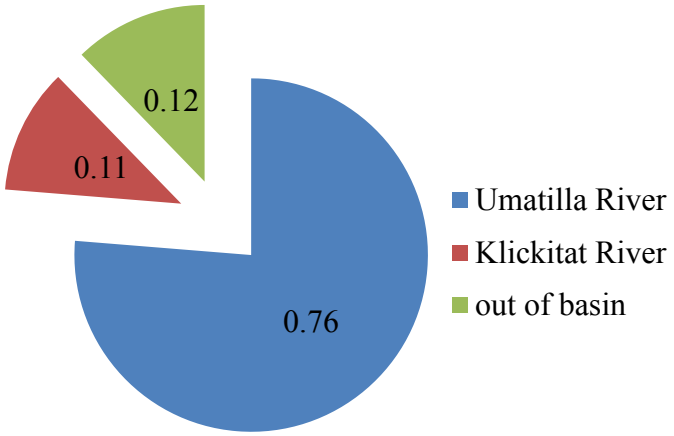

Figure 9. Origin of stray fall Chinook salmon returning to Lower Granite Dam from 2005 – 2012.

Run Timing

Comparing run timing to LGR for hatchery and natural Snake River fall Chinook salmon was not possible because of the inability to determine origin from scale pattern analysis. As a surrogate analysis we compared run timing to Ice Harbor Dam (ICH) from 1962 – 1968 to that from 2008 – 2012. When ICH was completed the majority of the return was composed of natural-origin fish, whereas recent returns are predominately hatchery-origin. Although this is not an ideal comparison, it provides some information related to changes in run timing.

Results demonstrated that the median run timing for all fish and adults-only was earlier now compared to that of the mid 1960's by four and seven days, respectively (Table 2). The 80% return window (10th and 90th percentile) period has been reduced from 40 days to 31 days, suggesting that the return timing has become compressed.

Table 2. Historic (1963 – 1968) and current (2008 – 2012) median, 10th and 90th percentile return dates of Snake River fall Chinook salmon at Ice Harbor Dam.

	10th Percentile	Median	90th Percentile
1963-1968	3-Sept	19-Sept	12-Oct
2008-2012 adults + jacks	1-Sept	15-Sept	1-Oct
2008-2012 adults only	30-Aug	12-Sept	29-Sept

Analyzing the cumulative run timing to Ice Harbor Dam revealed that the historic timing was later than current returns, but the difference was not significant (Kolmogorov-Smirnov two-sample test (K-S test); MaxD = 0.133 on Sept. 3).

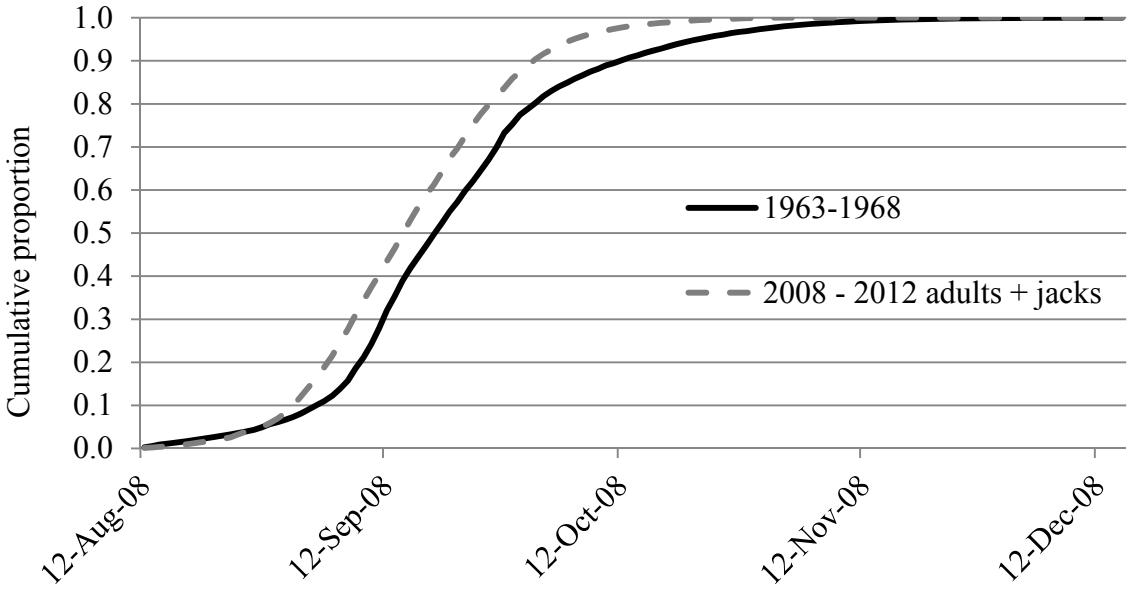

Figure 9. Historic (1963 – 1968) and current (2008 – 2012) cumulative run timing of Snake River fall Chinook salmon returning to Ice Harbor Dam.

Conclusions

Abundance trends have been increasing for both hatchery- and natural-origin Snake River fall Chinook salmon and accurate abundance estimates are critical for meeting mitigation and recovery goals and managing complex harvest regimes. The abundance and population composition estimates presented here significantly increased estimates of natural-origin fall Chinook salmon returns to LGR from 2005 – 2012 compared to previously used methods. The ten-year geometric mean for natural-origin fish was estimated to be 6,342 (5,323 adults), which is greater than two times the interim abundance goal set by the Interior Columbia River Technical Recovery Team (ICTRT, 2007). In addition, accurate estimates of returns from mitigation and supplementation hatchery release groups were obtained, allowing for evaluations of hatchery return goals set by LSRCP and other fall Chinook salmon programs (Nez Perce Tribal Hatchery, Fall Chinook salmon Acclimation Project, Idaho Power Company).

Although it was impossible to verify the accuracy of these methods at this time, tissue samples from all fish used as broodstock are currently being collected which will allow for a parentage-based-tagging (PBT) analysis of an entire brood year in 2015. PBT results will provide an

accurate assessment of the run reconstruction methods presented here and more precise estimates of both hatchery and natural returns.

Significant population composition differences were observed for hatchery compared to natural populations for age composition and jack proportion. Significant differences in age at return observed for hatchery compared to natural fall Chinook salmon generally resulted from a decrease in ocean residency. In spite of the younger overall age composition and the higher proportion of jacks in the hatchery population, no difference in sex composition was observed between the hatchery and natural populations. Hatchery fractions were high, averaging 74% of the total population. However, rates of straying from non-local hatchery fish into the Snake River were low, mainly originating from the Umatilla and Klickitat Rivers. It was not possible to determine the magnitude of hatchery introgression on the natural population or if interbreeding caused changes to the natural population.

Citations

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